PROCEEDINGS

THIRTEENTH ANNUAL

U S ARMY OPERATIONS RESEARCH SYMPOSIUM

AORS XIII

29 OCTOBER - 1 NOVEMBER 1974

FORT LEE, VIRGINIA

VOLUME I

CO-HOSTS

U S ARMY LOGISTICS CENTER FORT LEE, VA	U S ARMY QUARTERMASTER CENTER AND FT LEE, VA

U S ARMY CONCEPTS ANALYSIS AGENCY

DEPARTMENT OF THE ARMY

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PROCEEDINGS

of the

Thirteenth Annual

US ARMY OPERATIONS RESEARCH SYMPOSIUM

Volume I

Sponsored by the

US Army Concepts Analysis Agency

It was my privilege as Commander, US Army Concepts Analysis Agency, to sponsor the Thirteenth Annual US Army Operations Research Symposium at Fort Lee, Virginia from 29 October to 1 November 1974.

The response from the ORSA and user communities was vigorous. The enthusiasm of the over 300 attendees (a record for this event), the high quality of the presentations, and the recognized importance of the program content combined to guarantee success. Attendee comments were almost unanimously favorable.

Many contributed to the success of the symposium. Special recognition and appreciation are due the US Army Logistics Center and the US Army Quartermaster Center and Fort Lee for their contributions as the co-hosts, as well as to the US Army Logistics Management Center for the use of its facilities.

I congratulate Mr. John T. Newman, the Technical Director of USACAA, for his major role as the overall symposium Chairman, our guest speakers, the working group chairmen, and the many contributors whose papers are contained in these two volumes of the symposium proceedings. We are indebted to them for their outstanding efforts.

Hal E. Hallgren

HAL E. HALLGREN
Major General, USA
Commanding

ACKNOWLEDGMENTS

Keynote Speaker	GEN Henry A. Miley, Jr. Commander, US Army Materiel Command
Banquet Speaker	Mr. Paul D. Phillips Principal Deputy Assistant Secretary of the Army (Manpower and Reserve Affairs)
Theme Speakers	Dr. Hugh M. Cole Consultant
	Mr. Abraham Golub Technical Advisor to the Deputy Chief of Staff for Operations and Plans

Working Group Chairmen

A Army Force Structure Process	Mr. William A. Bayse Director, Methodology and Resources Directorate US Army Concepts Analysis Agency
B Materiel Acquisition Process	Mr. Richard J. Trainor Director, Systems Review and Analysis Office Office of the Chief Research Development and Acquisition
C Logistics Matters	BG Richard H. Thompson Director of Logistics, Plans, Operations and Systems Office of the Deputy Chief of Staff for Logistics
D Weapons Effectiveness Analysis	Mr. Keith Myers Assistant Director for Integrated Studies US Army Materiel Systems Analysis Activity
E Operations, Plans, Doctrine and Concepts	Dr. Marion Bryson Scientific Advisor US Army Combat Developments Experimentation Command
F Methods of Assessing the Value of ORSA	Mr. Edgar B. Vandiver, III Research Analyst Office of the Deputy Under Secretary of the Army (Operations Research)

G Special Activity — COL Louis F. Dixon
Director, ADP/MIS
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THE IMPACT OF ORSA ON THE US ARMY - HISTORICAL OVERVIEW

DR. HUGH M. COLE

Even the most cursory glance at the program of the Thirteenth US Army Operations Research Symposium will convince one that General Hallgren and Jack Newman have gone first class in sponsoring this formation, and in persuading Generals Graham and Van Lydegraf to host the same. There is something missing, however. This convocation really needs a motto, a slogan, an advertising trademark. The use of Roman lettering in the program and invitations--as AORS XIII--gives a certain touch, but not much! I do have a suggestion. You all have seen on television the very charming and seductive "doll", dressed as the scenario may require in skimpy bathing suit or white fur parka, who belts out in a moderately musical voice but loudly and with impeccable diction and come-on for a world-wide hotel chain: "What has Sheraton done for you lately?" After more than two decades of attendance at meetings such as this in the United States and abroad, I am convinced that the one slogan which applies to any and all such Army meetings is a paraphrase of the Sheraton Theme, i. e., "What has Operations Research done for you lately?" But as you will discover, I do not propose to recite, as does the Sheraton girl, the specific contributions (by agency, name and date) which OR has made to the US Army during the past quarter of a century. My thesis, stated simply, is that our national proclivity for introspection and soul searching is in general bad business--and in the particular of Army OR--can lead to an unhealthy disregard of the indisputable fact that OR has been an Army tool for a quarter of a century and needs to be used--not defended.

Our program bills this meeting as the "Thirteenth Annual U.S. Army Operations Research Symposium." The history of OR in the Army, however, is somewhat longer than the chronological numerator "Thirteenth" suggests. The first Army-wide OR Symposium was held twenty years ago when the Office of Ordnance Research sponsored a one-day conference on Army operations research at Frankford Arsenal. The meeting was called "in order to disseminate information on the methods and new developments in the field of Operations Research to a large number of government personnel." In 1954 the Army already had moved a long way toward the incorporation of OR into its planning and research facilities and operations. When the keynoter at Frankford Arsenal, Dr. T. J. Killian, spoke on the subject: "Operations Research and Its Usefulness during the Last War", he was addressing a goodly number of officers and civilians in the audience of one hundred and fifty who were full-time or part-time practitioners of OR in or for the Army. Killian, I should add, was not really talking about the "last war", although the Korean War had ended the previous year, a war of great significance to the US Army but one which in 1954 was overshadowed by the size and the drama of World War II. Killian, then, was speaking of OR as practiced by the British in WW II. It is fair to say that during the first decade of OR in the Army the standard justification of OR as a "practical" tool was adduced from the exploits of the British scientists, Watts, Blackett, Zuckerman, who had "invented" Operations Research, had (as the name itself connotes) done research on the conduct of actual military operations and could cite lists of kills inflicted on German submarines and German aircraft which were directly the result of Operations Research.

In the United States, early in WW II, the Army Air Force and the US Navy had set up OR Staffs on British lines and then moved, almost immediately at the close of the war, to incorporate OR (or Operations Analysis) personnel and organizations in their peacetime establishments. The Army, lacking wartime experience in OR and without noteworthy precedents in the British Army OR (or so it then seemed) moved belatedly and did not introduce OR until the Operations Research Office (ORO) was fully activated in 1949. This morning, then, we are looking back over a quarter of a century of OR in and for the US Army. Two wars have been fought and two major military interventions on foreign soil have occurred in these years; none of the major weapons in the hands of Regular Army divisions at the beginning of this period are "standard issue" today; the Army has had ten Chiefs of Staff; if we average a tour of duty in the Pentagon as three years, the Army has had eight successive generations of planners and operators in the General Staff and Major Commands--and more likely twelve generations. Also, during these twenty-five years, the Army OR community has been addressed on occasions such as this by 257 Senior Officers and civil servants of which number 23% forcibly expressed the opinion that OR was useless, 22% believed that it had some value and 55% had no opinion. (These figures, I hasten to say, are strictly my own and should be viewed with great distrust.)

Looking back over these 25 years of Army OR I can see no way in which standards can be developed by which we might make objective evaluations of the worth of Operations Research to the Army. I know of only one serious attempt to assign grades to any considerable body of OR studies.

In this case the top Army officers charged with Staff Administration of Military Government, Civil Affairs, and Psychological Warfare rated and graded a large number of OR studies in these particular areas. Most of the studies examined passed with flying colors, none were rated as valueless. In less than two years,however, the Army had removed Military Government, Civil Affairs and Psychological Warfare from the General and Special Staffs and for all practical purposes closed down all Army instruction and planning in these areas. The Army decision that the Army needed little or no competence in these areas of course rendered moot the favorable judgment which had been made on this collection of OR studies.

During these twenty-five years Army OR has been often "hoist on its own petard", namely, the concept of"cost-effectiveness." I refer to the numerous demands from critics that Army OR justify its existence by showing savings in some part of the Annual Army Budget which can be demonstrably attributed to OR studies and which total more than the monies expended during the same fiscal year to maintain an OR studies capability in and for the Army. This kind of bookkeeping in a "not-for-profit" organization such as the Army makes little sense.

On the other hand I cannot prove, nor can anyone else, that Army OR increased the enemy "body count" in Korea and Viet-Nam or reduced our own roster of killed-in-action by so much as a single man, much less by the strength of a battalion or brigade.

• To be truly analytical we should first consider what the Army had as objectives when it turned for assistance to an existing OR community twenty-five years ago. Then, as a corollary, we should ask what the OR community proposed to provide the Army in the way of advice and assistance. The expectations of the two consenting parties, of course, have to be reviewed against the environment, the personalities, the tools, tactics and techniques of this early period. Next, we should take a look at the changes in the Army and in the OR profession which, over time, altered the perception of what Army OR was and what it could be expected to accomplish.

In 1946 some members of the Army Staff raised the specter of an Army falling behind the other Services in the race to modernize and to survive in what, it was believed, would be a long postwar slump characterized by massive budget cutting. The touchstone determining the degree of "modernization" was the atom bomb. The Services which had the atomic weapon and the requisite delivery means were "modern." The Army, however, had no claim to being a "modern" fighting force because it had not established its right to a voice in the allocation of scarce fissionable material, possessed no weapons capable of delivering an atomic warhead on strategic targets, and had neither theory nor doctrine for the employment of this new weapon. Indeed, as late as 1947, the US Army stated as official an approved policy that the military value of the atomic weapon was essentially the same as the military value of tube artillery and should be thought of in the same way. About this time, however, a group of officers came to the top of the Army hierarchy who had the imagination and the desire to move the Army into the new era. Such men as J. Lawton Collins, Matthew B. Ridgway, Maxwell D. Taylor, James M. Gavin, Anthony C. McAuliffe and Manton S. Eddy--I cite these names only as examples--had the combat credentials, won on the battlefields of WW II, to bring them to positions of power and to give their opinions solid weight.

The immediate problem facing the postwar Army was this. There existed a new and complex weapon whose design, manufacture, application and potential effectiveness required a brand of technical and military expertise which the Army schools, arsenals and laboratories did not then possess. The problem would become even more difficult as the Army was forced to assume responsibility for the defense of the Continental United States against this weapon. In the months following the end of World War II the scientists who had left their universities to help win the war and who were responsible for the great technological advances of that war (the atom bomb, radar, ballistic rockets, the bazooka, FM radio, the proximity fuse, etc.) returned in droves to their quadrangles and ivy-covered laboratories. These engineers, physicists and mathematicians were, of course, the raw material from which Operations Research or Operations Analysis professionals had been and could be molded.

The Navy and Air Force had tasted OR and found it good--both services moved promptly to re-establish a peacetime OR capability. The Army finally asked the well-known scientist Vannevar Bush for advice as to how it might secure the services of the scientific community. Bush stated flatly that the Army could not attract "name" scientists to Civil Service jobs because of the poor reputation Civil Service employment then enjoyed in academic and scientific circles. He proposed that the Army use an established university as the "connection", and that the new organization be independent, nonprofit, and dedicated by its articles of incorporation to operate solely for the Army. The Johns Hopkins University, close to Washington, was selected as the contract and professional vehicle, the Operations Research Office (ORO) became the name (a name indicative of the rising popularity of OR), and the initial organizers and leaders came in from the Navy (where they had wartime service in uniform or as civilians). I refer here, of course, to Ellis Johnson, Lynn Rumbaugh, Jimmy Johnson and their cohorts. The men named, now dead, were known to some of you.

The Army wished to have access to scientists who could give technical advice on the atomic weapon, as well as other novel and complicated devices in the offing, and whose reputations and analyses would be useful in furthering Army claims to money and to new roles and missions. To insure that this scientific serum was injected close to the brain, ORO was specifically given the mission of providing support to the General Staff of the Army, this with the clear understanding that each of the Technical Services would be responsible for generating its own "in-house" OR capability. One should say in all candor that at this time the General Staff probably knew little about the burgeoning profession of "Operations Research" and cared less. Its rather limited perception of Army OR, however, would be promptly and drastically altered by two major perturbations in the international environment: the creation of the North Atlantic Treaty Organization and the outbreak of the Korean War. (We will return to these events in a moment.)

What did the party of the second part, the newly-formed OR community, in and for the Army, perceive as its mission and relationship with the uniformed, "serving" Army? In the first years of Army OR a standard exercise at meetings such as this was a long, tedious and--in my judgment--quite worthless general session devoted to "defining" Operations Research. There were probably as many definitions as there were speakers at OR conferences in these years. In general, however, the understanding of the Army OR mission was derived from British reports on the wartime employment of OR and from preachments to the Army OR community by American academic figures who at the time were fighting to gain some degree of autonomy for OR in the faculties of a few major universities. These leaders in the new profession (Killian, Flood, Morse, Kimball, et al.) appeared regularly before Army OR conferences and symposia, acted as paid consultants to the Technical Services and Army Scientific Committees and published textbooks and case studies on which the neophyte practitioner of Army OR cut his teeth. Dr. Morse put the scalpel to this whole business of definitions in the First Ordnance Conference on Operations Research at Frankford by begging the question; he said that the time for definitions was past and that "Operations Research is what OR workers do." A few months later Ellis Johnson, then Director of ORO, added another dollop of common sense to the turgid controversy over the new titles and definitions in a thoughtful and well-reasoned essay which discussed "Systems Analysis" and concluded that "systems analysis" was no more than Operations Research applied to large systems.

Nonetheless, despite much intellectual wheel spinning the OR community in and for the Army was in general agreement as to mission and methodology (this despite the continuing battle between those who wanted Army OR organized outside of the regular Army structure and those who wished to bring it inside of and make it a subordinate part of the existing Army civilian structure). One may summarize as follows:

a. OR practitioners were optimistic as to their future with the Army and the possibility of making major contributions to the Army (although few went so far in their optimism as Dr. Killian, who told one Army Conference that "many of us feel that Operations Research is going to have a greater effect on the economy of the country than nuclear physics.")

b. Army OR types tended from the first to understand that operations should be looked at as a combination of men and equipment. (This attitude coincided with the Army shibboleth that "we do not man our weapons, we arm our men.")

c. Army OR emphasized the use of parameterized models--usually written in mathematical form in this early period--and ultimately succeeded in introducing to the Army vocabulary and manner of thought this basic concept.

d. The OR professionals with the Army believed that the Army would be best served if the advice provided was not biased by the OR type becoming personally engaged in the actual conduct of Army operations. Looking back in time, one may think this was a very naive view of the practical world in which budget cuts and hiring restrictions would encourage the Army to use OR people as extensions of the overworked Army staffs. Also, it is quite true that some of the more academic types in Army OR could have profited from a "hands on" experience of the US Army. Nevertheless, the Army OR community was able during most of its first decade to get a more favorable reception of its recommendations in the Army and provide the Army with more persuasive and cogent argumentation before the Office of the Secretary of Defense and the Congress because those who prepared the OR analyses were divorced from the conduct of and responsibility for on-going operations.

e. The leaders in Army OR were convinced that the techniques of this profession could be applied to practically every problem which might surface in the Army or in the larger society of which the Army was a part. Thus despite OR rosters in the early 1950's which consisted almost entirely of engineers, physicists and mathematicians (with a few chemists thrown in as a nod to the Chemical Warfare Service), there was a kind of "opportunism"--particularly at ORO--which said that whenever an Army problem of importance appeared and the expertise was lacking to tackle this, then the answer was simple: hire the man or woman who has the appropriate professional competence and eventually he or she will learn the basic OR techniques and tools.

f. The OR community would offer the Army an introduction to the high-speed computer and modern computational aids as something more than huge and quick "numbers-crunchers" useful only for bookkeeping tasks and routine ballistic computations. (If we remember the dramatic flowering of computer technology from 1950 on, we can, I think, give much credit to the OR community for the timely incorporation of these technological advances into the warp and woof of the Army establishment.)

g. I must mention one final perception of the role of OR in and for the Army, which clearly manifested itself in the early years, was accepted by the Army for more than a decade, and to this day gives rise to bitter debate, professional feuds, and gross misunderstandings. The early OR community in wartime Britain had established the principle that OR on military operations, where human lives were in the balance, must be free to conduct analyses without service bias or military control and present the results of such untrammeled research without leave from or sanction by intervening echelons of administrative authority. With few exceptions the great British scientists had been able to make this demand for "free scientific investigation" stand, even under the authoritarian conditions of wartime. The military and scientific leaders who first brought OR into the US Army accepted the principle of free investigation and findings and subscribed officially, as a review of Army Regulations and D/A Circulars published in the 1950's and 1960's will show, to the slogan: "The Army may tell the OR scientist <u>what</u> to do but not <u>how</u> to do it." It is true that the principle of free investigation often was honored in the breach rather than in the observance, and that the degree to which military and administrative controls were imposed on the individual researcher varied greatly between ORO and the Army in-house OR groups, and indeed between the in-house laboratories, institutes and arsenals themselves. Often, however, individual Army Staff officers and commanders in high quarters intervened to encourage individual and independent research within Army installations as a means of attracting or retaining high caliber personnel. Thus, the first directive permitting the diversion of 10% of total research funds to individually selected free research projects went first to the Army laboratories and only then was extended to cover ORO.

You may think from the relative amount of attention I have given to the Army and to the Army practitioners, in this review of early aims and perceptions of mission, that the producer of OR understood the market better than did the consumer. This certainly was the case during the period 1946--1948 when the Army was examining the desirability of bringing OR into the Army. But the two perturbations in international affairs which I mentioned earlier, the creation of NATO in 1949 and the commencement of the Korean War in 1950, drastically expanded the Army's mission and with this expansion brought the Army to turn more actively to its new OR capability, to seek to use it,and to understand it. But, of course, this did not happen overnight.

In 1954 at the First Ordnance Conference on Operations Research the Commanding Officer at the host installation--a colonel--excused himself at the very commencement of the one-day session because he had, as he said, "some very important meetings scheduled." Two years later at the Third Ordnance Conference, convened at Rock Island Arsenal, the Commanding General of the host Ordnance Weapons Command,gave the opening speech, entitled "A Philosophy of Management", in which he deplored the dearth of scientifically-trained people in the Army and asked that specific OR projects be undertaken. Perhaps these two gentlemen represented two different and competing segments of "Army" opinion. I suggest, however, that the passage of only two years in this first decade of Army OR probably explains these two drastically different attitudes on the part of the Army customer. By the time of the First USA Operations Research Symposium, staged in a three-day session at Durham in 1962 with over two hundred participants, the role of Army OR was of sufficient importance to call for a keynote address describing the use of Operations Research at a higher level, that is, in the Department of Defense. By this time, too, the ties between the serving Army and Army OR were so well recognized that General Ely, the Director of Army Research, felt it necessary to call for a re-examination of the roles of Operations Research in order to achieve concord with the three new major Army Commands which had just been activated.

Now let me turn to the environment in which Army OR was structured and nurtured. Recall, if you will, the posture of the Army subsequent to the signature of the NATO agreements and acceptance of the Lisbon Force Goals. The Army had expected a short tour of occupation duty in Europe like that following WW I. Suddenly the Army was charged with indefinite deployment on the European Continent, was handed a mission demanding constant combat readiness (only the constabulary squadrons had combat worth in 1949), was forced to leave the defense of its flanks to other nations, was told as a matter of national policy to fight a desperate and hopeless delaying action against what would be overwhelming odds yet somehow gain enough time and save enough tactical cohesion to permit a stand on the west bank of the Rhine, while NATO reserves mobilized and the women and children from the American garrison communities fled (as best they could) to Spain. The "trip-wire" strategy then obtaining placed the army in the unenviable position of forming this "trip wire" with the lives of its troops and their familites and left the Air Force and its atomic weaponry to engage and destroy the putative enemy. Here was the nub of the matter. The so-called "single weapon strategy", i. e., strategic reliance on US possession of the atom bomb and massive Air Force delivery of the same, promised to reduce the Army to a supportive, "spear-carrying" role. Indeed there was some thought in high places that the Army should be restructured as simply a logistic and police force providing support to the Air Force and Navy. And remember that the US Army also had to fight a war in this period, clear across the world. With the survival of the Army as the Senior Service in doubt, and with accepted planning figures which put the Red Armies at the Rhine and the English Channel in five days or less, the US Army commands in Europe were willing and indeed anxious for advice and scientific support from whatever source. So OR became a part of the US Army establishment in Europe. The first formal Report ever published by ORO (ORO-R-1) was a multivolume analysis of the conduct of atomic warfare in Central Europe and for many years it provided the technical basis for the Army version of NATO strategic plans. Army OR types in USAREUR and in Army Ordnance and Engineer installations at home collaborated in the search for ways and means to delay the anticipated onslaught of whole Russian tank armies, or perhaps even halt the same.

OR involvement in one area of Army interest quickly led to involvement in another, sometimes of only tenuous connection. The Truman doctrine, originally enunciated for Greece and Turkey, brought the Army full tilt into the Military Assistance Program (MAP) as this contributed to the weaponing and logistic support for the NATO armies, and cleared older equipment from Army inventories. Large-scale analyses of the arms and reserve stocks held by NATO members led directly to OR tactical studies for USAREUR, which brought into question the assumptions underlying the NATO/MC Reports and the validity of the Force Tabs accompanying the same.

From whence came the impetus for OR engagement in Army problems of the magnitude and importance of those referenced above? The answer to this question probably should be the same as the answer to the classic Army question whether the impetus for supply should come from the front or the rear: namely, "it depends on the situation." In some cases the Army in Europe lacked the scientific competence to evaluate the potential effects radius of new weapons and turned to OR, thus bringing the OR types into tactical and strategic planning. In other cases the OR people turned the spotlight on problem areas which the Army had failed to recognize or had neglected, for example, the possible impact of refugee movements on D-Day deployment from the German Kasernes and the planned withdrawal to the Rhine.

Now permit me to step clearly outside the bounds of Army OR as a profession and speak as a historian of the US Army in the Twentieth Century. Recall that the United States Army emerged from World War II with all the prestige of a great victory, that the armies in the combat zones clear across the globe literally collapsed in the rush under public pressure to demobilize, and that the small regular Army cadre remaining had "battle fatigue" and could be pardoned if it wanted nothing more than to go back to the old peacetime way of soldiering. It is my judgment as a military historian that, given these conditions, the US Army made a truly remarkable and generally successful effort to shed its features as a World War II fighting force and enter the Atomic Era with minimal hesitation and delay. For the most part this transition was prompted by the new demands of the Army's role in NATO: a theater in which Army OR was consciously and successfully employed. I conclude, therefore, that Army OR must be given a full share of credit for the post-WW II modernization of the US Army.

We need give little attention to the effects of the Korean conflict on the Army/OR relationship. The OR participation in the Korean War was far from negligible--well over a hundred Army OR types received UN recognition for service in Korea. However, the revival and restudy of the Korean OR reports during the recent combat in Southeast Asia probably has given most of you an appreciation of the OR effort in Korea. In general those analyses used standard OR methods to examine infantry weapons, artillery fire direction, signal communications, tank kills and battlefield illumination, and to effect changes in the field. In three areas, however, new ground was broken. S. L. A. Marshall, a consultant with ORO, took the cultural mumbo jumbo and psychological claptrap out of the popular explanations of the way the Chinese fought and reduced the same to a common-sense exegesis of Chinese tactics and combat techniques. For the first time in the history of the US Army statistical analyses using OR methods were made on the "behavior"--mentally, emotionally, and physically--of the individual man in combat. Finally, the OR analysts were able to create a "factual" picture of race relations under combat conditions which dispelled many cherished myths and had a direct effect on the way in which the Army took the lead in implementing the Truman Executive Order ending segregation in the Armed Forces.

We now come to the era of these Annual OR Symposia and each of you can be his own historian, evaluating success or failure as your own experience and prejudices dictate. When the First Symposium convened in 1962, and those present called on the leadership of the Army to make this an annual event, OR had grown in stature great enough to attract close scrutiny by the DOD, Bureau of the Budget and the Congress. The keynote speaker, therefore, warned that the evaluation of the role of Operations Research in the Army would no longer be left solely to the Army.

What, in general, were the paramount features of the environment in which this evaluation from 1962 to the present would take place? I see them as follows:

a. ORO lost its position of leadership in the Army OR community as its founder and Director, Ellis Johnson, was dismissed and the association with the university was terminated. Although personally painful to many, what happened in this case was common experience in the early '60's in the Board Rooms of American industry and education: The rugged individualist who built with his own hands and "crusaded" for the freedom to build in his own image had too often proved unable to administer the "institution" he had brought into being or sustain it by ad hominem tactics. The conventional solution in these years, as the Harvard Business School noted, was to replace the individual with what has been styled as "faceless management", and so it was when the Research Analysis Corporation succeeded ORO. Naturally there was much fishing in these troubled waters by those in the Army who wished to destroy the special status originally accorded ORO and by the profit-making OR corporations who resented the "nonprofit" concept and actually raised a "war chest" of several thousand dollars to finance the attempted subversion of ORO/RAC in the Army and in the Congress. There would be a ten-year reprieve, however, before the Army finally abandoned its original concept of a not-for-profit organization and, interestingly enough, some of the most innovative applications of OR to formidable Army problems took place in these years. Parenthetically, I notice several presentations by the General Research Corporation, successor to RAC, on our program.

b. Robert McNamara introduced into the defense establishment an insistence that "facts" replace "experienced military judgment" in the decision-making process, and made the critical analysis of alternatives a mandatory way of life in the E Ring of the Pentagon. Although Army OR sometimes suffered by reason of "guilt by association" with the "Whiz Kids" in OSD, on balance one must say that the McNamara Era saw Army OR increase in usefulness and in stature. Those in the Army who hoped that the McNamara insistence on factual analyses would disappear when McNamara left the Pentagon missed the point. American industry, transportation, government (at all levels), the Navy and the Air Force had turned to analytical and computer techniques as unavoidable and useful in the solution of the complex problems created by the new technologies and the new demands of an expanding society. Army planning and management willy-nilly, with or without McNamara, would have to walk the same road.

c. The war in Viet-Nam preoccupied the Army for nearly twelve years and ended without victory in the field, this for the second time in two decades. The Army, as usual, had provided the bulk of the forces and sustained the bulk of the 46,000 battle deaths, but the Army had not solved the problem of fighting this kind of war. OR was little utilized by the Army in Viet-Nam nor, in contrast with Korea, did the OR community make a concerted, high-level attempt to find an entry to that theater. The OR types, in their sphere, were no more successful than the Army in getting a handle on this kind of war, as witness the abortive attempts to simulate on the computer or produce a model of the combat in Viet-Nam. It is true that the use of OR techniques and personnel in the Howze Board did contribute to the emergence of the helicopter in Viet-Nam. Costing techniques used by OR types got an accurate fix on the actual dollar value of US military support to specified parts of the South Viet-Nam war effort. And OR-developed reporting systems permitted the Army commanders in the field to evaluate the expenditure of artillery ammunition and isolate the causative agents in the battlefield attrition of equipment. Nonetheless, OR, like its Army partner, cannot point with satisfaction to its role in Southeast Asia.

d. There was little time for either the Army or its OR assistants to indulge in introspection or recrimination as the Viet-Nam conflict dwindled away. A new phenomenon appeared on the Army horizon called "inflation." The Army and its OR establishment have developed protective procedures--sometimes effective, sometimes not--against budget cuts. Neither, however, has thus far produced acceptable and defensible methods for projecting the impact of inflation on future Army budgets. Neither has demonstrated a clear understanding of how tradeoffs, in an era of runaway prices, can best be determined between the procurement of very expensive nuclear weapons and the acquisition of larger numbers of cheaper conventional weapons. Also, I am concerned, as are other old friends of the Army, as to whether or not the Army and Army OR are readying the intellectual tools which will be required if the United States Army is to make its voice heard and respected in the reassessment of national strategy which the parlous state of our economy surely will demand.

At the end of a quarter of a century, Army OR, I believe, has the potential of playing a role far more important than at any time in its first twenty-five years. We leave the next speaker to predict whether or not that potential will be realized. But I question whether Defense Secretary Schlesinger's warning that the Army cannot afford "ossification", and his admonition that the Army must show itself "capable of imaginative, innovative and nonroutine responses" to current problems, is in any degree answered by the repetition ad nauseum of the question: "What has Operations Research done for you lately?"

Instead, I suggest that we should, as Bing Crosby opined, "accentuate the positive." Instead of dwelling on what OR has not been able to achieve in previous years and rather than giving undue credence to those who reject OR in the Army, the US Army must accept the premise that OR represents a serious and usable approach to complex but soluble problems and is here to stay. From this premise the Army should make a firm commitment (a) to sustain a viable, cohesive and prestigious OR capability (no matter where currently it may be found or what its antecedents) and (b) to employ this capability in a rational, consistent, continuous and optimistic manner with priority application on those problem areas where the national stakes are the highest and where the future of the United States Army is most in question.

PRESENT & FUTURE ORSA TRENDS -
A FORECAST FOR THE US ARMY

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I always welcome the opportunity to talk about ORSA in the Army. The Army was the first of the services to perform formal ORSA work. I'm proud of that fact, and I'm proud of the Army's record in this area. I also welcome the challenge of making some forecasts and predictions about Army Operations Research in the future. I recognize the clear danger that some years from now someone will look up my remarks today and regale an audience with the disparities between today's predictions and the realities of that time.

Well, I refuse to worry about that -- it's happened before and I'm sure it will happen again. Let me give you a quick example: I recall an AMC System Analysis Symposium that was held in November 1968. General Bunker of AMC was the opening speaker. He warned the audience that such symposia could become a rarity in the future because President-Elect Nixon had just indicated that he would reduce the importance of systems analysis in the DOD and return more of the decisionmaking authority and responsibility to the military. Later that same morning Dr. Alan Enthoven gave an address during which he singled out the CHEYENNE Helicopter as a shoo-in that would greatly enhance our combat capability in the 1970's. That afternoon I gave an address titled "Operations Research in AMC - Past and Future". And although I made some suggestions of ways that AMC could further improve their contribution to Army O.R., I warmly applauded their past performance and confidently predicted that AMC would continue to do great work. Well, obviously all of us were a bit wrong -- even Nixon.

As one of the early practitioners in this business of ours, I especially enjoyed Dr. Cole's historical review of Army Operations Research. I feel he did a splendid job of setting the stage for my remarks on current and future trends, I should like to start out by commenting on a trend that is already several years in being and which I strongly believe we should reverse as soon as possible.

I am talking about the recurring self-deprecating dialogue which has become the vogue for far too many elements in the Army. To engage in self-examination is always, of course, desirable. It becomes unhealthy, however, when such self-examination results in dialogues which increasingly distort the image of the Army, or in this case, the Army's study effort. Once started, such dialogues have a natural tendency to become overcommitted to self-criticism and, when that happens, it does so at the expense of an honest search for solutions to the real problems.

It's fairly clear how some of these attitudes developed. In the decade of the sixties, under the combined influence of Secretary McNamara's support, Dr. Enthoven's publicity, and expanding budgets, "ORSA Activity" simply mushroomed. From my various vantage points in Aberdeen, in the Army Secretariat and the DA Staff, I watched all this happen with mounting concern over the general lack of what might best be called "Quality Control". Now I don't mean to say that everything that was done in that era was bad, but it seemed like every job shop in the country could get a piece of the action by simply advocating a "Systems Approach" to any problem.

The net results of this surge of activity under the banner of "ORSA" can be summarized in three brief statements:

1) The number of people who could claim ORSA experience and ORSA qualification on their resumes had multiplied to unprecedented levels.

2) There was a great deal of work done that ranged from marginal to simply "bad".

3) Criticism of the newly enlarged "ORSA Community" mounted to the point where even congressional leaders and the President-Elect got on the bandwagon.

In the two or three year period centered around 1970 many members of the Military ORSA Community began to react to the mounting criticism. Several symposium themes or principal addresses had titles like these:

1) An Assessment of the Current State of Military Operations Research

2) The Value and Limitations of Studies and Analyses Directed to the Senior Government Decision Makers

3) Challenges in Military O.R. in the 1970's

4) Ethical Problems in Military Operations Research

5) On Professionalism and Ethics

Clearly we were listening and accepting much of the criticism but unfortunately, our reactions were really overreactions which largely placed us on the defensive. It was about this time that I began boycotting as many of these symposia as I could, and when I couldn't escape I spoke out to urge that the ORSA Community stop beating itself about the head and put a halt to all their self-deprecating activities. And I do so again today.

It bothers me to see that we are apparently still on the defensive; still blaming ourselves. Even the theme of <u>this</u> symposium, "The Value of Operations Research to the Army" was born of negativism. Unfortunately, to this day there are those who still question the value of

O. R. To me that is no different than questioning whether or not there is value in thinking. Let me ask: When the optical society meets or the metallurgists convene, do they adopt themes challenging the very need for their professions? Of course not! What I am pointing out, is that there is no reason to challenge ORSA as a professional activity. ORSA is valuable!! As far as I'm concerned that's a given!!

Our problem, as in every discipline, is that there is good ORSA, bad ORSA, and a fraction that falls somewhere in between. Our goal, of course, is to minimize the bad -- and we've been making good progress toward that goal. The recent cost and operational effectiveness studies on the Heavy Lift Helicopter and on BUSHMASTER may have had a few blemishes -- and perhaps the tools used weren't the best possible -- but, nevertheless, the results sufficiently and objectively illuminated the issues and alternative courses of action. Even if they had been less adequate they still would have served a useful role by forcing others to think hard about the deficiencies and issues not satisfactorily addressed. Last year's HELLFIRE study was an example of this. That study managed to surface, but leave unanswered, a number of important issues. This helped us to initiate certain field tests which are providing valuable inputs to a second and much more meaningful examination of the system. In line with my appeal for positive thinking and discussion, I was especially encouraged at last year's AORS Symposium. As General Chairman I was privileged to move freely about and sample most of the working groups in action. What I heard time and time again from the speakers was an attitude that can only be described as, "Look at what I have done - and I think it is good". That was great; it was most heartening. I fully expect you to hear more of the same at this symposium - despite the negative interpretations some may have put on the announced "theme".

As a final comment on this business of self-criticism, I reject the notion that we need to establish academic criteria for professionalism or a formal set of ethical standards. I maintain that in the years ahead the most stringent performance standards will be met by Army ORSA analysts through peer group pressure and by our structured system of reviews. (SAGs, IPRs, ASARCs, etc.) I believe the word is already out that you are likely to be shot out of the saddle if you report an inadequate analysis to any of these groups. Thus, by internally developed procedures we automatically institute standards of professionalism and ethics. There is no need to adapt testing procedures and licensing criteria.

A few moments ago I gave you a sample of some symposium themes and addresses that included the title, "Challenges in Military O.R. in the 70's". I researched this particular item (actually it was a 1971 panel discussion) to identify what were then perceived as some of the major challenges. I made a partial listing -- in no particular order -- simply to give you a flavor of what some leaders of the ORSA Community saw as some of the problems and challenges confronting us nearly four years ago. I have taken the liberty of slightly re-phrasing some of these challenges to put them in the common format. It's easier to show you these on a slide than to read them all ---

CHALLENGES IN MILITARY O.R. IN THE 70'S

THERE IS A NEED TO:

- DEFINE THE TYPE OF SERVICES WE ARE PROVIDING
- PURGE THE ANALYTIC QUACKS AND EARN GREATER CREDIBILITY
- SHARPEN UP THE PROCEDURES AND TECHNIQUES WE NOW TAKE FOR GRANTED
- USE MILITARY OPERATIONS RESEARCH RESOURCES MORE EFFICIENTLY; ESPECIALLY COMPUTERS
- REMOVE OBSTACLES TO INNOVATION IN ORSA
- DEVELOP A CODE OF ETHICS TO BE APPLIED TO CONTRACTOR ORGANIZATIONS
- ADAPT TO CHANGE IN THE DEFENSE ENVIRONMENT AND DECLINING DEFENSE FUNDING
- DEVELOP A HIERARCHY OF MODELS WITH VARYING LEVELS OF RESOLUTION
- DEVELOP A DISCIPLINED SET OF MEASURES OF EFFECTIVENESS APPLICABLE TO ARMY SYSTEMS
- GAIN A BETTER UNDERSTANDING OF THE WAYS IN WHICH NIGHT OPERATIONS DIFFER FROM DAY OPERATIONS
- STRUCTURE A BETTER FRAMEWORK AND METHODS FOR STORAGE AND RETRIEVAL OF THE ACCUMULATED BODY OF ORSA WORK AND KNOWLEDGE

Now I have no intention of addressing this list on an item-by-item basis. My purpose in mentioning these recent challenges is simply to let us see, in general, how future trends as I see them will work toward meeting these and related challenges.

Now, as to the future! Certainly the most prominent and the most critical trend impacting on Military O.R. is the decreasing defense budget. In actual purchasing power it is lower than at any time in the past quarter-century. How low it can get is anyone's guess, but it seems likely that it will bear its share of the nation's economic burden in the immediate years ahead. In fact reduced defense spending is, already a five year old trend. Barring overt acts of aggression by potential enemies, I see nothing in the political and social fabric of the nation that will reverse this trend. This trend impacts on Army Operations Research in two principal ways: First, ORSA activity will have to continue to adapt to reduced funding, and secondly the reduced funds to support new R&D starts on weapon systems and maintenance of a reasonably structured Army will require a much better analytical batting average than ever before. Because we will have fewer opportunities to begin new programs, we will have to get a higher increment of effectiveness from those that we do, and that means we who analyze will have to do better and 'smarter work'. With respect to materiel systems, we will be helped in this by our new materiel acquisition procedures which most of you are just learning about now. Those procedures have built into them a more deliberate, a more cautious, approach calling for intensive analysis and testing before proceeding into hardware development. They also require periodic reviews and updates of the COEA's prior to the final commitment to go into production. This will give us more time to make certainties out of the uncertainties and there should be no excuse for not doing "smarter" analyses.

The continuing trend toward fewer dollars to support Army Operations Research means that fewer tasks and studies can be undertaken. That will force us to be more critical and selective in choosing which one to fund. From the standpoint of quality, however, it should enable us to concentrate our best resources on the fewer but very important studies. This reduced level of effort has already had a major impact on the amount of work we will contract out. I have not attempted to quantify this, but the reduction thus far has been quite significant, and I do not see this as a trend that will be reversed. Actually, and although I personally hate to see it happen, I am convinced that we will shortly be entering an era of near-zero contractual effort. I can tell you today that we at HQ are already planning against that eventuality -- and I advise you to seriously do the same. That era is coming and you'd better harness your in-house resources, accordingly.

Fortunately, the organizational changes within the Army during the past 18 months anticipated the aforementioned trend. The establishment of the Concepts Analysis Agency, TRANSANA in the Training and Doctrine Command, the Operational Test and Evaluation Agency, together with AMSAA consolidate many of our O.R. and test functions and responsibilities. These organizations will provide a much-strengthened in-house capability. This centralization of our in-house talent will give the Army the organizations which not only can manage and conduct large segments of the O.R. effort, but which can also act as the essential "Colleges" in which newcomers to the field can learn the trade. The Army Materiel Systems Analysis Agency, born of the Weapon Systems Laboratory at BRL, is the prototype of this type of college. Apprenticeships at doing O.R. studies are fairly long, but the resultant talents and skills are very good indeed. I look for much the same level of quality in education and training over the next few years from CAA, TRANSANA and OTEA because of the amount of experience and talent we are consolidating in these organizations. Ladies and gentlemen, as trends go, this is a darn healthy one.

For years it was common in meetings such as this to speak of "Practitioners" and "Clients" as two separate populations. The contractors, as practitioners, performed operations research studies on behalf of the military services and the OSD offices and agencies who were the clients. Although it was not entirely true that the clients never practiced, the distinction was reasonably valid because the ORSA types in the services were quite fully occupied reviewing the practitioner's work. This is rapidly changing. It has to! The Army organizations I mentioned a moment ago are and will continue to be full-fledged practitioners. While it may still be valid to think of the DA Staff and the Army Secretariat as clients, the practitioners are now really part of the same family. And, I think that's a darn good trend.

One of the major developments of the past few years that has made this possible is the increase in the number of "Green Suiters" officers who are ORSA trained and qualified. Prior to 1968 there was only a handful of Army officers with ORSA credentials. Scattered as thinly as they were among the Army Staff and major commands, they could do little except review other people's work. Today there are nearly 600 Army officers on active duty with graduate degrees in Operations Research, and more are being trained each year. With this kind of talent to add to the civilian resources, it is not surprising that organizations like CAA and TRADOC are beginning to produce quality work. My own observation is that the ORSA trained Army officer brings his own special enthusiasm and specialized knowledge of the military which effectively complements the civilian's longer experience and continuity. They work well together, and the best part is that more and more of these young officers are being given the opportunity to be practitioners. In this regard, we are beginning to enter another interesting phase: The first of these ORSA trained officers are beginning to enter the 0-6, 0-7 grades. In the years ahead, their increasing influence in more responsible positions signals, not only a more perceptive and more penetrating review of the fine grain detail of our analyses, but also a better understanding and acceptance of our products. I personally fought against great odds to preserve the ORSA career program -- I won that battle -- and I'm darn glad about that.

You will recall from that earlier listing of challenges on the slide that there were several that called for greater efficiencies in the performance of our work. One trend that I see developing, and that clearly works in the direction of improved efficiency, is that one of "Standardization" within our COEA's. TRADOC has developed a set of standard scenarios for use in computer simulations. These include nominal Blue and Red forces with weapon types appropriate to the time frame, and detailed terrain data for representative battlefields in different parts of the world. The user of these standard scenarios can, of course, introduce variations in forces, weapon mixes or tactics to suit his particular needs. However, these scenarios have a healthy capacity for the integration of our efforts. Somewhat the same thing is happening with regard to simulation models. From the earliest planning for the creation of the Concepts Analysis Agency I have advocated making CAA the lead laboratory for all Army force analysis and force structuring models. Although this is obviously going to take a while, we are making it happen. Now, don't misunderstand what this means; CAA is not going to do all force analyses in the Army. They will become the focal point for collective knowledge about all such models, and for maintaining up-to-date information on inputs and model improvements. This should make available the best force structuring models for major studies and should lead to a better, and commonly shared understanding of these models throughout the Army ORSA Community. Incidentally, we are now examining a plan to designate some of the other major Army study agencies as lead laboratories in other subject areas.

A recent innovation to the Cost and Operational Effectiveness Analyses being conducted in the Army is the establishment of a "Red Team" to work in parallel with the main study group. The Red Team provides a vital new dimension to these study programs by assuming the role of the resident "Devil's Advocate". Their charter permits them to challenge any aspect of study such as: assumptions, costs, force deployments and so forth, on the grounds of accuracy, realism or even just good common sense. One of the ways Red Teams may make their most significant contributions will be to insure that the Enemy Forces are made to act and react with intelligence in our war games and simulations. I think the addition of the Red Teams to the study and analysis process will provide valuable and broadened insight into many of the new and sophisticated weapon systems under study. They will also serve to lighten the burden of the small managerial and review group at Headquarters, DA, who traditionally have had to perform this same function.

There is another category of operations analysis that is relatively new. It is called "Net Assessment". While it may not exactly qualify as a "Trend", it is currently in vogue and it could very well become part of our stock in trade. Net assessments, which were initiated or at least promoted by a Blue Ribbon Defense Panel in 1970, were defined as integrated systematic analyses of existing and proposed programs as they established capabilities and limitations of the United States versus possible antagonists. Simply stated, the objective of Net Assessments is to identify asymmetries in military capabilities that can be exploited or need to be remedied by changes in governmental programs or allocation of resources.

The initial work on Net Assessments was performed at the highest level -- the estimation of relative balances of power or of critical elements of power, existing or projected, among nations or alliances. Since then, concepts of Net Assessment have been broadened and extended to serve a range of purposes, including the future effectiveness of military force elements and Net Technical Assessments of particular classes of military equipments. So far, the principal impetus for this work has been from OSD. Some recent and current examples of Net Assessments that the Army or outside contractors have worked on include: Artillery, ICM and ICCM, Tank-Antitank, Chemical and even one on Tank Crew Training. In some ways all of this may not be very difficult from assorted "Special Studies and Analyses" we have all done from time to time; it's just that we didn't have a good, all encompassing name for this kind of work. Nevertheless, it is more formalized now and the primary user of the results is OSD -- not some intermediate level of Army management. It is very important, therefore, that O.R. analysts participate in these Net Assessments to insure that the proper judgments and inferences are brought out and the limitations of the assessment are made clear. I caution, do not write these off as simple data-gathering exercises.

There is another area of work that is likely to become a growing trend, because I plan to do all I can to make it happen. I'm talking about analyzing current operations. It seems that the bulk of the ORSA work in progress today is oriented toward 1977 and beyond. Who is studying today's Army operations and activities to make them more efficient and effective? Let's talk about a typical tank battalion in Europe for example:

- What is their week-by-week activity profile?

- How far do their tanks travel each year? By road march? By rail? At what cost?

- What are the spare parts costs?

- How frequently must the tanks be overhauled? At what cost?

- How much training ammunition is used? What does that cost?

I happen to have obtained some of the answers to these and many related questions because I became involved in a special project for the Under Secretary of the Army just a few weeks back. It was an interesting and informative exercise. The answers to the questions I have just presented can be obtained. In fact, you can get them very gradually by going to AMC, HQ USAREUR, DCSLOG, etc. The interesting and curious thing is that no one is really both collecting and analyzing these kinds of data; no one is really challenging the current practices; no one is asking the provocative questions about how current practices might be made more efficient and more economical. Many of these kinds of data are being accumulated under various existing Army procedures. They can be obtained and they are amenable to thoughtful analysis, but no one seems to be doing it. Now, I will concede that this type of work is probably less glamorous (and less publishable) than an elegant mathematical treatise. However, it could be a heck of a lot more useful to the Army. For example, when you consider the fact that the Army's maintenance costs have been running at 20% or higher of the total Army budget for the past five years, you can begin to appreciate the dimensions of what I am talking about (and I might note that ammunition costs are not a part of this -- they are in addition to the maintenance costs). In comparison, total Army R&D budgets are only at about one-third the level of the maintenance costs. The message is clear: If we can shave 10% from the maintenance costs without significantly affecting operational capability, then we should be able to expand in other demanding areas. I hope that a number of you will leave here with a resolution to delve into this subject of current operations. Believe me, it is a fruitful area of study.

I think it's time I began to wind this up. There are a number of other topics I could have expanded upon, but I will just mention these in passing:

- Urban Combat - This is gaining increased attention, and its complexities are a real challenge. Much work in this area is needed.

- Increased reliance on field testing, and the potential for testing and simulation to support and augment each other.

- Earlier and more detailed incorporation of the logistical implications of adoption of new materiel systems.

- Night Combat - In terms of modeling or simulating this we are not much better off than we were five years ago. Meanwhile the quality and performance of night vision equipment has drastically improved.

- Survivability is something we will be hearing more of and paying more attention to in the future. I'm speaking about survivability in its broadest sense -- encompassing passive protection, signature reductions, camouflage, redundant systems, field expedients, etc. I'm willing to predict that we'll hear more on this as early as tomorrow afternoon.

- Risk analysis - This was the theme of AORS XI in 1972. I should know - I gave the keynote speech. This has been evolving rather slowly, but surely. I envision the day -- fairly soon -- when a formal technical and economic risk analysis will be a part of the concept formulation package for any new system.

I'd like to take just a moment or two to summarize my remarks and attempt to point out where we are headed in Army Operations Research.

- There has been a significant trend toward consolidating Army ORSA activities within the Army with a corresponding reduction in the use of outside contractors. Contractual efforts will enter a near-zero era.

- One of the primary reasons this is possible is the sizable growth over the past six years of ORSA - qualified Army officers. They are beginning and will continue to enter the group of General Officers.

- There is a definite trend toward standardization of scenarios, models and analytical methods.

- The quality, quantity and health of the ORSA Community is generally good. We need no control mechanism to insure professional performance -- we have become self-disciplining and self-regulating.

- The defense budget, and indeed the social climate with regard to defense spending, will inescapably impact on our profession, the dimensions of the work we do and the environment in which we work. I'm afraid that we are in for an extended period of belt-tightening; our work must be much more selective and a lot "smarter".

- Some of the buzz-words of the next 4-5 years will likely be:

  - SURVIVABILITY
  - NET ASSESSMENT
  - OPERATIONAL TESTING
  - DECISION RISK ANALYSIS
  - NIGHT COMBAT
  - URBAN COMBAT
  - RED TEAMS

And finally:

- ANALYSIS OF <u>CURRENT</u> OPERATIONS: It's a must, a need, and we will be doing much of it in the future.

On the whole I'd say that Army Operations Research is improving in quality, is gaining more credibility among the top decision-makers, and has some promising new directions to move into. Most importantly, it is gaining increasing respect and attention from the decision-makers -- and that's what it's all about, isn't it? So let's stop beating ourselves over the head.

ORSA HELP IN MANAGING THE ALL VOLUNTEER ARMY

BANQUET SPEAKER
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Thank you very much for the kind introduction. It is a great pleasure for Mrs. Phillips and me to be here - our first visit at Fort Lee. We've been delighted with the hospitality shown us. Mr. Newman, General Hallgren, General Graham, General Camm, other distinguished visitors at the head table, at the symposium this morning I was delighted to hear my old friend and mentor, Dr. Cole, my West Point Classmate, General Miley and an associate of many years standing, Abe Golub. We have heard about the past of ORSA, we have heard of the prediction of the future of ORSA. My subject tonight is ORSA and management of the All Volunteer Army, which is the present of ORSA. You heard Abe Golub say this morning that he thought there was a great deal of work to be done in OR in the present. Unfortunately he cited the operations of a tank battalion as a suitable place for that to start. My thesis is that the right place to start is in manpower management.

Now this after dinner speaking is rather a new forum to me, typically I have a lecture at a War College or at Leavenworth or somewhere else and there is a question period so I am fairly circumspect in what I have to say. Tonight, not being that constrained, I'll be somewhat contentious, I hope.

Secretary Callaway spends between 65 and 70 percent of his time on people-related matters involving making the all-volunteer Army an unqualified success, a reality. That leaves about 30% of his time on the kinds of things that you usually deal with, force structure, R&D, procurement, planning, programming, budgeting, and legal matters that don't have to do with the all-volunteer Army. How much ORSA effort is being spent in support of Secretary Callaway and his tough decisions? My thesis is not nearly enough, particularly when, as General Miley correctly stated, well over half of the Army budget is spent on people and people-related things. And I'm talking about people taking well over half of the budget not counting the people-related part of O&MA.

Not quite two years ago now we got into a brand new ball game, brand new rules, brand new problems. Overnight our least expensive, least worrisome, easiest to manage resource became our most precious, most worrisome, most difficult to manage. During the draft we simply had to call on General Hershey to send us how ever many men we wanted, whenever we wanted, where ever we wanted. This permitted our training base to run on essentially an even flow basis, being perturbed on slightly to permit us to replace people in units as they left the Army. Moreover, General Hershey sent us a rather consistent and representative cross section of the military age population. They were qualified to fill all the hard and soft skill MOS vacancies that we had. Under these circumstances you would be right to assume that recruiting, making service life attractive to the junior enlisted men, the need to entice young men into the less desirable but essential skills such as infantry men, tanker, and artillery men were not among the Army's higher priority problem. Suddenly when we stopped drafting we discovered seasonality. Not many people want to join the Army in the months of February through May. The best and the most join through June to September and again in January. From being a very simple task to match a vacant school seat with a qualified student, it became a very difficult task. From being a very simple task to replace losses in units as they occurred, it became a very difficult task. From being able to get by with a small, second rate, poorly housed, recruiting force, it became necessary to establish as a top priority getting a large highly motivated, superbly trained, superbly housed and superbly led recruiting force. From being able to ignore career attractiveness, it became necessary to analyse what it was we were offering, to improve on it, and to present it in the best possible light. And that meant a fourteen fold increase in our advertising budget. We now spend about forty-three million dollars a year in advertising and we decided to do that without benefit of ORSA, unfortunately. From being able to ignore high school guidance counselors, parents of potential enlistees and their coaches--those that influence the youth--we found that we have to find ways to get them to work with us. Suddenly too, commanders in the field, for example a Division Commander, were told if you want to Command this Division get out and recruit it. So recruiting became everybody's business.

Now in achieving the success that we had in fiscal '74 (and by the way we were the only service of the four who reached their legislative end strength as of last June 30th and this success is continuing into this fical year), we took, again without benefit of any ORSA help because of the time involved, a number of costly actions and a number of nominally low-cost actions which nevertheless have reduced considerably our managerial flexibility and our efficiency. Thus, whereas before we decided where a man would go and what he would be trained to do, we find now that he and increasingly she tells us what they will do and where they will go and this in a written contract that is morally and legally binding. As is readily apparent these new rules and constraints don't leave very much room for error. They presume we know today how many men and women we ought to start training tomorrow in which of about 800 skills to fill vacancies that will occur up to a year from now in an Army the size of which and the force structure of which will certainly change at least once between now and then by action of Congress and more frequently by other people, notably the Deputy Chief of Staff for Military Operations. If we make a mistake it is pretty costly. We either have a skill mismatch and have wasted a lot of training money or we have a breach of contract and we have to discharge the soldier or we have a disgruntled soldier who is not likely to reenlist.

To help manage under the changed situation that I have described and to come as close as possible to putting the right face in the right place at the right time which is all the Deputy Chief for Personnel has to do to be successful, we invented a number of new policies all of which were costly as I have indicated and all of which are in jeopardy now by opponents either within the Army or without. I want to talk briefly about a few of these. As I do I am sure you will see where we might have been able to benefit by an ORSA analysis and where we may still be able to benefit as we try to defend what we have done. First, we fought for and we got an enlistment bonus, first of all for the combat arms for which we always seem to need an edge in the marketplace over the other skills and the other services. Later we got the bonus for a limited number of hard to fill, hard skills which require long difficult training and high mental capacity. The bonuses are offered only to upper mental categories who are high school graduates and who agree to serve for four years. We use about 50 million dollars of our precious money for this program and as I have indicated there are those who would terminate it. That's why I have asked the Concepts Analysis Agency to develop models to determine when an enlistment bonus is cost effective. (That study was one (and as far as I am able to determine the only one) of seventy items that were listed in your seminar topics. So, I guess during this symposium manpower management problems are getting a little more than one percent of the attention of this group.) Now don't be fooled by the simplicity of that statement because it is a very tough nut to crack determining when a reenlistment or enlistment bonus is cost effective. It includes projecting, for example, reenlistment rates. I have also asked the Concepts Analysis Agency to determine how we might assure ourselves that a soldier who takes the bonus for four years service remains in the skill for which he signed up for the bonus. I have a recurring nightmare alternately of Chairman Hebert and Senator Stennis riding from the Pentagon back to the Hill with a Pentagon motor pool driver who they start to talk to and who reveals that sure enough he signed up for a combat arms bonus and for the last two years he has been driving a sedan in the Pentagon motor pool. Well this latter study, determining how we may assure that a man who signs up for a bonus for a particular skill stays in the skill, clearly requiries a full understanding of the people distribution system of the Army by the researcher and I maintain that is a far more difficult distribution system than the logistics distribution system though I could be wrong on that. I know of three ways to make that possible, first of all you can assign people who know the distribution system to do the research. With the decrease in the Army staff, that is not possible. You can also assign to the researcher an expert as a liaison person who knows the distribution system. Again that is not possible because the people running the distribution system have enough on their plate every day not to have to be involved with teaching somebody how the system works. The third way is to immerse the researcher in the milieu of the operator. With the cooperation of CAA that is what we have done in this case. As an aside, my observation has been that unless an analyst and the eventual user of an OR product work hand in glove from the very beginning of a project, the result is not likely to be used by the Army. I'll admit that is not a sufficient basis for success of an OR project but I rate it as an indispensible one.

The second policy that we started to help us is the unit of choice or station of choice option which I have hinted about before. These options permit an enlistee to be guaranteed up to sixteen months with the unit of his choice after he has finished training. He can also choose the skill in which he wishes to be trained and he can piggyback if he wishes a combat arms bonus on top of those. That option, unit of choice/station of choice, has done more to attract soldiers than any other thing we did in the Continental United States. Apparently it is a no-cost option, but it is not without its problems and I'd like to outline those to you. First of all it demands a much finer quality of management on the front end of an enlistment than we have ever known before. We must control enlistments so that the popular units and stations don't get over subscribed, and we have not done very well in that up to now. We must also see to it that the unpopular skills and locations do get fully subscribed because we only get one face for every manpower space that we are authorized. The tool we created, with contract help, to solve this problem is known as the Request system. It is a computerized system very like but more complex than an airline reservation system, with a query and response capability at each of our 64 main recruiting stations. Another problem of these options is that they seriously reduce our flexibility in distributing people. Even if we capture every soldier when his 16 months is up for an oversea tour (and generally we need them to fill Europe), if he is on a three-year enlistment, he has only 14 months to do. This, of course, in the face of the fact that OSD and the Congress are insisting on pushing the enlisted tour toward the 30 month average and beyond. Of course we would like to do that too because it avoids PCS costs and avoids personnel turbulence which affects readiness.

These options also demand a much closer control on recruiters and on unit canvassers. They require much closer coordination between TRADOC, FORSCOM and the Recruiting Command than we have ever had before, because not too long ago we had the CG of the 9th Division at Fort Lewis recruiting in Jacksonville, Florida. And in Dallas on any fine Saturday afternoon you could find unit canvassers at $25 a day per diem from two Armored Divisions, an Air Mobile Division and two Infantry Divisions all competing for the same people. So we were directed by the Congress in their last appropriation act to justify in the FY 76 budget hearing the Unit of Choice canvasser program and the size of the recruiter force which is now about nine thousand. There is an excellent OR problem for you. Find and defend the smallest or the least cost recruiting force necessary to satisfy the Army's quantity and quality requirements for enlisted accessions taking full account of the effect of advertising, the economy, the enlistment options and bonuses and the varying requirements of the other services for recruits.

A third policy we established to help us is called the Trainee Discharge Program. This was started a year ago last September and it reversed the age old philosophy of the training base of the United States Army which was "Make soldiers out of anybody we send to you even if you have to recycle them." to "Don't let anybody graduate and enter a unit of the Army unless he is a fine, qualified, well-trained soldier so that he won't create administrative burdens once he has joined the unit. But in doing that be sure you get him out of the Army before he's been in 180 days" so that he doesn't qualify for any expensive Veterans Administration benefits. And we made this discharge during training a very easy thing for the training centers to do. Such a program increases our non-prior service accession requirements annually by about 15,000 and wastes a lot of training dollars but, it does permit us to overcome our inability to measure a man's real ability before enlistment by validating his on-the-job performance. Or less elegantly, one could say that it permits us to take more below average people into the Army than we would like to have and then to discharge those who can't, won't, or don't shape up. The problem we now face with this program is proving to the Congress that it is cost effective, something they believe should be relatively easy to do since it has been running for fourteen months. As you can probably see, the only dollar savings that we would have to offset the initial and increased costs would accrue if the loss rate from the units for the first term soldiers were to turn out to be lower than those in the units prior to the time we initiated the program. Unfortunately, we won't have enough data to do that until we have tracked cohort groups that started last September for at least two years. The first of these cohort groups won't finish two years until next September. So we have the reproblem of convincing a skeptical and saving conscious OSD, OMB and Congress and we have perhaps too little data with which to do it. How shall we do it?

The final policy change I will cover is the two-year enlistment option. There is a law that requires any service which uses draftees also to offer a two-year enlistment, so we have had a lot of experience in the Army with two-year enlistments. We were fairly certain that we had to continue them if we were going to get the number of soldiers we needed during the first year of the all-volunteer Army. A year ago this month we were having trouble making our enlistment goals. Our quality wasn't as high as we would like it to be, and we were having trouble filling Europe. So we sweetened this two-year enlistment by offering a couple of either/or options. We offered to the upper mental categories either training or skill of the man's choice, or we guaranteed assignment in Europe. Now nobody likes two-year enlistments. They do not provide a very good return on the investment of the training dollar, unless their reenlistment rates are considerably higher than three or four year enlistees, and we don't know that yet. Typically though they create the kinds of problems we try to avoid: large annual requirements for accessions which move into the Army and out of the Army very quickly, they require a relatively large training base and a relatively large recruiting force, they are responsible for a lot of personnel turbulence, and a large piece of the transient account. However, we have found that there are a lot of men and women who, when they get out of high school, are not certain of exactly what it is they want to do. Some of them don't have enough money to go on to college, some of them are not even certain that they want to go to college. But they know about the VA educational benefits and in-service educational opportunities, so a great many of them are willing to sign up for two years. Clearly the key question is how many of these same people would sign up for three years if the two year option were not available? And that is a question we cannot answer. We are under great pressure to terminate the two-year enlistment for the reasons I've outlined. Shall we do so on our own? Shall we try to defend three-year enlistments on a cost-effectiveness basis? This means eventually having to assign some benefit to having an authorized space filled as opposed to not having it filled. Or shall we simply wait and be ordered to drop two-year enlistments?

I might summarize these four policies, and I could talk about four or five others equally as interesting, by estimating for you that the issue we now face with the budget and inflation in managing this all-volunteer Army is simply this: Shall we continue to spend essentially what we have been spending on the personnel of the Army and raise quality, which we can do because next year our accession requirements go down or shall we be satisfied with the same quality we got in fiscal 74 and which we bragged a good deal about and turn the savings back to the Treasury or into some other Army program? Secretary Callaway has come down very hard on quality. That is, for the same resources, get fewer of the lower mental categories and get more of the high school graduates. But we do have a lot of opponents in this and we are going to need all the ORSA help that is available to defend ourselves.

Finally, I want to talk about minority representation in the Army and specifically about black representation. We have two concerns: black officer content is clearly too low--under 5 percent of the officer corps--and black enlistments are proportionately much higher than the national average of the military age group. We are enlisting blacks today at about 27 percent of all enlistees and the black enlisted content of the Army at the end of the last quarter was 21.9 percent. We have taken some steps which we think will solve the officer problem: New ROTC in all-black colleges and great recruiting efforts to get blacks into good ROTC's and to West Point.

On the enlistment side Secretary Callaway has first made clear that we will never deny enlistment to any qualified candidate for any vacancy based on race. He also feels, however, that the Congress and the American public of all races want to have and need to have a representative Army, racially, geographically, economically, and where tradition permits sexually. There are about three major reasons for our concern. We are concerned that Congress may be reluctant to support a draft free Army becoming more and more racially imbalanced. We are concerned that blacks would take a disproportionately high share of casualties in any future emergency or war. And we are concerned that there may be a point, and we don't know this, in which the predominence of a racial minority group will inhibit enlistment or reenlistment by a broad cross section of our population in certain units or in the Army as a whole. There obviously cannot and will not be any ceiling or quotas by race. However, Secretary Callaway has directed, and we are proceeding now with a long-range plan to insure that everyone has the opportunity to know about the Army's opportunities and to serve in it. We intend therefore to establish enlistment goals throughout the United States for our recruiting hiarchy that are proportionate to the qualified military availables in the geographic area and hopefully to match our resources to the problem in such a way that we do get a good geographic distribution rather than as now getting a disproportionate representation from the Southeast and Southwest US. At the same time we hope to draw a racial mix that is much closer to the national average. I am sure you recognize that this is a very sticky issue and in my opinion the only one that could possibly jeopardize the all-volunteer Army. So there is a final problem for you: Design the least costly set of legally and morally defensible policies and actions to assure that the racial balance in the Army remains acceptable to the American people and to the Congress.

In what I said I have raised many more questions than I have answered. For those of you who habitually think in terms of hardware, force structure, strategy and tactics, I challenge you to turn your best thoughts to where the really big problems and the really big money are and where the really big money can be saved. That is in manpower and personnel management systems. In the final analysis, the size of the Army force structure and the degree to which we can modernize that force structure will depend in large measure, critically I think, on our ability to manage more efficiently our manpower resources. We need your help. Thank you very much.

SUBJECT: Conceptual Design for the Army in the Field (CONAF)

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AGENCY: US Army Concepts Analysis Agency

ORIGIN

The need for resource constrained force design became irrepressibly evident to the Army in the late 1960's. At that time, the gap between force requirements and resource capabilities was fully exposed by the family of Army plans and the studies which were spawned in response to two very different sets of guidance. On the one hand was objectives-type guidance, on which the force design community based its type forces. The result was a series of relatively unconstrained forces which clearly were very capable while highly demanding of people, equipment, and support. Obversely, capabilities-type guidance reflected that structure, people, and materiel the Army could really expect to have. Studies and analyses in this area generally sought to reconcile requirements with reality while preserving some cognizance of what the Army should have if it were possible. This dichotomy was fully revealed when the combat development community presented its blueprint for the mid 70's--the Army 75 Report. That document provided for powerful division forces, modernized in anticipation of projected systems availability, and supported adequately by the fully functionalized support echelons of the Army in the Field. Unfortunately, not all the structure, manning, modernization, and support was reasonably attainable. Thus, a basic decision was made to find another way to conduct the force design function, this time within projected resource availability. The result came to be called CONAF, and it evolved from the experience of the Army's Combat Development Command in the force design area. It is an amalgam of several methodologies and represents the integration of expertise and techniques relating to resource projection, strategy, doctrine, materiel development, and force structuring, all built around the fundamental idea of improving the effectiveness of the Army's forces in the field.

METHODOLOGY

Development of methodology has been a central feature of CONAF since its inception. The basic functions of CONAF--resource definition, force design, and force analysis--require rather demanding methods and model applications in their own right. Thus, the methodological challenge in CONAF was to integrate the conduct of these functions in a comprehensive, consistent manner while achieving reasonable efficiency. The diagram in Figure 1 graphically portrays the CONAF general methodology.

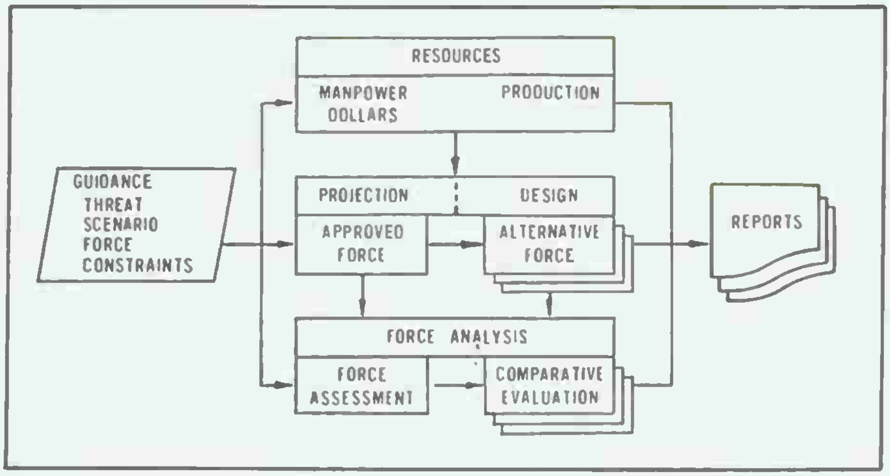

Figure 1, CONAF GENERAL METHODOLOGY

At the beginning of the CONAF cycle, guidance is developed by the Army staff concerning the framework within which the study is to be conducted. Scenario guidance sets the stage and threat, force level/composition, and constraint guidance establish the parameters for design. Necessary assumptions are then developed to further define the problem or, in some instances, to simplify the design and evaluation tasks.

Resources are prescribed in terms of manpower, production capabilities, and dollars. In extension of these expressions of overall resource levels, guidance is usually stated in terms of limits on fluctuations on a fiscal year basis and also among the various appropriations and program categories. The result of this is to further define the guidelines within which force design can occur.

The first step in carrying out force design activities is to project the current approved force through the timeframe of interest. This is done to establish a bench mark for purposes of costing, manning and structuring alternative forces. Using the projected approved force as a "known," the designer can better visualize the effects and relative contributions which his conceptual and structural ideas will bring to the Army. This is fundamental to all three functions identified in the general methodology, for it enables the coster, designer, and evaluator to work in a commonly understood medium. It also enables the decision maker to better understand CONAF results and relate them to real world problems and issues.

A parallel approach is used by the analyst in assessing the performance of the approved force and in comparing that assessment with the simulated performance of the designed (alternative) force. In carrying out the evaluation process, reliance is placed primarily on the outputs of the Concepts Evaluation Model--a fully automated, deterministic, computerized model designed to simulate large-scale, nonnuclear warfare between two opposing forces. The force evaluator considers model inputs, model operations, and simulation results in analyzing force performance. Using these indicators in combination with strategic, threat, and scenario factors, he can then develop insights as to the utility of a force alternative vis-a-vis that of the projected approved force.

EVOLUTION

The initial CONAF report, CONAF I, was strongly oriented toward methodology--seeking to articulate the most useful way of integrating resource definition, force design, and force evaluation--and toward the development of tools to accomplish these functions. In the resource area, attention focused on economic and cost analysis. It required the gathering of cost data for current and developmental materiel, consideration of peacetime structure and equipment plans on an annual basis, and the application of consumption and other factors which act to prescribe the resource levels available to the Army.

For the force designer, the problem was to somehow marry type force design techniques with resource parameters developed by the coster. The solution eventually worked out led to a linear programing approach which used high dollar value items as the pacing factor and attempted to maximize firepower within dollar constraints. Using this technique a large number of plausible dollar-related performance combinations were identified for refinement and analysis of their potential. This approach remains at the heart of the CONAF methodology.

Concurrently, the force evaluator was faced with the need to create a tool for measuring the contribution of various resource combinations to force performance. A model was required which would be sensitive to weapons mixes and also reflect the support requirements necessary to sustain such a force in combat. For this task, the Theater Combat Model developed at the then Research Analysis Corporation in McLean, VA, was selected, and efforts to modify it were started. This model came to be called the Concepts Evaluation Model, or CEM, and today rests at the center of the CONAF evaluation methodology.

In retrospect, the CONAF I efforts produced the foundation for resource constrained force design and identified the essential tools and individual methodologies. While no immediately useful products emerged from this effort, the feasibility of the approach was made evident.

For the CONAF II project, emphasis was placed on refining and improving methodology and models and better integrating the CONAF process. Promising force employment concepts developed during the initial project year were earmarked for more detailed treatment. While progress was made in all phases of CONAF, the bulk of the work focused on force design. In particular, emphasis was placed on the interaction of combat and support concepts and the fleshing out of weapons mix alternatives identified during CONAF I. This work was accomplished within a framework of resource constraints, the methodology for which was also being improved. During CONAF II, development of the CEM was substantially completed and tests were conducted to determine how well it would handle the challenging evaluation tasks planned for it. CONAF II was clearly the year of the conceptual force designer.

The recently completed CONAF III project brought to fruition the concept of resource constrained force design. With the advent of the CEM as a discriminating force evaluation tool, all elements of the CONAF methodology could be adequately supported. The CEM enabled the evaluator to make quantifiable judgments as to the merits of alternative forces. For example:

- a differing allocation of firepower between antitank and antipersonnel

- a different structure as between combat forces and support forces

- a greater or lesser commitment to logistic support

As developed for CONAF, the CEM was intended to be sufficiently sensitive to variations in force composition and force employment concepts as to be useful in force design. It was constructed so that conceptual forces, even if designed against severe resource constraints and consequently not differing grossly from one another, could nonetheless be differentiated in their capabilities to accomplish a theater mission. The CEM, which has the following predominant features, quite obviously satisfied its intended purpose:

- Theater-wide, campaign-long

- Fully automated

- Deterministic

- Resolves to battalion level for twelve-hour periods.

- Controlled by simulated commanders' decisions

- Sensitive to design-important force characteristics

Thus, CONAF III became the year of the evaluator because the increased capability afforded by the CEM enabled the CONAF team to address problems and issues of current interest to the Army.

CONAF CONTRIBUTIONS

At the last Army Operations Research Symposium, COL John R. Brinkerhoff reviewed the objectives and methodology for CONAF III. 1/ Briefly, CONAF III focused on a NATO First Scenario for 1986 but included, significantly, a task to assist the Army staff in the development of the Program Objective Memorandum for the period FY 76-80. CONAF III was intended to provide analyses for both periods. For FY 80, an assessment of the programed force was undertaken with a view to assessing its capabilities and limitations and addressing to the extent feasible the force issues facing the Army. For FY 86, alternative forces were designed and evaluated with a view to identifying promising force concepts for the NATO mission.

1/ Proceedings, Twelfth Annual US Army Operations Research Symposium, 2-5 October 1973.

Both tasks were accomplished and observations backed by quantified analysis 2/ 3/ were submitted to the Army staff earlier this year. These results are summarized in Figure 2, somewhat abbreviated due to security considerations.

Resource reallocation within equal cost constraints is a useful design option.
Resource constraints govern the extent to which design changes can be realized--even over a 12-year period.
The planned structure of the force does not appear consistent with projected personnel and weapons replacements.
Current employment concepts will generate high losses.
Force performance is highly dependent on planned levels of logistic support and replacements.

Figure 2, CONAF III - Observations

The collective impact of these observations has been to focus renewed attention on ways to:

- maximize early combat capability in Europe

- treat combination scenarios

- improve the balance between deployed and reinforcing combat units

- improve the balance between theater and CONUS stocks and post-D-day production.

- develop more supportive manpower policies and plans in peacetime to meet wartime requirements.

These observations imply a great many ramifications for force designers as well as those engaged in the daily work of managing Army resources and planning for the support of the Army's wartime tasks. The utility of CONAF in this area is evident from the kinds of analyses it is capable of conducting as evidenced by the observations listed above.

2/ USA CAA, CONAF III FY 79 Approved Force Warfighting Capability, December 1973.
3/ USA CAA, CONAF III Final Report, August 1974.

Another way of assessing the contribution of CONAF, and its utility or value to the Army as a product of operations research, is to list the kinds of questions that CONAF can address. Figure 3 is derived from an appreciation of the capabilities demonstrated by CONAF as it exists today. These questions are posed somewhat cryptically, with the intent of eliciting responses which would generate a dialogue and thus create some guidance as to how CONAF should be oriented in the future.

Short War - retreat or opportunity?

Tooth-to-Tail - sense or rhetoric?

Are there real opportunities in novel defensive concepts for NATO?

What kind of NATO rationalization and specialization offers advantages for US forces?

Does the high-low concept result in measurable improvement in Army force performance?

Can strategic deployments be improved by re-balancing forward deployed units, readiness, strategic lift, prepositioned material (POMCUS), and stocks?

Figure 3, CONAF QUESTIONS

In summary, CONAF contributions can be generalized as a demonstrated ability to provide analytical assistance for decision making in four areas:

- force capability - resource requirement quantifications
- internal force balance within a given scenario
- force support problem identification
- force development process integration

Today, the CONAF capability resides in the US Army Concepts Analysis Agency. It consists of accumulated CONAF experience and familiarity with the methodology. The models which are employed in this methodology also belong to the agency, to include the CEM, which was brought in-house this year. A listing of the models currently used for each phase of the methodology is shown in Figure 4.

DEFINITION	DESIGN	EVALUATION
FAS - Force Accounting System	ATLAS - A Tactical, Logistical, and Air Simulation	CEM - Concepts Evaluation Model
	BN SLICE - Modular Force Planning System	TARTARUS - Computer Assisted Wargame
FCIS - Force Cost Information System	PFD-SAM - Preliminary Force Design Simulation Allocation Model	SMOBSMOD - Strategic Mobility Simulation Model
UDS - Unit Data System	FASTALS - Force Analysis Simulation of Theater Administration and Logistics Support	
	CAMP - Computer Assisted Match Program	

Figure 4, MODELS

Other models are being added to this list as we pursue the continuing task of improving CONAF methodology. In addition, improvement of the CEM is in progress and expansion of its capabilities in the combat support area is under consideration.

It should be pointed out that while the CONAF capability resides in the Concepts Analysis Agency, the conduct of CONAF-type studies requires some interaction with other parts of the Army. In particular, this includes the production and materiel development communities within the Army Materiel Command and the combat development community, with particular emphasis on the exercise of that function within the Training and Doctrine Command.

CONAF IN FY 75

Turning now to the future, CAA has investigated opportunities for employing the CONAF methodology in support of high priority, as well as mission oriented, projects. As a consequence of describing current CONAF capabilities to a number of Army elements, the scope of the FY 75 program emerged as follows:

- Wartime Active Replacement Factors (WARF)

- Force Analysis and Capability Evaluation (FACE)

- CONAF IV

The orientation of each of these projects is discussed in the following paragraphs. In each case, the CONAF methodology has been modified to support the project objective in the most appropriate manner. Central to all of these applications, however, is the use of the CEM as the principal generator of analytical data.

WARTIME ACTIVE REPLACEMENT FACTORS (WARF), PHASE III

The WARF III Study is being sponsored by OCRDA and was formally tasked to CAA on 22 April 1974 as a continuation of the Phase II effort to improve estimation of Wartime Active Replacement Factors. These factors are used as inputs to the planning, programing, and budgeting system (PPBS) to compute combat consumption and pipeline requirements. In the past, they have been developed in accordance with policies specified in AR 710-60 and in part based on judgment. The current WARF's are possibly outdated and lacking in credibility for various reasons.

In this phase of the WARF study, CAA will produce computer programs and a user's guide required to implement the WARF II system design, test adjustment of attrition factors, and provide WARF's for P-20 materiel items. Further, CAA will develop attrition factors for CEM by utilization of higher resolution models. Other objectives are to:

- Provide documentation and rationale for CEM attrition calculations.

- Develop formats and related user-level instructions for system inputs and outputs.

The general methodology employed in this study uses the Concepts Evaluation Model (CEM) to develop simulated loss rates. These were evaluated as candidates for replacement of the historic loss rates pertaining to major tactical items of equipment; namely: tanks, light-armor, helicopters, antitank weapons, and mortars, all of which are played in the CEM. The WARF's for these items are to be developed based on the resultant CEM outputs.

In an effort to obtain "compatibility and consistency" among CAA study efforts, the WARF study emphasizes several important aspects of the CONAF methodology. These are: (1) the PFD-SAM model is used to develop the deployment schedule; (2) the simulations are based on a common scenario; and (3) the CEM-generated loss rates for the major tactical items of equipment are utilized in developing the WARF's. It should be noted that the WARF study deals exclusively with the analysis of "equipment attrition" in exploiting CEM capabilities. Other measures of effectiveness (e.g., FEBA movement, personnel casualties, etc.) addressed in the CONAF methodology will be reviewed to determine consistency of results and, thus, to assure that attrition data and these MOE are in reasonable agreement.

FORCE ASSESSMENT AND CAPABILITIES EVALUATION

During the past several years, the Army staff has attempted through the Total Force study efforts to provide the most suitable basis for the development of the Program Objective Memorandum (POM). Total Force studies have established force structures which are required to accomplish the US Army portion of national security objectives. In addition, these studies have attempted to develop and use analytical methodologies to provide a firmer basis for identifying and justifying required force structure. This year the Force Assessment and Capabilities Evaluation (FACE) has been integrated into the Total Force study effort and tasked to provide:

- An assessment of the warfighting capability of the projected force and selected alternative forces in the FY 80 timeframe.

- An assessment of the impact of war reserve availability on warfighting capability.

- An assessment of the impact of personnel replacement policies on warfighting capability.

- An analysis of the capabilities of projected service support forces.

A modified CONAF methodology will be used to accomplish these tasks, using a CEM simulation of the projected approved force (POM 80) in combination with other model results to identify any internal imbalance and establish a basis for examining structural changes. Of particular importance will be the conduct of analyses aimed at prioritizing support unit requirements for the NATO conflict situation. Alternative deployments and roundout schemes will be simulated, as well as alternative force combinations (within current force guidance) in order to obtain an analytical basis for influencing POM 81 preparation.

CONAF IV

The continuity of the CONAF effort under the aegis of the Deputy Chief of Staff for Operations and Plans (DCSOPS) is important because of its unique capability to assess the impact of current and projected plans and programs of the Army in the Field in the mid-range period - the mid-1980's. The prime reason for CONAF IV hinges on a need for the Army to look downstream from its near-range planning and programing efforts in order to determine what the broad characteristics of the Army in the Field should be in the mid-range, considering: forecast missions and tasks; the projected availability of manpower, dollar, and materiel resources; and the assumed threat.

The CONAF IV study objectives are as follows:

- Within projected resource constraints, develop conceptual forces which recognize the current trends in US defense policy and have a potential to improve on the capabilities of the projected approved force to accomplish Army objectives and missions at end FY 87.

- Improve CONAF methodology and models for application to the development and evaluation of force design alternatives.

The methodology for CONAF IV requires that a base case force be defined for end FY 87, with manpower spaces and costs determined in order to establish resource parameters for subsequent development of conceptual force designs. Concepts will progress through definition, pilot design and full force design stages. During the pilot force evaluation phase, analysis will focus on the sensitivity of the design to evaluation and its potential for improving Army capabilities. Given positive results from the pilot stage, a full CONAF treatment will be applied to the concept and its associated force design. If negative indicators are obtained the concept will be documented and placed in an inactive status for reference or future consideration under different conditions. Various computer models, in addition to the CEM, will be used in analyzing force design potential. The specific models to be used will be determined by the design characteristics of the force to be analyzed. However, in the process of comparing a specific conceptual force with the base case force, the same set of models will be used to facilitate comparative analysis.

SUMMARY

Where CONAF interactions to date have focused on developing and demonstrating a useful methodology, the FY 75 program of CONAF-based studies will mainly support the resolution of current Army problems. This is appropriate and is indeed a long-sought goal among those who have contributed to its development over the years. However, CONAF IV will continue the evolution of this methodology and pursue the design and evaluation of conceptual forces within resource constraints as was visualized from the beginning of this remarkable project.

THE MEDICAL PLANNING PROJECT

Mr. Joseph G. Stenger
Captain James H. McEliece

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INTRODUCTION

The medical planner at various levels of the US Army is responsible for designing medical organizations capable of providing responsive medical support to Army units in combat. In performing this function, the planner must make two basic judgments. First, he must assess how many and what types of patients are likely to result from anticipated tactical situations. Second, he must determine the medical resources required to provide an acceptable level of support for those projected patient loads. A medical planning study, "Medical Planning Factors" (MEDPLN), is being conducted by the US Army Logistics Center at Fort Lee, Virginia, to improve the medical planning process by applying operations research/systems analysis techniques. The study is being conducted for the Academy of Health Sciences at Fort Sam Houston, Texas, which is responsible for a variety of medical planning functions including the development of medical TOE (Tables of Organization and Equipment).

BACKGROUND.

Initially, the idea of developing a sophisticated "tool" to plan for Army-in-the field medical units began in the early 1960s at the United States Army's medical center at Fort Sam Houston, Texas. At that time, a contractor developed a complex computerized Hospital Model. This model was designed to accept patients as inputs and to simulate processing the patients through an Army field hospital.

The organization that initiated the contract for the early work later became the Medical Service Agency of the US Army's Combat Developments Command. This Medical Service Agency recognized the need to develop improved medical planning factors so that medical planning, to include inputs to the Hospital Model, would be realistic. This need for improved factors resulted mainly from advances made in warfare and in protective devices, from advances in medical knowledge, and from the emergence of guerilla and counterguerilla warfare. As a result, the Medical Service Agency initiated the Medical Planning Factors study in 1972. The 1973 reorganization of the Army incorporated the Medical Service Agency into the Academy of Health Sciences, still at Fort Sam Houston. The conduct of the study remained the responsibility of the Logistics Center and will be completed by February 1975.

STUDY APPROACH

For purposes of this study, medical planning factors were defined as multiples, constants, or factoring rates that can be related to appropriate strengths and missions to provide estimates of patient admissions, medical workloads, and medical resource requirements in terms of personnel and medical units. Purposes of the MEDPLN Study are to develop improved patient admission rates and to develop a methodology which can be used to develop the other types of medical planning factors.

Patient admissions include wounded-in-actions, disease cases, and non-battle injuries. These categories have been further refined by the Academy of Health Sciences into 75 classes of patient medical conditions. In each of the 75 classes the "patient rate" is expressed as the number of US Army personnel admitted to Army-in-the field medical facilities per day per 1000 troop strength.

The approach taken for developing patient admissions was to first determine the variable conditions that could influence patient rates. These conditions were determined by Medical Service Agency and Logistics Center personnel and are shown in figure 1. The selection of these independent variables was governed by available resources, money, and most important, the availability of the data.

At this juncture, the US Army Chief of Military History was drawn into the process. He selected a number of representative battle actions from World War II, the Korean War, and the Vietnam War for each combination of the independent variables. Experimental analyses were then conducted by Logistics Center and Academy of Health Sciences personnel to correlate various combinations of the independent variables with existing medical data from the three wars. Once this procedure proved feasible, a contractor was engaged to perform the detailed data collection. This data collection effort involved collecting operational data (e.g., unit strengths, type posture) for each combat action identified by the Chief of Military History, computerizing the operational and medical data, and combining the operational and medical data into a set of summary files. This effort was completed on 30 September 1973 and an automated medical/operational data base, consisting of 28 separate files, now exists on the Control Data Corporation 6500 computer system located at Fort Leavenworth, Kansas.

The hiring of a contractor to collect and automate the required data was necessary because of limited resources available at the time within the Logistics Center. However, despite the best efforts of the contractor and the MEDPLN team, the resulting data base contained numerous errors and inaccuracies. As a result, many man-months of effort have been expended by the MEDPLN team to correct the data base. This issue is not raised in an attempt to establish blame, but only to emphasize the risks inherent in divorcing the data collection responsibility from the data application responsibility.

The data base was structured to permit a statistical analysis of the data for purposes of gaining insight into the influence that the

INDEPENDENT VARIABLES

- POSTURE
  - MID-INTENSITY
    - ATTACK
    - DEFENSE
    - RESERVE
    - DELAY
    - PURSUIT
    - INACTIVE
    - RIVER CROSSING
    - AMPHIBIOUS
    - AIRBORNE
  - LOW INTENSITY
    - TO BE DETERMINED
- UNITS
  - INFANTRY DIVISION
  - ARMORED DIVISION
  - MECHANIZED DIVISION
  - CORPS
  - ARMY
- INTENSITY
  - MID
  - LOW
- LENGTH OF BATTLE
  - DAYS
- TERRAIN/CLIMATE
  - MOUNTAINS - COLD
  - MOUNTAINS - HOT
  - MOUNTAINS - JUNGLE
  - MOUNTAINS - ARTIC
  - PLAINS - COLD
  - PLAINS - HOT
  - PLAINS - JUNGLE/SWAMP
  - PLAINS - ARTIC
  - PLAINS - ARRID
- AREA
  - EUROPE
  - NORTH AFRICA
  - PACIFIC
  - KOREA
  - VIETNAM

Figure 1

selected independent variables have on the number and type of patients. The statistical analysis involved the use of computerized analysis of variance packages for analyzing various scenario combinations of World War II and the Korean War. The results of the Korean analysis show that the selected independent variables explain at most 35 per cent of the variance in patient rates. This result only emphasizes that numerous other factors are contributing significantly to the occurrence of combat casualties. However, as mentioned earlier, data on these other factors were not obtained because of the limited resources available to collect the data and the limited amount of data recorded on the other factors.

RESOURCE REQUIREMENT METHODOLOGY

The methodology developed by the MEDPLN team to use in computing various types of medical planning factors is shown in figure 2. This methodology addresses the two primary requirements of medical planners identified in the MEDPLN Study.

The first requirement identified was to develop improved patient rates. The data on the summary files were analyzed to provide hospital bed occupancy rates for the Office of the Surgeon General (OTSG). These rates include only that portion of patient admissions who occupied a hospital bed. OTSG can use these rates to update field manuals concerned with theater level resource requirements, as well as input the rates to an existing Patient Flow Model for determining Army-wide

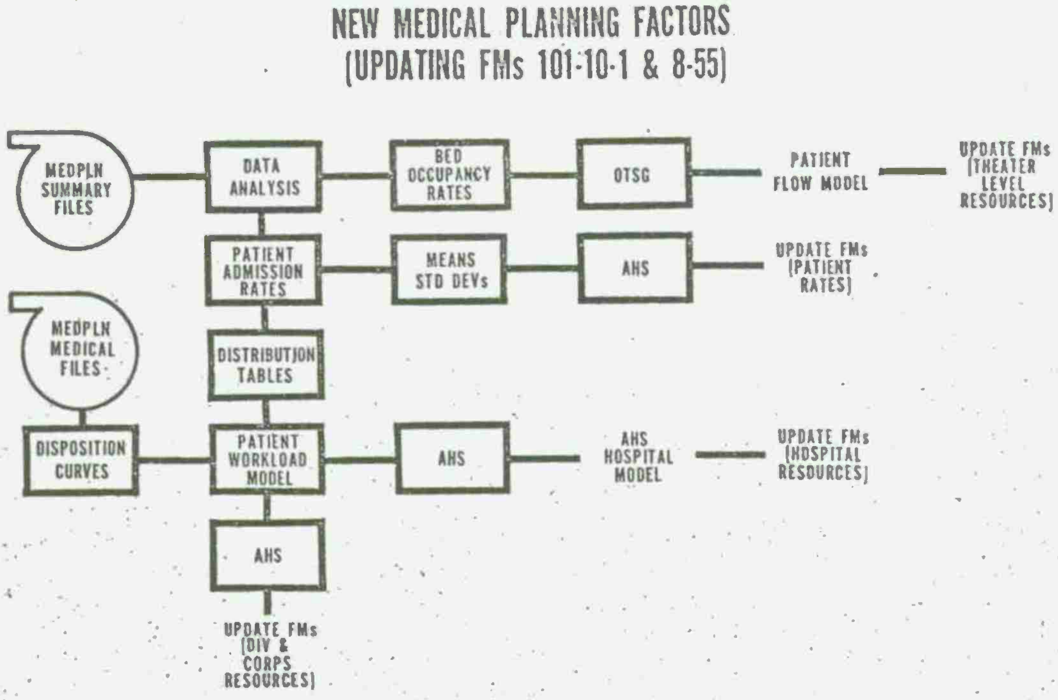


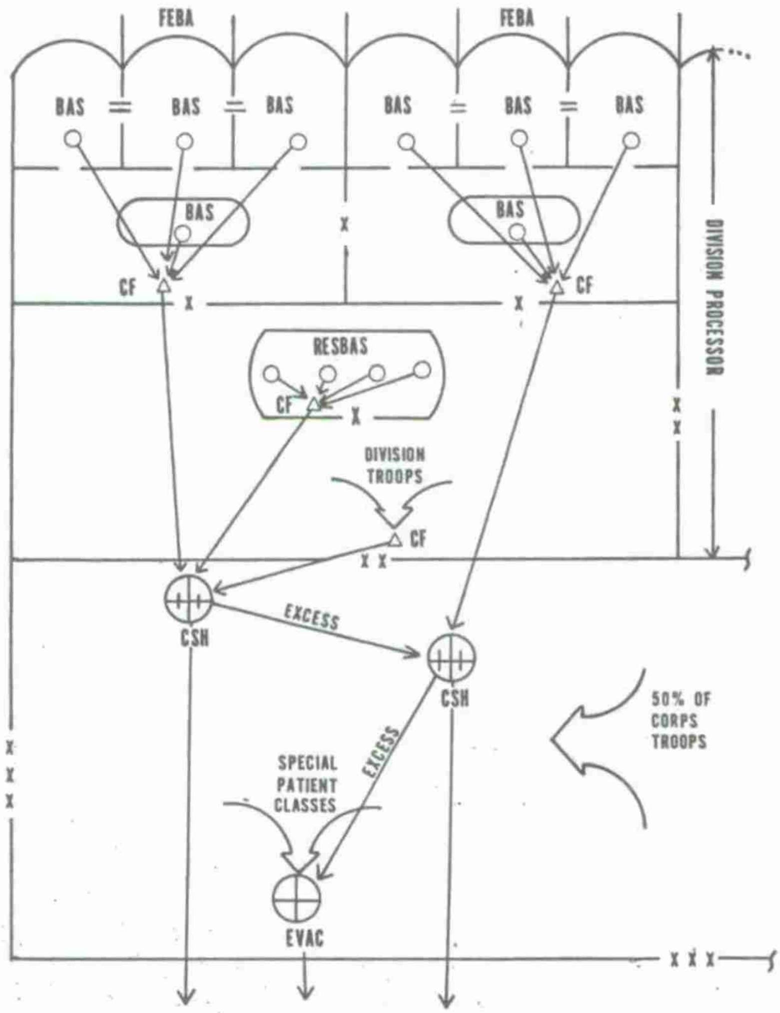
Figure 2

medical requirements. The analysis of the summary file data has also provided patient admission rates that are currently being used by the Academy of Health Sciences to update portions of field manuals for which it is responsible.

The second requirement identified was to develop an analysis tool to assist in estimating resource requirements for combat zone medical support. This requirement was met by providing high resolution computer simulation models. The MEDPLN automated data base was used to provide rate distribution tables and patient disposition curves. The existing Academy of Health Sciences' Hospital Model can be used to analyze resource requirements for combat zone hospitals. The MEDPLN team developed a Patient Workload Model to interface between the data base and the Hospital Model and to provide an analysis of medical resource requirements at combat division level. Details of this patient Workload Model are discussed below.

THE PATIENT WORKLOAD MODEL

The general purpose of the Patient Workload Model is to fill the



TYPICAL SYSTEM TO BE MODELED

Figure 3

gap in the MEDPLN methodology for determining medical resource requirements between the automated data base and the existing Academy of Health Sciences' Hospital Model. Its specific purposes are to:

Generate a realistic patient load impacting on the Army-in-the field medical system based on the MEDPLN improved patient rates.

Simulate the processing of patients within the division level medical system, providing reports useful to medical planners.

Deliver patients to the Hospital Model in a manner suitable for further processing.

The portion of the Army medical system addressed by the Patient Workload Model is shown in figure 3. The unit of interest is a combat division in a tactical posture and its immediate support. The medical units of interest are the Battalion Aid Stations (BAS) associated with each battalion of the committed brigades, the reserve Battalion Aid Stations (RESBAS) associated with the battalions of the reserve brigade, the Clearing Facilities (CF) located in each brigade area and the DISCOM, and the hospitals directly supporting each committed division (Consisting of some mix of combat support hospitals (CSH) and evacuation hospitals (EVAC)). A typical flow of patients might be as shown by the arrows in the figure.

The Patient Workload Model must perform two basic functions: First, it must generate a realistic patient stream; and second, it must process the division level patients from the front door of the the BAS to the front door of the hospitals. Since these are basically different and distinct functions, the Patient Workload Model was divided into two submodels. These submodels are the Patient Generator and the Division Processor and each is discussed inturn below.

As its name implies, the Patient Generator performs the function of generating the stream of patients impacting on the medical system. The first requirement of this model is for the user to specify in detail a scenario in which he is interested. The items shown in figure 4 specify the general nature of the scenario. Notice that several periods of a variable number of days each will allow the user to vary the conditions under which the tactical unit operates.

Attention is directed to the items in columns 2 through 6 which are cross-related to the MEDPLN data base. The data base will provide patient admission rates for each of 75 classes of injuries and diseases for combinations of these 5 factors. For example, rates will exist for leg wounds in Korea (Column 2), mountains/cold (Column 3), mid-intensity conflict (Column 4), an infantry division (Column 5), in the attack posture (Column 6). Given these or similar sets of factors, the MEDPLN data base can be entered and appropriate patient rates randomly selected. The patient rate is next combined with unit strength (Column 7) to arrive at the number of patients per patient class per day to be generated within the modeled scenario.

The inputs on the center part of the figure describe the particular combat division being modeled, further refining the scenario and structuring the medical system within the division.

The corps level patients to be treated by the hospitals under their area support mission are calculated in a similar manner from the user inputs shown on the lower part of the figure.

Once the number and type of patients to be generated are calculated, other information must be provided to ensure each patient is properly processed. The following items are computed for each patient

MODEL USER INPUTS

GENERAL SCENARIO

I \ J	NUMBER OF DAYS IN PERIOD 1	AREA 2	TERRAIN/ CLIMATE 3	INTENSITY 4	• • •
PERIOD NUMBER					• • •

MODELED DIVISION

• • •				NO. FACILITIES ASSIGNED			% PATIENTS ENTERING RESBAS		HOLDING POLICIES IN EFFECT				• • •
	UNIT 5	POSTURE 6	STRENGTH 7	BAS 8	RESBAS 9	CF 10	BAS 11	CF 12	BAS 13	CF 14	CSH 15	EVAC 16	
PERIOD NUMBER													• • •

CORPS LEVEL

	TOTAL CORPS STRENGTH 17	FRONTLINE DIVISIONS		DIVISIONS IN CORPS RESERVE				CORPS HOSPITALS			
		NUMBER 18	TOTAL STRENGTH 19	NUMBER 20	TYPE 21	UNIT STRENGTH 22	%PATIENTS ENTER BAS 23	NUMBER ASSIGNED CSH 24	NUMBER ASSIGNED EVAC 25	% PATIENTS ENTERING CSH 26	% PATIENTS ENTERING EVAC 27
PERIOD NUMBER											

Figure 4

generated to facilitate this processing:

- Patient class number
- Patient processing priority
- Litter/ambulatory status
- Time of entry into the medical system
- Point of entry into the system
- Total days required to complete the medical case
- Final disposition
- Ultimate destination within the modeled system

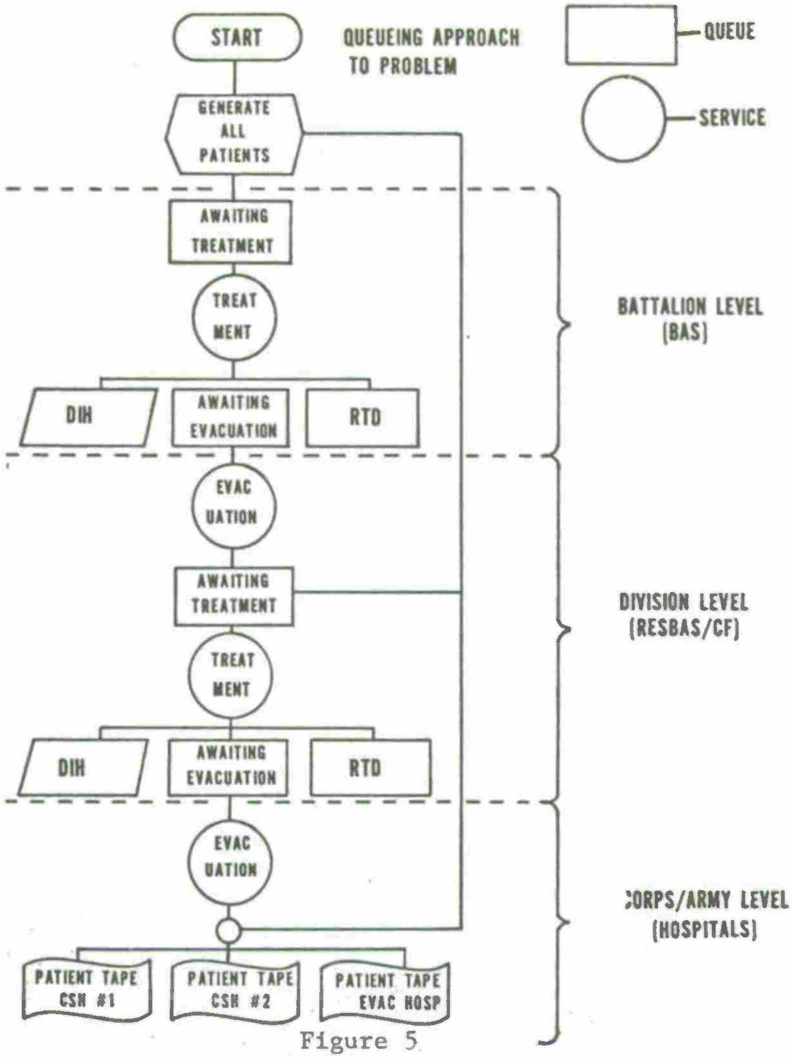


Figure 5

As each patient is generated, his data record is written on a magnetic tape. When all patients have been generated, the records are sorted by the patient's time of entry into the system and the tape is delivered for processing by the other models.

At this point the division processor submodel is ready to be exercised. This is the actual simulation portion of the patient workload model and basically respresents a multi-channel, multi-server, multi-level queueing system, as shown in figure 5.

The patients are selected one at a time from the input tape when they are scheduled to enter the system. They arrive at their appropriate input facility and enter a queue to await treatment. When the necessary treaters are available, they are given the treatment they require and are then disposed of. Their disposition may be that they die or return to duty at which time the model is through processing them. If they require further treatment, they enter an evacuation queue until an evacuation vehicle is available to transport them to their next destination. The process is then repeated until they die, return to duty or reach a hosptial, at which time they are written out on a tape for further processing by the Hospital Model.

The key to the resolution achieved by this model is the fact that the model keeps track of each patient in the system as he is processed through the system. At the time he enters the system his patient priority is checked and he enters a treatment queue behind those patients of a higher priority and those of the same priority who arrived earlier, but ahead of all patients with a lower priority. Then a series of work units that this patient requires is determined based on his patient class and the level of the medical system at which he is located. These work units are medical procedures that a panel of medical experts determined would be performed on each class of patient. The expert panel specified the work units, the sequence in which they would usually be performed, the treater to perform them, and a range of time required for each treater to perform each work unit.

Next, the model searches each patient in the treatment queue, determines the next work unit required, and determines the preferred treater to perform the work unit. It then tests whether that treater is available at the current time; if not, it will attempt to select an allowable alternate treater. If no treaters are available, this patient remains in the queue and the model goes on to check the next patient. If a treater is available, the patient is removed from the queue, placed in the treatment area and the treater becomes available. The model then calculates a random time for the given treater to perform the required work unit and schedules the patient out of treatment at the appropriate time.

When the patient leaves treatment the treater returns to availability and one of 2 types of things can happen to the patient:

If there are more work units to be performed on him at this facility, he goes back into the treatment queue and repeats the process just described.

If his treatment is completed, the model determines his next destination, based on his final disposition, final destination and total days for completed case. One of three things will happen to him at this point: (1) if he is due to die and his time of death has been reached or exceeded, his death is recorded and he leaves the system; (2) if he returns to duty from this facility, he is placed on quarters until his total days for completed case are up at which time he also leaves the system; (3) if his destination is further in the system, he enters an evacuation queue, based on his patient priority, to await evacuation.

The evacuation system is based on the use of both ground and air ambulances, and 4 evacuation options exist. These options specify whether each patient priority will normally be moved by air or ground in this particular scenario.

In keeping with medical doctrine, evacuation assets are normally located at the supporting facility and must travel to the supported facility to perform the evacuation. An exception here is that ground ambulances from the supporting facility may be prepositioned at the supported facility to provide more rapid response to evacuation requests. The user is able to specify how many patients of each priority are required to justify the dispatch of each type of evacuation vehicle. As soon as enough patients are ready for evacuation, and if there is a vehicle available for use, it is dispatched to perform the evacuation. This vehicle is filled with all the patients available, or all it can carry, with highest priority patients loaded first. The travel time to the supporting facility is then calculated based on a random distance between the two facilities and the average travel speed of the vehicle. At the completion of the trip, each patient evacuated is placed in the treatment queue of the receiving facility and the evacuation vehicle is returned to its originating facility. At this point, the process repeats itself again.

As stated earlier, the model was required to produce reports on the functioning of the medical system. The design of a model's output reports depends primarily on the types of questions the model users wants to answer. Many conferences were held with the Academy of Health Sciences to determine exactly what the analysts needed to know. Then a series of standard reports were designed to describe the system's operation for each day simulated by the model. For example, one of these reports describes the utilization of the medical treaters in the system. The data is listed by type of treater at each facility and presents information concerning:

How many treaters of each type are assigned at each facility.

How many hours each day the average treater spent performing medical work units.

How many times each treater's services were requested when all the treaters of this type were busy at the time of the request.

Antoher standard report deals with evacuation vehicle utilization and presents data for both ground and air ambulances. This report shows, by facility:

The number of ambulances of each type assigned.

The number of round trips made by these vehicles.

The average utilization of each vehicle (in KM's traveled and hours in use).

The average number of patients carried on each trip.

And the number of times the use of a vehicle type was requested when none were available.

These are only two examples of the eight standard reports printed for each simulated day. There are also reports for the operation of the entire system, the patients generated and disposed of at each facility and the treatment and evacuation processes at each facility.

However, the standard reports are by no means all the information the model can provide. The fact that the model keeps track of what's happening to every single patient at all times provides the capability of extracting a wealth of highly specific information. For instance, the exact time the surgeon at the division rear clearing facility spent performing tracheotomies on severe thorax wound patients could be reported. The only requirement is for the model user to specify exactly what information he needs so the programmer can enter the model and extract the desired data.

The kinds of information this model is capable of providing indicate a wide range of potential uses. Obviously no one would think of saying that under the conditions of a given scenario any specific patient workload produced by the Patient Generator would occur exactly. However, the workloads are typical of those that might occur and can be used to examine the adequacy of the supporting medical system. The following kinds of analyses are relevent:

The effect of peak loads on the system can be assessed. If the system is normally processing in the neighborhood of five hundred patients a day and suddenly receives a one day load of a thousand patients is the system flexible enough to respond? Would additional resources be required? How many days could a peak patient load be sustained before augmentation would be required?

The existence of bottlenecks in the system can be examined. How many battalion aid stations can be supported by a clearing facility before the clearing facility becomes overloaded and begins to disrupt the timely flow of patients? What resource augmentation would be required to eliminate a given bottleneck?

The adequacy of treater resources can be assessed. How does the assignment of one more surgeon to a clearing facility affect treater utilization and the times patients spend waiting for treatment? Should some work units be shifted from one treater type to another considering the numbers of each type available and differences in the times required for work unit performance?

The adequacy of evacuation assets can be examined. Should ambulances be prepositioned and if so, how many? Should air or ground ambulances be used predominately and under what circumstances. What effects do larger or smaller patient loads required for vehicle dispatch have on vehicle utilization and the times patients wait for evacuation? Is there an optimum mix of these factors and if so, what is it?

The effects of patient holding policies at each level of the system can be determined. If the clearing facility can hold patients for five days rather than three, what increase in treatment resources is required and what reduction in evacuation assets accrues?

The types of questions indicated above can be answered by the Patient Workload Model through extensive sensitivity analysis. The resulting answers should significantly assist medical planners within the US Army medical community, in the development of medical TOE's and doctrine for the employment of medical units.

CONCLUSION

The Medical Planning Factors project has developed new patient admission rates for various scenarios of combat conditions of World War II, the Korean War, and the Vietnam War. These rates now exist along with medical statistics from the Korean and Vietnam Wars, on a readily accessible automated data base. The project has also provided an automated tool, the Patient Workload Model, for evaluating and estimating medical resource requirements for Army-in-the field medical units. Finally, the MEDPLN project is currently analyzing the effects various combinations of selected combat conditions have on the number and type of patients.

THE SURVIVABILITY OF PERSONNEL AND MATERIEL IN A COMBAT ENVIRONMENT

Mr. Keith A. Myers

US ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY

Many of the weapon and materiel oriented papers presented here, as well as at similar symposia elsewhere, deal with the capability of weapons to inflict casualties or damage materiel or with the capability to perform some specified function or mission. As we progressed in the sophistication of our analyses, it became more fashionable to consider reliability and eventually the full scope of RAM---Reliability, Availability and Maintainability. However, there is an aspect of system performance closely related to RAM (in fact, one might define it as combat induced RAM) which I believe has had much less attention than it deserves; and indeed than it requires in these days when we must extract every ounce of combat capability from our defense dollars. What I am talking about is placing more emphasis on, and devoting more of our energies toward, the improvement of system survivability. We have, to be sure, not completely ignored system survivability. In combat simulations and wargames we do generally consider attrition on both sides, and for a number of years BRL and AMSAA collected combat damage data on aircraft for the purpose of developing the data necessary to identify potential payoff areas for increasing survivability. However, what I would like to discuss with you today is a more subtle, and quite possibly, a more important aspect. I am concerned with the survivability of the system itself as the principal topic of analysis; not just as an input incidential to an effectiveness analysis or just the identification of vulnerable components. Questions to be addressed in such analyses include evaluation of alternative design features affecting survivability, field expedients and tactics of employment to increase survivability, etc. A further area, almost totally neglected as far as I am aware, is the use of survivability analysis as a basis for influencing procurement and stockage of repair parts, maintenance, training and planning, etc. It appears that in many cases we may estimate our replacement parts stock more on the basis of our expected wear associated attrition than on combat attrition. This can be quite significant since repair of combat damage may require replacement of a major subsystem rather than just components comprising the subsystem. This not only leads to inefficiencies such as having to assemble subsystems from their component parts in the field but may create further difficulties where an imbalance in component availability limits the ability to construct the subsystem. The irony of the situation is that the modeling necessary for the analysis is not all that difficult. In fact, several years ago when comparing attack helicopters of differing complexity we modified our combat simulations to estimate not just the probability of the total system being "killed" but to also estimate what non-attritional damage was done so that we could examine comparative times to repair the returning aircraft.

A further area of concern is that at the present time we appear to be concentrating our limited efforts to study survivability mainly on weapon systems and not too much on our logistics system. We hear stories from the mid-east of the inability to resupply artillery units because of successful interdiction by the enemy. What difference does it make in the final analysis if the gun can't fire, whether it is damage to the gun or a lack of ammunition or repair parts which temporarily puts the weapon out of action? What I would like to do in the remainder of the time available is to discuss some of the things we have done or are doing, not by way of bragging (for we really have't done enough) or not so you can sit back and say "Hey, that's nice that AMSAA is taking care of that," but rather in hopes of stimulating your imagination and activity to undertake similar efforts in your own areas of concern.

One of our earliest efforts in the area of survivability---stretching back almost two decades---is our concern with helmets and body armor as a means of increasing the survivability of the fighting man. The questions of greatest interest in these analyses have been whether new materials recently developed really offer significantly greater protection when incorporated into the personnel armor system. Typically, one is interested in either the extent to which casualties are reduced (or the severity of the wound lessened) or the extent to which the weight of an item of personnel armor can be reduced while maintaining the same level of protection. Variations of the standard lethal area programs are used in these analyses. These programs have been modified so as to allow a consideration of the effect of the helmet or body armor on fragments impacting on that part of the body covered by the helmet or body armor and to consider the severity of the resultant wound.

This effect is reflected in the model through the use of input data which allow one to estimate the extent to which penetrator velocity is reduced when it strikes the body armor or helmet.

Alternative casualty criteria are available to allow one to examine either the reduction of battlefield deaths or to examine the reduction in severity of the wound. It is possible, with minor extensions of the methodology to examine tradeoffs between areal density of the armor and body area covered for a fixed weight limit to obtain maximum protection, although not too much work has been done on this aspect so far. Results of these analyses, as stated above, are generally expressed in terms of percent reduction in deaths or severly wounded and are reported in various classified documents.

Another area with which AMSAA has been concerned for quite a period of time is survivability of surface to air missile systems.

In these analyses we must consider the SAM site as a complex target consisting of many interrelated components. In assessing damage to the targets one must be concerned with these functional relationships between components and their importance to the efficient functioning of the fire unit. For example, there may be three generators in the site but if any two are required for the site to function, then at least two must be killed to degrade the performance of the unit. Similarly, if there are multiple launchers at the site, one might completely disable the site by either disabling all missiles on their launchers, "knocking out" all launchers, some combination of the above which leaves no operable missiles on operable launchers, perhaps by knocking out the Battery Control Center (BCC) (if it is not possible to operate from an alternate BCC or in another mode) or by whatever other damage will leave the unit unable to successfully engage for the specified time period. It is beyond the scope of this paper to detail the programs used to conduct these analyses but basically they consider the munition delivery pattern on the target SAM site and the fragmentation or blast pattern thus created to predict hits on components and cables in the site. Appropriate vulnerability data then allow a prediction of component and cable kill probability. By considering the functional relationships of these elements one can determine the probability that the site is unable to fire or the extent to which its capability to fire is degraded. These programs are useful for examing susceptibility of the site to damage by various weapons under a variety of attack tactics, the effect of site component dispersal or component location, the value of redundancy or the value of field expediencies such as revetments or burial of cables. One may also examine the effect on site survivability as selected components are hardened. Several studies of this type have been made in the past and are described in various reports.

A more recent expansion of this work, which has been described in some detail in a paper presented in the Weapon Effectiveness Working Group by Mr. Halahan of AMSAA, extends the analysis to consider a two sided engagement involving attack tactics and relative detection capabilities. In this expanded analysis, a formation consisting of several groups of aircraft are assumed to fly toward the general location of the site. They know the general location of the site but must detect the site itself visually in order to convert to an attack. If one of the groups of aircraft detects the site and converts to an attack, it is assumed that all following groups will also be able to attack the target. The missile site may engage the attacking aircraft to the extent of its capability as limited by terrain, rate of fire, missile supply and other tactical considerations. The model is designed to compute the probability of the site being killed by the aircraft that convert to attack the site and survive long enough to deliver their ordnance and the probability of the SAM site surviving such an attack. This type model allows one to consider the effect of such factors as the probability of site detection (possibly useful for weighing the value of camouflage), site configurations, rate of fire, single shot kill probability, etc.

Viewgraph 1

One can also consider the effect on total site survivability when hardening various elements of the site.

Viewgraph 2

One might also wish to look at how the reaction time of the site affects its survivability as shown in the next viewgraph.

Viewgraph 3

In the last year, AMSAA has made a first crude attempt to look at improving survivability in the electronics and communications area (from a ballistics threat standpoint).

Because of the lack of detailed vulnerability data at this time, it was not possible to model the electronic package in detail or to examine the effect of component locations or mutual shielding components in the analysis. Rather, we have simply treated the equipment as a vulnerable body and assessed the protection achieved by applying varying amounts of protective material around the equipment. For equipment which might be located anywhere within potential target areas we have used such measures as percent reductions in lethal area (equivalent to an estimate of the percent reduction in equipment damaged) as a result of the bursting shell.

Viewgraph 4
Viewgraph 5

Where the piece of equipment is such that it might be the aimpoint for the attack, one can consider the delivery accuracy of the attacking weapon and compute the probability of the piece of equipment being "killed" in the attack.

Viewgraph 6

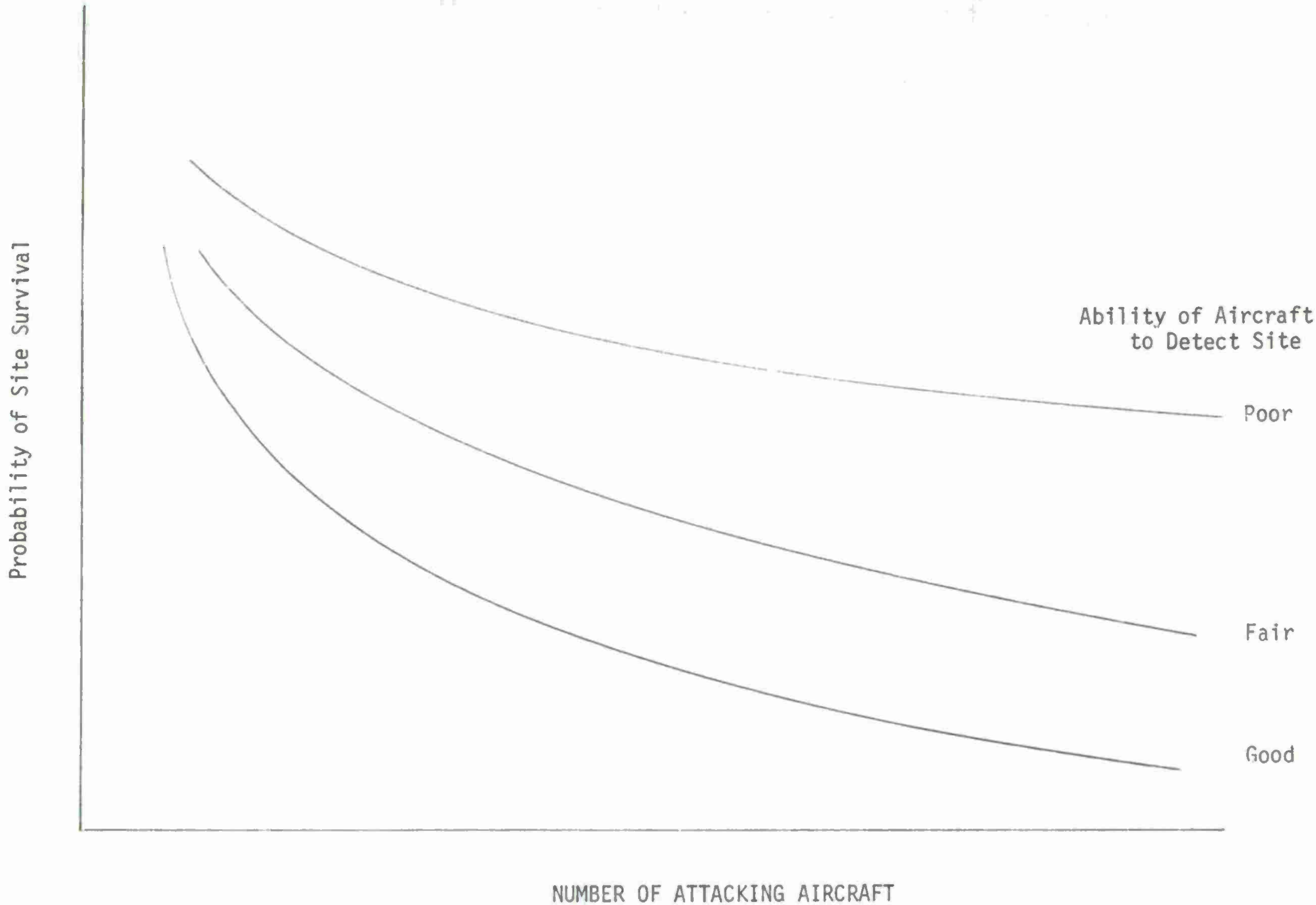
More recently we have looked at the vulnerability of an artillery position. In this analysis we address such questions the relative survivability of towed and self propelled Howitzers and their crews and the survivability of the unit's ammunition. The value of revetments and selective armoring are also examined. The hazard considered consisted of enemy counterbattery fire in varying amounts. Delivery accuracy of the counterbattery fire and fragmentation pattern of the multiple rounds were then analyzed to predict fragment impacts on personnel, ammunition and equipment. The effect of the various possible reactions of personnel when they came under attack was also considered. The anlaysis was repeated a number of times to vary such things as size of revetments at the gun positions, protection for the personnel and ammunitions, etc. Typical results are displayed in viewgraphs 7, 8.

Viewgraph 7
Viewgraph 8

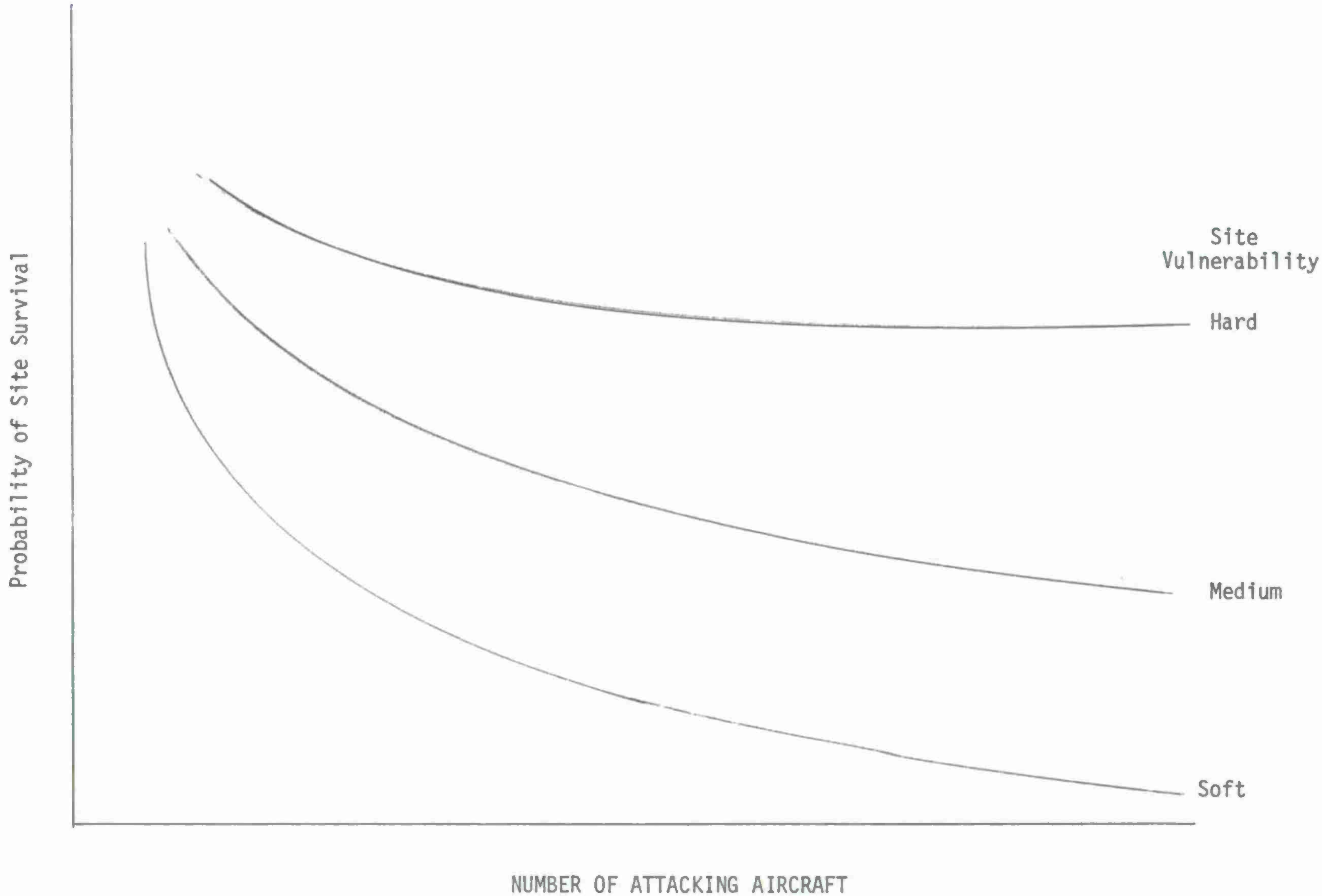
A final area I would like to discuss is a study we are conducting to examine the survivability of infantry anti-tank missiles and their crews.

The emphasis here is to look at both the value of field expedients such as revetments, flak blankets, selective deployment, etc., as well as to consider equipment modifications such as attempts to put TOW under armor. In one of the initial phases of our study we deployed TOW and Dragon in a defensive unit deployment as part of a closed wargame. The Red commander was then allowed to develop a preparatory fire plan against the defending unit position based upon limited intelligence data assumed to be available to him. An assessment was then made to estimate how many of the TOW and Dragon positions would have been "killed" in the preparatory fire. In addition, lethal areas were calculated for various enemy weapons employed against the TOW and Dragon systems. These computations were repeated to guage the impact of some of the alternative means of providing protection to the crew or weapon. Finally, we plan to conduct as a part of this study a two sided combat simulation in which we will attempt to measure the benefit of various protective measures through an examination of the effect they have on the outcome of the combat simulation.

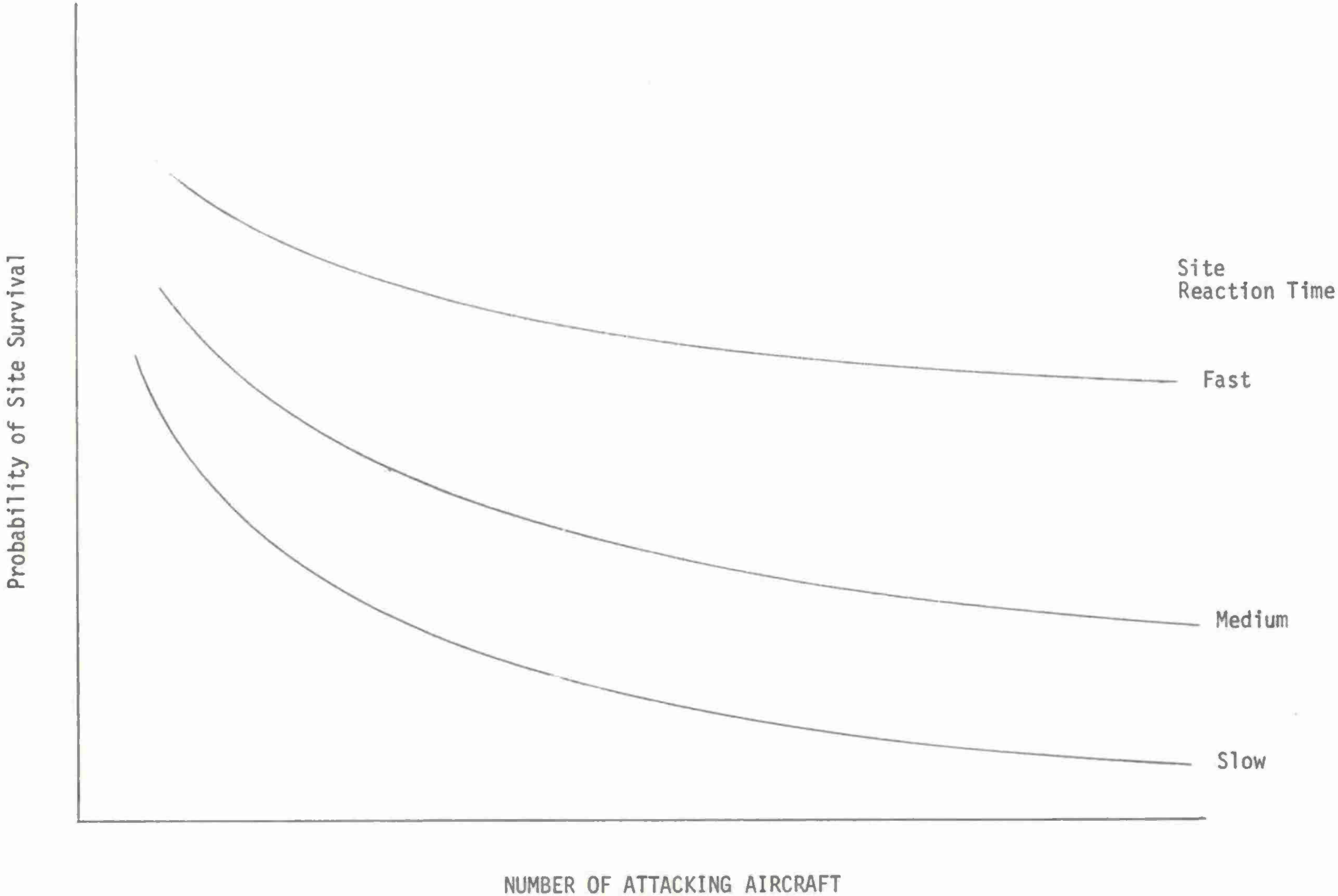
While almost all of that which I have discussed in the preceding presentation is the work of AMSAA, I would not like to leave the impression that we are the only ones contributing in this important area. The Ballistic Research Laboratories has an extensive vulnerability program which provides much of the input data needed for these studies. The also have a portion of their effort directed toward the reduction of equipment vulnerability there are small Vulnerability Analysis Teams (VATS) at each of the AMC Commodity Commands. But there is still much to be done. Too little effort is being directed to the improvement of operational survivability, and we neglect our duty to the user -- the soldier in the field -- to provide him with advice and insight we gain on ways we can improve his chances of survival. Finally, what work we are doing is focused on too small a portion of the whole spectrum of systems. We must "think survivability" across the board for logistics as well as combat systems.


Probability of Site Survival
Ability of Aircraft
to Detect Site
Poor
Fair
Good
NUMBER OF ATTACKING AIRCRAFT

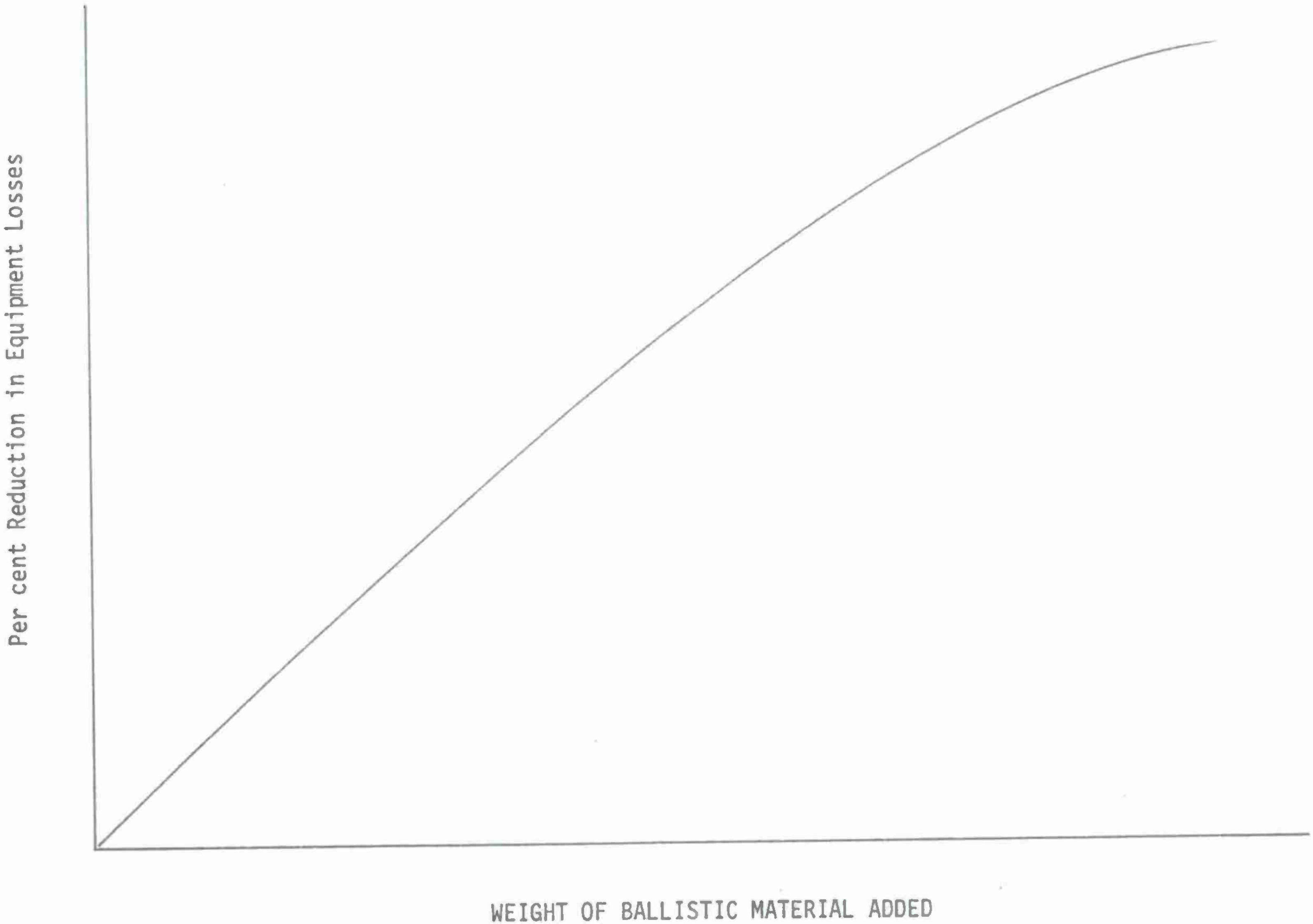
VIEWGRAPH 1


Probability of Site Survival
Site
Vulnerability
Hard
Medium
Soft
NUMBER OF ATTACKING AIRCRAFT

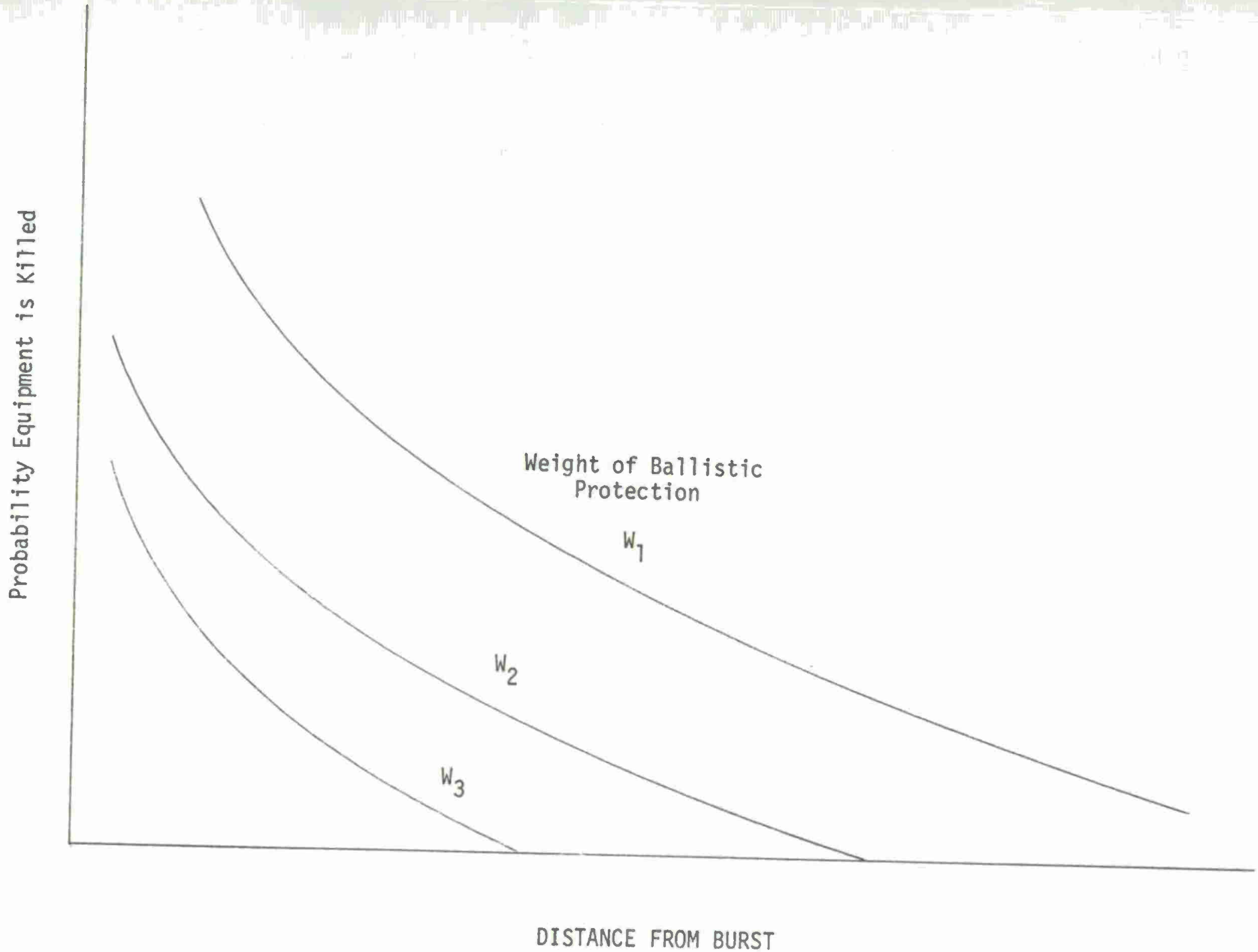
VIEWGRAPH 2


Probability of Site Survival
Site
Reaction Time
Fast
Medium
Slow
NUMBER OF ATTACKING AIRCRAFT

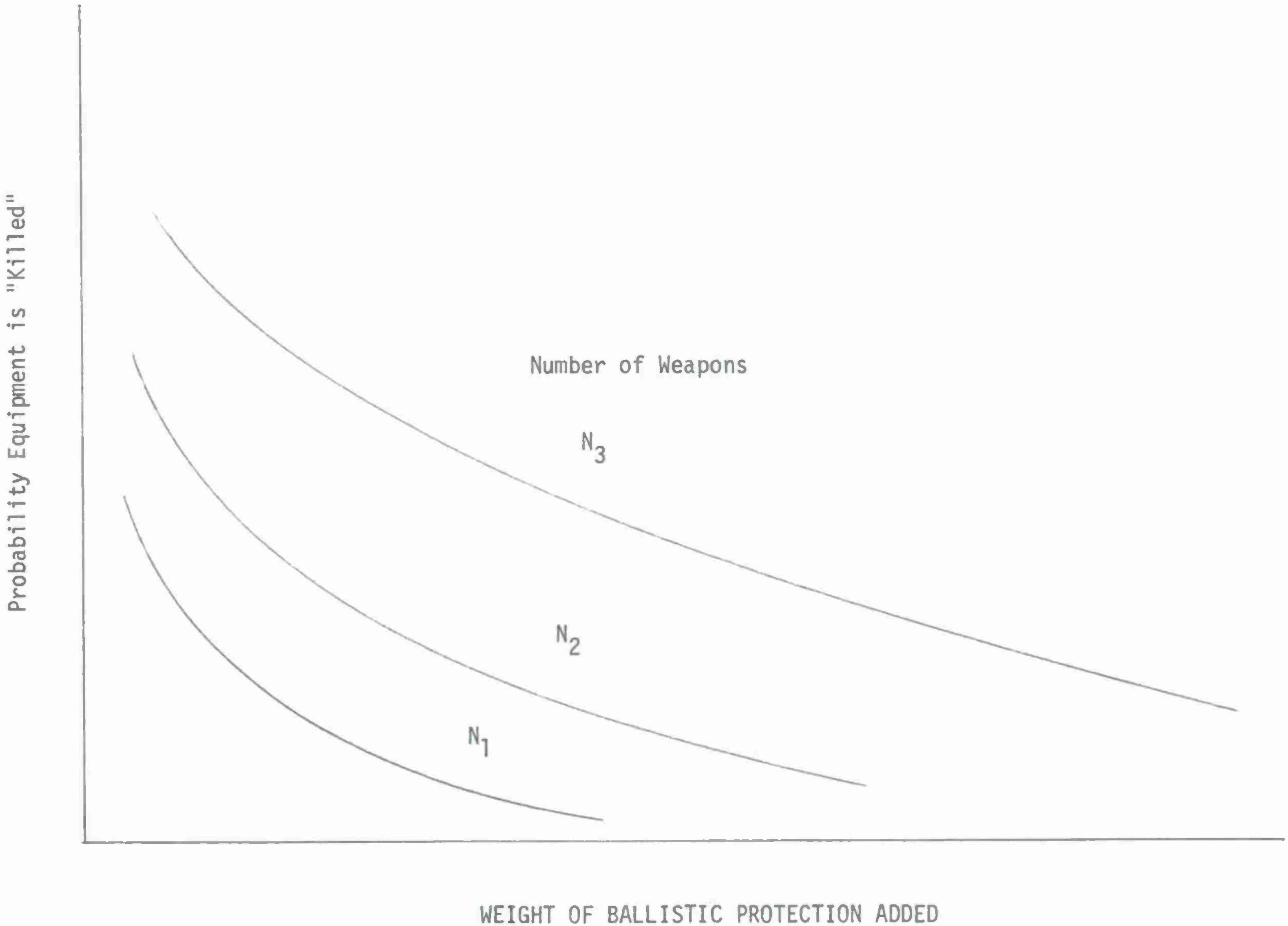
VIEWGRAPH 3


Per cent Reduction in Equipment Losses
WEIGHT OF BALLISTIC MATERIAL ADDED

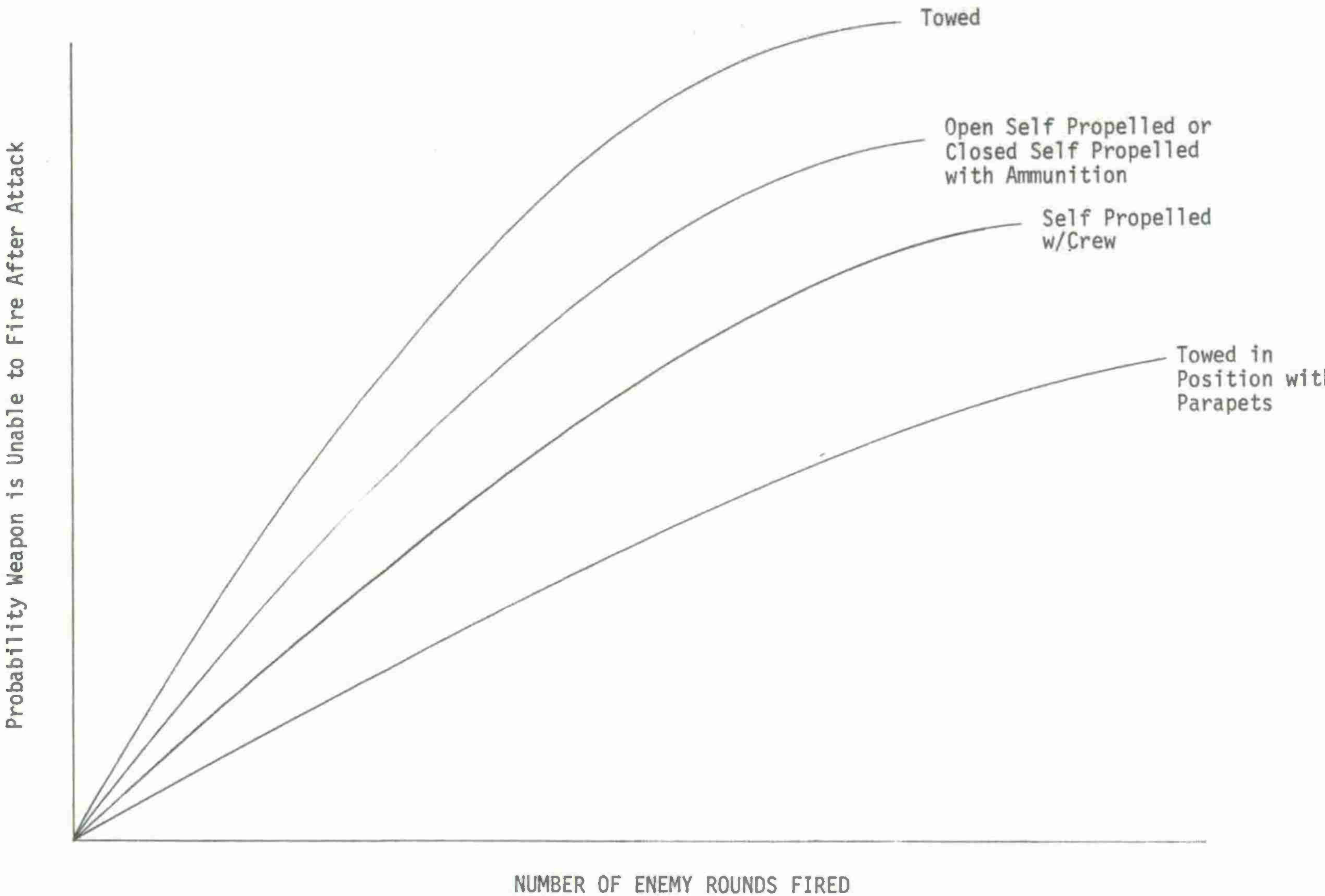
VIEWGRAPH 4


Probability Equipment is Killed
Weight of Ballistic Protection
W_1
W_2
W_3
DISTANCE FROM BURST

VIEWGRAPH 5

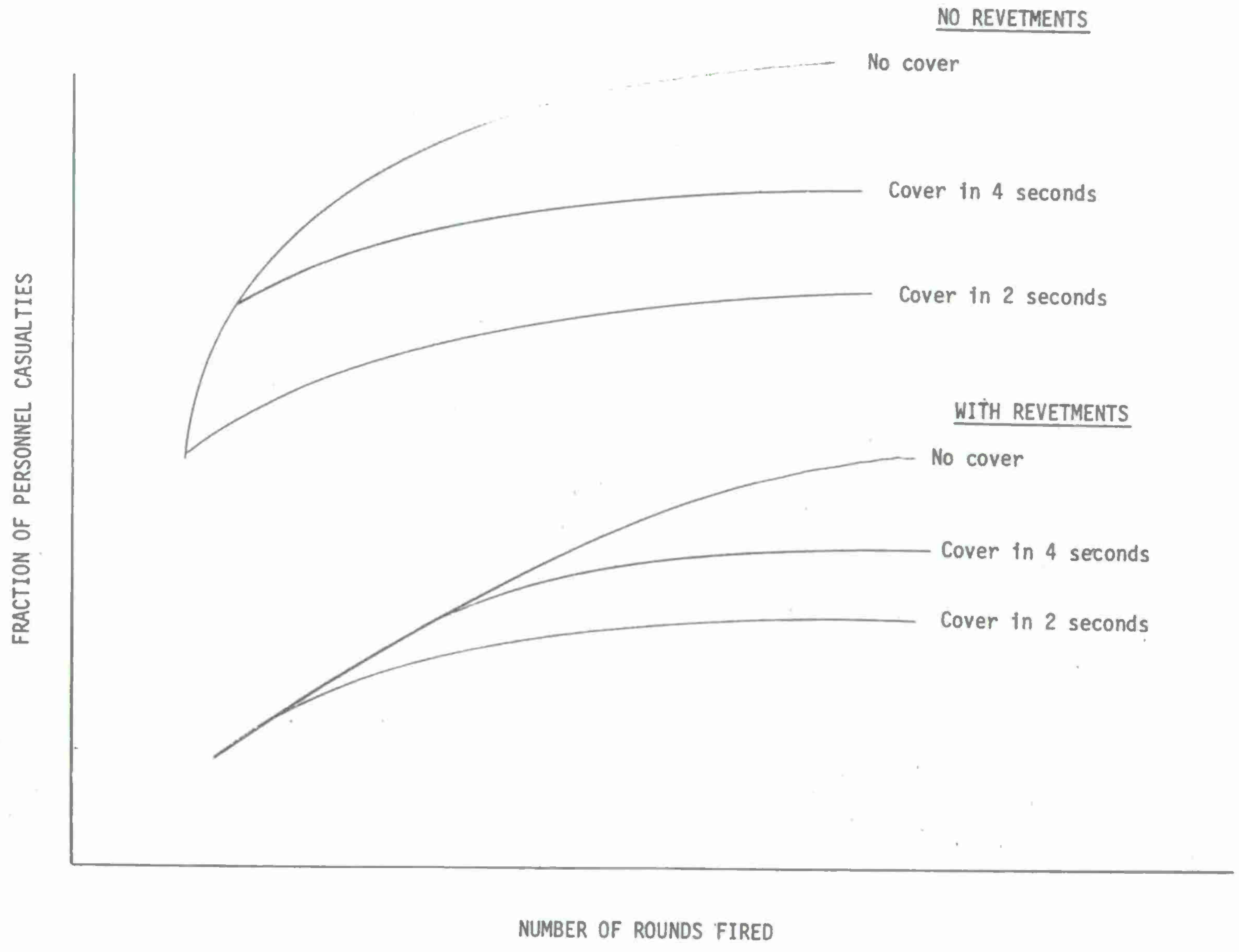

Probability Equipment is "Killed"
Number of Weapons
N_3
N_2
N_1
WEIGHT OF BALLISTIC PROTECTION ADDED

VIEWGRAPH 6



Towed
Open Self Propelled or
Closed Self Propelled
with Ammunition
Self Propelled
w/Crew
Towed in
Position with
Parapets
Probability Weapon is Unable to Fire After Attack
NUMBER OF ENEMY ROUNDS FIRED

VIEWGRAPH 7



NO REVETMENTS
No cover
Cover in 4 seconds
Cover in 2 seconds
WITH REVETMENTS
No cover
Cover in 4 seconds
Cover in 2 seconds
FRACTION OF PERSONNEL CASUALTIES
NUMBER OF ROUNDS FIRED

VIEWGRAPH 8

OPERATIONS RESEARCH IN THE WARSAW PACT ARMED FORCES

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Good afternoon. John Anderson and I, the coauthors of this paper, are from the US Army Foreign Science and Technology Center in Charlottesville, VA. The mission of the Center is to provide worldwide scientific and technical intelligence to the US Army. The primary users of this intelligence are the Army R&D laboratories and the systems analysis community. Although directly subordinate in the chain of command to the Army Material Command, the center receives the bulk of its tasking through the Defense Intelligence Agency. I think at this time it would be appropriate to point out that any Army agency desiring a product from the Center should direct its request through the Army Assistant Chief of Staff, Intelligence.

John Anderson is primarily interested in foreign applications of operations research, while I am engaged in applying OR and systems analysis to foreign, particularly Warsaw Pact, weapon systems.

Since last year when we presented a status report on the same subject, the Warsaw Pact countries, especially the Soviet Union, have been heavily engaged in the development of large scale automated systems to control aspects of the military and industry. Hand-in-hand with this development is an acceleration in the use of OR techniques in these same areas. The goal of this automation appears to be to streamline large scale operations such as production and logistics. High level reorganization activity and the development of large system technologies give evidence of this effort. Furthermore, the aggressive push to acquire the latest and largest computer systems and sophisticated software of Western design indicates a major thrust in the direction of large scale automation.

First, let me review briefly the development of OR and systems analysis within the Warsaw Pact. From this base of understanding, I will then describe the current efforts and attempt to extrapolate the future trend.

The Warsaw Pact is a mutual defense pact between the Soviet Union and six countries. A seventh country--Albania--withdrew from the Pact in 1968. The Pact provides not only for mutual defense, but also allows Soviet Army units to be in the territory of the other countries.

The Warsaw Pact countries are shown here.

Since its inception in 1955, the Pact has been used to improve the military position and the diplomatic bargaining power of the Soviet Union in European and worldwide relations. Today the Warsaw Pact Armed Forces are a formidable array of men and weaponry--still strongly dominated by the Soviet Union.

The use of operations research in these Forces is varied--and it is growing.

Within the Pact it had a slow beginning. Not until the early 1960's was evidence of its use uncovered. From that time until 1968, operations research activity spread and became more generally accepted in at least four countries of the Pact. From 1968 to present, such activity can best be characterized as experimentation with a growing variety of techniques, in both strategic and tactical applications. These activities have contributed to and continue to influence the technical revolution in the structure and operation of the Pact Forces.

This growing acceptance of OR techniques may be better understood in the context of several larger trends or factors, as follows:

(1) The new Soviet leaders who replaced Khrushchev in 1964 were proponents of scientific management. (2) Soviet military leaders also reacted to Khrushchev's policies and other complicating factors with increased stress on improved decision making. The new political leaders also exerted pressure for greater efficiency in defense resource allocation. (3) System Science became widely accepted as the unifying theory for techniques for the control of complex organizations; and (4) The Soviet reliance on central planning of its political-economic system creates special demands for analytical and reporting systems.

Khrushchev was ousted in 1964 by proponents of scientific management. Their description of his management style, shown here, display the frustration they felt with his "seat of the pants" approach to decision making.

In 1965, the Chief of the General Staff, Marshal M. V. Zakharov presented the military's argument for improved decision making in an article titled, "An Urgent Demand of the Time: On Further Raising the Scientific Level of Leadership." He also stated that all officers need not be engineers but that every commander should have a deep knowledge of physics, mathematics, chemistry, electronics, and cybernetics. As shown here, he recognized the value of computers in making rapid arching in the well-founded decisions.

During the 1950's and 60's, the percentage of technically trained officers was also increasing significantly as well as the complexity of military operations. Such factors combined to generate a new science of military management in the Soviet Union. Additional inspiration came from the innovations in defense management in the United States and the Soviet interest in management science.

Some Soviet planners consider modern military advancement to be divided into three stages:

(1) The Atomic Stage
(2) The Missile-Nuclear Stage
(3) The Cybernetic Stage

Here the Cybernetic Stage means the optimal use, and interaction of available troops, arms and equipment. The Soviets recognize that in modern warfare both sides possess sufficient armament to overkill the opponent and that advances in armament alone are not sufficient to insure victory. The onset of unlimited hostilities will be devastating to both sides and victory may well be determined by the swift and effective use of the man and machine force. In the cybernetic stage of warfare, emphasis is placed on the development of improved automated systems to aid in troop and weapons control and on the development of advanced managerial techniques.

Such thinking has not been confined to the Soviet Union alone but has spread throughout the Warsaw Pact countries. At present, there is some resistance by officers to the changes in operations entailed by increases in automation. These officers apparently fear that automation will preempt their authority. This resistance can be expected to diminish as greater experience is gained and as the number of technically trained officers continues to increase.

Consequently, the Soviet Union and other Warsaw Pact countries now have far-ranging interests in the military applications of OR. The theoretical basis for these applications is often taken from theory developed in Western countries. Exceptions to this are mathematical optimization theory and probability theory, where the Soviets are doing some excellent theoretical work.

The primary Strategic application is the development of a Pact-wide automated system to aid in military decision-making. The primary tactical applications area of interest is military war gaming and its associated analytical techniques. There is also interest in the following areas as shown here: (a) Improving search and detection methods by math modeling, (b) determining routes for the transport of military personnel and supplies by the use of network theory, (c) finding optimal or near-optimal distribution of weapons or personnel by the use of mathematical programming techniques, (d) use of computer systems to assist the commander in decision making, (e) the employment of mathematical techniques to analyze individual weapon characteristics, and (f) the use of queueing theory to improve air defense and ground combat capabilities.

In general there are not Warsaw Pact developed concepts or significant advances which are superior to Western techniques. The difference lies in the extent to which implementation of such techniques receives high level support, and the central role which system science is assuming in military activities.

In addition, military OR should receive significant spinoff from equipment and techniques developed in support of the Soviet central economic planning system. The chief difference between Western and Soviet-type economies lies in the role assigned to the market. In the West, the principal decisions of the economic system are made and carried out through the market mechanism. In the Soviet-type economies, the market plays a minor role in decision making. Thus, the Soviet-type economies must develop channels of communication and control which are unnecessary in the West.

In the Soviet Union, Automated Management Systems have been in operation for industrial applications for about eight years. More recently, Automated

Management Systems have been reported in East Germany, Poland, Czechoslovakia, and Romania. These systems function similarly to management information systems in the United States, but with an important difference. Their systems are generally based on the dynamics of the firm, rather than on a series of transactions or operations. This is due to the nature of Socialist business enterprise, and it requires software based more on dynamic system modeling than is the case in the United States. The Socialistic enterprise system is also amenable to a hierarchy of management systems to enhance overall planning and control. The lightly competitive nature of Socialist enterprise also allows developed software to be shared more freely between individual organizations. There is, in fact, an ambitious plan to simulate and control the economy of the entire Soviet Union. This system is known as the All Union Management System. It is to be a real-time system, encompassing all aspects of Soviet economic life. In its most modest form, it represents a nationwide management information system. The other Pact countries, particularly Poland, Hungary, and Czechoslovakia are planning similar projects. To help provide the computers for this and other computer needs, the RYAD program was implemented. The Warsaw Pact countries are building for common use a series of six different third generation computers. The program assemblers are designed to accept IBM-360 programs, which will result in a tremendous saving in software development costs.

The point of all this is to show the scope of intended computer usage to plan and control. The capability is thus present to develop a stragetic military command and control system. Such a system would be based on a hierarchy of computers with an interconnecting data transmission system. Hierarchy here means a multi-level system with the higher level device controlling more than one lower level device. Initially, the lowest level devices are place into operation. Higher level devices with the ability to monitor and control are then added. The operation is repeated until all devices are under one central control. The primary aim of such a system would be to increase the decision maker's capability by providing more information and by providing this information more quickly. The decision maker can then hopefully make, implement, and verify the implementation of decisions in a shorter span of time. Other benefits could be improved control of the movement of men and weapons, improved logistics flow, and improved integration of operating and service functions.

So we have seen that OR was slow to gain acceptance in the Warsaw Pact until the 1960's at which time a number of factors operated to increase their acceptability and, indeed to precipitate a headlong rush towards implementation on a large scale. The four predominant factors are shown here. The OR techniques utilized in the Pact have generally been drawn from the West. The most significant difference lies in the extent to which cybernetic theory (to include OR techniques) has been accepted as a unifying theory for the management of the Soviet politico-economic system and for the improvement of the defense forces. Also, system science or cybernetics may be considered by the Pact to be a stage of military development. We can expect significant effort in the development of equipment along with the necessary theory and software for military operations research with emphasis on techniques for the direction or control of large military systems.

In the future we will see in the Pact Armed Forces:

• Advances in central planning methods, which will utilize large scale simulation and computer networks.

• Simulation and other OR techniques will be used specifically to aid in the decision to develop weapons systems.

• On-line operating systems of interconnected computers for command and control.

• A widening of OR experience in the satellite countries of the Pact as more high-speed computers become available.

• A greater acceptance of OR techniques to aid in tactical operations as more officers become trained in the use of such methods. Operations Research has found its place in the Warsaw Pact Armed Forces, and its impact is already beginning to be felt.

All this has a great impact on US Army doctrine and plans, as these Pact advances represent at least an improvement in operational capability and may represent a full stage of advancement.

The floor is now open for questions and discussion.

AN OVERVIEW OF LAND BATTLE MODELING IN THE US[1]

Seth Bonder
Vector Research Incorporated

During the last 15 -20 years, a significant amount of methodology has been developed in the United States to assist in analyzing land battle systems for military planning. I have prepared some summary and very subjective remarks regarding the history and current state of modeling in the US. Specifically, I will

(1) comment on the three types of models that have been developed over the years,
(2) discuss considerations which have influenced the types of models that have been developed.
(3) describe briefly the history of model developments,
(4) present a brief review of existing models in the US to highlight some major problem areas, and
(5) note some modeling trends that I see occurring in the US.

Much of my review on the state of modeling (part 4.0) was presented at a seminar in the US about a year ago. I have not updated that review to include developments over the past two to three years, since it is my expectation that you will hear of them in formal papers from US participants and more so in the informal discussions of their current research.

1.0 Model Types

<u>War Game</u>: A war game is a model which is, in a sense, a step removed from the reality of a field experiment or a field exercise wherein only teams of players representing the commanding officers and their staffs are included. Assessments regarding the effects of combat and other decisions, in earlier war games, were made subjectively by a control team of experienced military officers and, in more recent computer assisted war games, have been made by some programmed assessment procedures. This type of model is very expensive in time and dollars to develop and use. Many existing war games have taken four to eight years to develop and, as recently as 1971, I know of a war game which took six months to obtain one realization of ten hours of battle. Since decisions are made by humans, it is not unreasonable to expect a high output variance if different decision makers were used; however, the long operation time usually precludes more than one realization of the process. It is my personal view that this type of model is not a feasible mechanism for analyzing a broad spectrum of system alternatives in a responsive manner to meet planning cycle requirements. Experience has shown, however, that they are diagnostic in

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[1] Many of the ideas presented in this paper were originally prepared for the Seminar, "Analytic Modeling for Tank/Antitank and Ground Engagements," US Army Concepts Analysis Agency, Bethesda, Maryland, 28-29 June 1973, and also presented at the NATO/SPPOSS Conference on "Modeling Land Battle Systems for Military Planning," Ottobrunn-Munich, Germany, 26 August 1974. They are repeated here at the request of the organizers of the symposium.

the sense that they reveal problems that need to be resolved with future systems, and are viable mechanisms for training decision makers.

Simulation: Perhaps the most widely used technique employed in military systems analysis is that of pure simulation, which runs completely without human intervention. In the development of this type of model, the military process is studied and microscopically decomposed into its basic events and activities, which are then ordered in a sequence as in a network. In solving this type of model to obtain predictions of outputs such as casualties, resources expended, etc., the events and activities of the different combat processes are essentially followed in a specified sequence, and decisions are based on predetermined rules which are programmed into the automated evaluation procedure. In essence, the process is "acted out."

Most simulations used in military planning contain a significant number of stochastic or probabilistic events and activities in an attempt to capture the chance element associated with many combat processes. These models require probability distributions for many of the input variables and generage the probability distributions for the output variables or results. In such a stochastic simulation, the model is solved by Monte Carlo sampling of all the input distributions in the appropriate sequence to produce a single output or result; thus they are called Monte Carlo simulations. In order to generate the full probability distribution of combat results, the sampling process is repeated or replicated a number of times for a fixed set of input parameter values. The replication process is required to determine the frequency with which different model outputs can occur and is continued until the output results appear to converge to a stable output probability distribution.

Although Monte Carlo simulations are perhaps the most heavily employed model in military planning studies, there exist a number of meaningful backs to their use. They tend to be more abstract than war games. Although they are appreciably less expensive and more responsive than war games, Monte Carlo simulation models still require a large expenditure of time and financial resources for their development and utilization. It would not be unreasonable to expect to spend 10 - 20 man-years just developing a simulation of tactical combat. Additionally, it would not be unreasonable to expect each replication of a battalion-level simulation to require 10, 20, or more minutes of computer time on a third generation computer and anywhere from 10 - 30 replications for statistical stability of the results. The large number of variables usually included in simulations makes it extremely difficult to run parametric studies with the model to perform sensitivity analyses over the simulation assumptions and input data. Finally, the large amount of detail contained in most Monte Carlo simulations makes it difficult to use by itself as a vehicle to single out those systems capabilities, tactics, and environmental conditions which significantly contribute to or delimit the system's effectiveness.

Analytic Models: Analytic models are like simulations in the sense that they also have no player involvement; however, they tend to be much more abstract. As in the development of simulations, the process is studied and decomposed into its basic events and activities. In analytic models, however, mathematical descriptions of all the basic events and activities are developed, and these events and activity descriptions are integrated into an overall assumed mathematical structure of the process. Where appropriate techniques exist, solutions are obtained by consistent mathematical operations giving rise to explicit relationships between independent variables and dependent ones of combat effectiveness. When such explicit relationships can be developed, they obviously simplify the conduct of sensitivity analyses and provide an increased ease in interpreting the results since the dynamics of the combat process are contained in readily examined equations. Most often analytic models of any degree of complexity require numerical solution techniques. However, even these provide marked reductions in dollars and time for the conduct of analyses and offer significant improvements in interpretability since the basic events and activities are described by visible mathematical equations.

Although it is well-recognized by this audience that analytic models can be either deterministic or stochastic, no such understanding exists among much of the practicing OR community or OR planners. Obviously, in the deterministic case a single set of input values always produces the same set of output results, while in the probabilistic case a set of input probability distributions produces a probability distribution over the output variables. In either case, no replications are required since the solution is obtained by either direct mathematical operations or by numerical solution techniques. There is a widespread, but incorrect, belief that models which contain chance elements or activities must be Monte Carlo simulations.

2.0 Conflicting Considerations and Implications in Development of Models for Military Planning

Because of the heavy emphasis on long-range planning, the DoD in the US has devoted a significant amount of effort to the development of predictive models of combat processes to assist in their force structure, weapon system, and doctrinal studies.[1] A number of conflicting considerations exist which, I believe, have influenced the types of models that have been developed and which have given rise to some of the recent trends in development and applications.

[1] The use of predictive models is somewhat in contrast to the operations research activities of World War II, which I like to refer to as "operational inference", for much of the effort was devoted to estimation of system effectiveness and inferences regarding future operations rather than long-range prediction. In World War II, the availability of systems and the ongoing military operations facilitated the gathering of data on the systems capabilities and effectiveness, enemy characteristics and tactics, and environmental factors for use in the studies. A major share of the questions addressed at the time were essentially concerned with how the next day's operations should be conducted. This is in sharp contrast to the long-range planning problems where greater emphasis is placed on prediction rather than inference because the future is concerned with a time frame of, at a minimum, 3, and usually 5, 10, and 20 years as compared to the WW II operational studies when time was measured in days, weeks, and months.

2.1 Complexity of the Combat Process

Military personnel have long argued that the land warfare process is a complex one. Based on my modeling and application experience, I agree with this observation but would state it slightly differently: predictions of combat results from our models are highly dependent on many process descriptors and their interactions. Specifically, it is easy to show that predictions of combat results vary significantly with the following characteristics:

(a) weapon system characteristics -- firing rates, accuracy, lethality, acquisition capability, maneuver capability, reliability, etc.
(b) organization structure -- the numbers of different types of weapon systems in the organization.
(c) doctrine or tactics -- the behavioral decision processes which drive much of the combat activities. On a broad scale these include the choice of battle type (attack a fixed defensive position, delay, chance meeting, withdrawal, etc.) and the choice of defensive position. On a more microscopic scale these include the weapon-to-target fire allocation decisions, route selection, assault speeds, assignments to maneuver versus overwatch roles, and the decisions to initiate and end the firing activity.
(d) terrain-environmental effects -- these include effects such as the interaction of the line-of-sight process on the acquisition capabilities, trafficability of the weapon platforms, and the effect of meteorological conditions on acquisition.

Each of these effects individually, and their interactions, have significant bearing on the predictions of combat results. This complexity strongly implies that the combat models take the form of simulations and, because of the strong impact the tactical decisions have on outcome results, player interfaces be included in the form of war game models.

2.2 Absence of Data to Verify Combat Models

I am firmly convinced that there exist almost no experimentally verified models of combat processes of interest to the military planner. That is, and let me emphasize, the field is devoid of any experimentally verified content. The military systems analyst must predict the operational effectiveness of combat systems; yet, there clearly do not exist any verified operational models of this type of process, nor does it appear that sufficient historical or experimental data to test any existing or next generation models will become available in the near future. Experience suggests that combat is a process that does not readily lend itself to measurement.[1]

[1] Recent test activities at the US Army Combat Developments Experimental Center are directed toward possible verification of some of the battalion-level simulations such as the IUA, CARMONETTE, and DYNTACS. It must be recognized, however, that data generated at CDEC are not combat data.

Because of the absence of data, we in the modeling community have been developing models somewhat as natural philosophers or Platonists in that the models are developed by pure reasoning and logic alone. I strongly believe that models developed on this basis which are not experimentally verified cannot and should not be used as an evaluation mechanism to provide accurate, point estimate predictions of combat effectiveness for use by decision makers. Rather, I think these intellectually developed models (rather than experimentally developed) should be used for analysis purposes to provide managers with

(a) insights into directional trends to increase their understanding of the system dynamics, and
(b) guidelines for the development of data collection plans (i.e., what data are important, how accurate must they be, etc.).

This kind of information is generated by parametric variation of the model variables and assumptions designed to answer "what would happen if" questions and to expose the full range of possible effects of a decision. This requirement for a large amount of parametric analysis strongly implies that many of the combat models should be analytic and perhaps simulatory rather than war games.

2.3 Requirement for Evaluative Studies

Although I do not believe we have models or methodology that can provide accurate and reliable point estimate predictions of combat effectiveness, decision makers require quantitative information as input to many of their force structure, weapon system buy, and doctrinal decisions. In the absence of any experimentally verified combat models, and with dim prospects of getting them in the future, this implies that the combat models that are developed should contain a high degree of logical fidelity with the "real world" and, where possible, be isomorphic to it. Thus model developers are, in a sense, driven to the development of complex, highly-sophisticated, detailed simulations of the combat process.

2.4 Resource Constraints on Planning Studies

Resource constraints on planning studies also tend to drive model developments in different directions. On the one hand, a move toward the development of analytic structures is suggested by both the smaller number of personnel required for their development and use, and the smaller amount of computer time and cost associated with their use. On the other hand, since analytic models are significantly more abstract, development of analytic models which include many of the relevant combat process descriptors requires a significantly high level of analytic capability. Accordingly, many of the model developments tend to be driven in the direction of simulations and war games which, although requiring logical structuring, require less use of highly abstract mathematics.

2.5 Higher Level Unit Evaluation Requirements

A significant amount of the modeling for weapon system planning (requirements, weapon mixes, etc.) has been done at the small unit (roughly battalion) level. Although, I believe, there is a recognized need to perform these analyses at higher levels (division, corps, etc.) of combat activity, the battalion level focus has been retained because that appears to be the highest feasible level in which detailed isomorphic descriptions of the combat process can be included. Additionally, broader-level force structure, net assessment, MBFR, etc. problems are generating the need for more credible and structural theater-level models than have existed in the past. These needs are giving rise to some new activities and trends in model developments.

2.6 User Understanding

All models are abstract representations of reality; however, some are more abstract than others. War games, because of the use of military officers as gamers, tend to be less abstract than simulations, while analytic models are usually more abstract since the battle is described by aggregate equations. Clearly, it is easier for most users to understand less abstract models (i.e., easier to visualize their horses on the battlefield), and it is not unreasonable to expect a high positive correlation between user understanding, acceptability, and use of a model. This idea, I believe, suggests the development of war game and simulation type combat models.

3.0 History

This section presents, in outline form, a brief history of modeling activities in the land warfare area through approximately 1972.

A. Pre-1956
   (1) Field exercises or games (contests)
   (2) Map or CPX exercises (to examine doctrine)
   (3) Simple analytic models; e.g., Koopman's work on simple Lanchester models in the 1940s.

B. 1956 - 1962
   (1) One-on-one duel models
      Monte Carlo simulations
      Simple analytic fundamental duel
   (2) Simple simulations of small unit actions
      CDEC-SRI global model
      ORO-initial version of CARMONETTE

   These were attempts to supplement some of the map and field exercises and, at least by today's standards, contained insufficient fidelity to the process.
   (3) Simple war games
      Manual games with subjective assessments which took an excessively long period of time to run.

C. 1962 - 1967
   (1) Development of more complicated and sophisticated simulations to increase their fidelity. This included enrichments to CARMONETTE, the development of the IUA, and the development of DYNTACS, all battalion-level Monte Carlo simulations.

(2) Development of computer-assisted war games such as DIVTAG I, ADVICE, TACSPIEL, LEGION, THEATERSPIEL, and TARTARUS.
(3) Mathematical enrichments in the theories of stochastic duels.
(4) Development of simple, highly aggregated, firepower score, analytic models of large-scale campaigns. This was principally the ATLAS model. This model has no tie-back to the physically-based small unit action simulation models.

D. 1967 - 1972

(1) Continued enrichment of small unit battalion-level simulations such as DYNTACS, IUA, and CARMONETTE.
(2) Development and application of hybrid analytic-simulation models of battalion-level engagements such as the BONDER-IUA differential model.
(3) Continued development and enrichment of war games such as DIVTAG II, DIVWAG, and DBM.
(4) Continued development of the mathematics of stochastic duels, although the rate of development has appreciably decreased.
(5) Continued development of firepower score, large-scale campaign models such as ATLAS, GACAM, and TCM.

4.0 Model Review and Problem Areas

In this section I shall briefly consider the state of existing models in the US. Both because of my experience and the limitations in time, I will focus on the state of representations or models describing combat and combat-related processes in conventional land warfare. Rather than discussing any one combat model in detail, I have prepared an overview for three levels of combat activity - an individual firer against a passive target, small unit combat, and large scale warfare. For each of these levels, I will try to indicate (a) where I believe models exist, (b) where tests have been conducted to verify the models, and (c) my subjective evaluation regarding the reasonableness of the model assumptions and structure. Before looking at each of the levels of activity, it is important to preface my remarks with the following cautions:

(1) The information provided here regarding the existence of models, their degree of verification, and the reasonableness of their assumptions is based strictly on my prior knowledge of the area and not on any detailed research or literature review. Although I can in each instance cite a rationale for my evaluation, the rationale is somewhat subjective and may in some cases be in error. The figures I will present are intended as a mechanism for portraying some general impressions which I believe to be reasonable and instructive and are not intended as a definitive state-of-the-art presentation of models of land combat.
(2) Because I personally believe war games are principally diagnostic methods and not vehicles for exploring a spectrum of alternative solutions to planning problems, I will consider only simulation and analytic model structures. Additionally, my comments will address principally descriptive structures representing military combat processes and not prescriptive models which specify what "ought to be done" -- e.g., the plethora of search theory models.

(3) My remarks do not consider some of the significant accomplishments in the US since 1972 (such as the development of the VECTOR,[1] ATHENA,[2] IDAGAM,[3] DIVOPS,[1] a simulation version of DIVWAG,[4] and air allocation models[3]) nor some current research (such as modeling penetration phenomena, large-scale intelligence, tactical decision behavior, and terrain LOS modeling) which will be either formally presented or discussed at this conference.

4.1 Individual Firer Models

Figure 1 is an overview of the state in modeling the combat activity of an individual firer engaging a passive target, with the view from the firer system. The row headings are individual firing systems such as a tank or anti-tank weapon (against either personnel or armed vehicle targets), an artillery weapon system, an air defense gun, a helicopter or a tactical aircraft. The column headings are performance and decision processes which should be modeled in describing an individual system's combat activity against a passive target. Although the list of processes (both here and in figures 2 and 3) may not be exhaustive, they appear to be the principal ones one would logically include in a model of the process.

Information regarding models for each combination of weapons system and process are shown in the cells. Each cell will contain at most four entries with the legend given on figure 1. Thus, an M indicates a model exists for the combination of the weapon system and process. A T indicates that tests have been conducted and, where this is the case, an I suggests that the tests have been inconclusive or a V that the tests have tended to verify the model structure. Finally, the symbol A indicates my subjective belief that the model assumptions are somewhat reasonable. A bar above the M, T, or A indicates a negation: that no models exist, no tests have been conducted, or the assumptions are not reasonable, respectively. The tilde above the M, T, V, or A is suggestive of partial results, indicating that a model exists but with incomplete structure, some tests have been conducted, the models have been partially verified, or some of the assumptions are reasonable, respectively. When no models exist ($\bar{M}$), I have not bothered to indicate any test or assumption information, and, when tests have been conducted which partially or fully verify the models, I have not indicated any assumption information. An asterisk denotes no knowledge on my part regarding the particular entry and an NA signifies that the system-process combination is not applicable.

Some general impressions can be drawn from this figure by considering the pattern that occurs when one looks at the negation (overbar) and partial (tilde) indicators with respect to each of the symbols: the model symbol, the test symbol, or the assumption symbol (across the figure as a whole). Generally speaking, there appear to be a significant number of performance process models. Some tests have been conducted on the models, and in some cases these have been verified or partially verified. In cases where the models have not been tested, the assumptions underlying the model structures do not appear to be totally unreasonable. In contrast to this overview of performance process models, there appear to be very few models

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[1]Vector Research, Incorporated.
[2]General Research Corporation.
[3]Institute for Defense Analysis.
[4]US Army Combined Arms Center.

	Performance Processes						Decision Processes						
	Maneuver	Target Acquisition	Fire Rate	Accuracy	Lethality		Movement - Search	Movement - Fire Position	Search	Target Choice	Open Fire	Movement - Fire Avoidance	Terminate Fire
Infantry (Rifle)	M T$\tilde{V}$	M TV	M TV	M TI A	M $\tilde{T}$* *		$\bar{M}$	$\bar{M}$	$\bar{M}$	M $\bar{T}$ $\bar{A}$	M $\bar{T}$ $\bar{A}$	$\bar{M}$	$\bar{M}$
Tank/Anti-Tank — Personnel Arm. Veh.	M T$\tilde{V}$	M TV	M T$\tilde{V}$	M TI $\tilde{A}$	Personnel: M $\bar{T}$ * Arm. Veh.: M $\widetilde{TV}$		$\bar{M}$	$\bar{M}$	$\bar{M}$	M $\bar{T}$ $\bar{A}$	M $\bar{T}$ $\bar{A}$	M $\bar{T}$ $\tilde{A}$	$\bar{M}$
Artillery — Personnel Arm. Veh.	M $\bar{T}$ A	M $\bar{T}$ *	M TV	M TI $\tilde{A}$	Personnel: M $\tilde{T}$I * Arm. Veh.: M $\tilde{T}$* $\bar{A}$		$\bar{M}$	$\bar{M}$	$\bar{M}$	M $\bar{T}$ $\bar{A}$	M $\bar{T}$ $\bar{A}$	$\bar{M}$	$\bar{M}$
Air Defense Artillery	M $\bar{T}$ A	M $\tilde{T}$I A	M TV	M T$\tilde{V}$	M $\tilde{T}$I A		$\bar{M}$	$\bar{M}$	$\bar{M}$	M $\bar{T}$ $\bar{A}$	M $\bar{T}$ $\bar{A}$	$\bar{M}$	$\bar{M}$
Helicopter (grd. tgt.)	M TV	M $\tilde{T}$ *	M TV	M T* $\tilde{A}$	M * $\tilde{A}$		$\bar{M}$	$\bar{M}$	$\bar{M}$	M $\bar{T}$ $\bar{A}$	M $\bar{T}$ $\bar{A}$	$\bar{M}$	$\bar{M}$
Air — Ground Air	M TV	Ground: M TI * Air: M TV	M TV	Ground: M T$\bar{V}$ * Air: M TV	Ground: M * $\tilde{A}$ Air: M $\tilde{T}\tilde{V}$		*	NA	M * *	M $\bar{T}$ $\bar{A}$	M $\bar{T}$ $\bar{A}$	*	$\bar{M}$

FIGURE 1: INDIVIDUAL FIRER AGAINST PASSIVE TARGET

Legend

M model exists
T tests conducted
  I inconclusive
  V verified

A assumptions are reasonable
— negation
~ partial

* don't know
NA not applicable

FIGURE 2: SMALL UNIT COMBAT-BATTALION AND BELOW

	Combat Processes							Decision Processes					
	Organization	Maneuver	Target Acquisition	Micro-Intelligence (False Alarms)	Firepower	Communications	Terrain and Environment	Battle and Battle Area	Deployment and Tactical Roles	Attack Routes	Target Choices	Open Fire	Terminate Fire
Homogeneous Forces													
Inf/Inf (firefight)													
Dismounted (squads)	NA	M * Ā	M TI Ā	M̄	M T̄ Ā	M̄	M IV̄ Ā	M̄	M̄	M̄ T̄ *	M T̄ Ā	M T̄ Ā	M T̄ Ā
Mounted (companies)	NA	M * Ā	M TI Ā	M̄	M T̄ Ā	M * *	M IV̄ Ā	M̄	M̄	M̄ T̄ *	M T̄ Ā	M T̄ Ā	M T̄ Ā
Armor/Armor (firefight)	NA	M * Ā	M TI Ā	M̄	M T̄ Ā	M * *	M IV̄ Ā	M̄	M̄	M̄ T̄ *	M T̄ Ā	M T̄ Ā	M T̄ Ā
Artillery/Artillery	NA	NA	M T̄ *	M̄	M T̄ Ā	NA	NA	M̄	M̄	M̄	NA	M T̄ Ā	M T̄ Ā
A.D.A./Air	NA	M * Ā	M T̄* A	M̄	M T̄ Ā	NA	M T̄ Ā	M̄	M̄	M̄	M T̄ Ā	M T̄ Ā	M T̄ Ā
Hel./Grd. Units	NA	M T̄* Ā	M T̄I *	M̄	M T̄ Ā	NA	M T̄ Ā	M̄	M̄	M̄	M T̄ Ā	M T̄ Ā	M T̄ Ā
Tac. Air/Grd. Units	NA	M T* *	M T̄* *	M̄	M T̄ Ā	NA	M T̄ Ā	M̄	M̄	M̄	M T̄ Ā	M T̄ Ā	M T̄ Ā
Combined Arms (inf., tank, A.T., arty., hel.)													
Prepared Defense	M T̄ Ā	M T̄ Ā	M TI Ā	M̄	M T̄ Ā	M * *	M IV̄ A	M̄	M̄	M̄ T̄ *	M T̄ Ā	M T̄ Ā	M T̄ Ā
Delay & Withdrawal	M T̄ Ā	M T̄ *	M * *	M̄	M T̄ *	M * *	M IV̄ Ā	M̄	M̄	M̄ T̄ *	M T̄ Ā	M T̄ Ā	M T̄ Ā
Meeting (then hasty defense)	M̄	M̄	M̄	M̄	M̄	M̄	M̄	M̄	M̄	M̄	M̄	M̄	M̄

	Combat and Non Combat Processes									Management Processes					
	Mobility	Data Collection	Data Interpreta-tion (Processing)	Intelligence Dissemination	Communications	Command Control Execution	Firepower	Unit Movement	Reinforcement and Reorganization	Battle and Battle Area Choice	Command Control	Force Allocation	Supply Allocation	Reserve Commitment	Break Point
Division-Corps Level															
Attack/Defend	M $\tilde{T}$I $\tilde{A}$	$\tilde{\overline{M}}$	$\overline{M}$	$\tilde{M}$ $\overline{T}$ $\tilde{A}$	$\tilde{\underline{M}}$ T $\tilde{A}$	$\overline{M}$	M $\tilde{T}$* $\overline{A}$	M $\tilde{T}$* $\overline{A}$	M $\overline{T}$ $\overline{A}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	M $\overline{T}$ $\overline{A}$	M * *	M T$\overline{V}$ $\overline{A}$
Delay	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$
Penetration	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$
Exploitation	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$
Siege	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$
Theater Level															
Single Front	M $\tilde{T}$I $\tilde{A}$	$\tilde{\overline{M}}$	$\overline{M}$	$\tilde{M}$ $\overline{I}$ A	$\tilde{\underline{M}}$ I A	$\overline{M}$	M $\tilde{T}$* $\overline{A}$	M $\tilde{T}$* $\overline{A}$	M $\overline{T}$ $\overline{A}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	M $\overline{T}$ $\overline{A}$	M * *	$\overline{M}$
Multiple Front	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$	$\overline{M}$

FIGURE 3: LARGE SCALE WARFARE

of decision processes related to individual combat activity (a significant number of M's in the figure). Where models do exist no tests have been conducted and, in my opinion, the models are based on highly unrealistic assumptions (lots of T's and A's on the right side of figure 1).

4.2 Small Unit Action Models

Figure 2 is an attempt to provide an overview of the state of modeling small unit combat (battalion size and below). In this activity the units are in direct contact with each other and actively engaging in combat. The row headings reflect different types of combat engagements divided into two main categories: homogeneous forces and combined arms units. Under the homogeneous force category we can have infantry versus infantry engagements (dismounted or mounted), armor versus armor engagements, counter battery fire, etc. Combined arms engagements include units comprised of infantry, tanks, anti-tank systems, artillery, helicopters, and tactical aircraft engaging an enemy who is in a prepared defense, delay, withdrawal or hasty defense posture. The column headings are divided into three categories of processes: combat, terrain and environment, and decision. The following main points can be obtained from the figure:

(1) Except for the meeting type of engagement (wherein one of the opponents takes up a hasty defense posture) attempts have been made to model homogeneous and heterogeneous force battles of the prepared defense, delay, and withdrawal, with primary development and application emphasis on the prepared defense.[1] Analytic modeling has been restricted to the prepared defense situation. As you can see, my knowledge of the models of delay and withdrawal engagements is less than satisfactory.

(2) Micro-intelligence which consider the false alarm problems of acquiring already attritted targets or non-targets is included in only one model, and at that cannot be used because of the lack of appropriate input data.

(3) The firepower descriptors (accuracy, lethality, etc.) are the most developed of the submodels. Questions are continually being raised regarding parameter values used in studies, and there are questionable assumptions in the models used to estimate them (e.g., no cumulative damage, dispersion that is independent of target size, normality and independence of impact errors, etc.). My questions regarding the assumptions are associated with my belief that the combat is occurring in highly compressed time which may be due to the attrition process model or data, the tactical decision model, or both.

(4) Although I thought the terrain and evironment characteristics (elevations, soil roughness, etc.) or their effects (LOS, maneuver capability, etc.) were reasonably well represented in the models, recent tests (TETAM) at the CDEC and related analyses indicate that the digitized LOS models used in our Monte Carlo simulations of battalion-level combat produced significantly erroneous LOS realizations.

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[1]Although they are not depicted in the figure, I do not believe counterattack situations have been modeled.

(5) Only a small number of decision process models exist; and, where they do, no tests of their validity have been conducted, and the model assumptions are deemed to be highly unrealistic. The decision to get engaged in combat, the choice of battle area, the deployment and tactical roles (maneuver, overwatch, etc.), and except for DYNTACS, choice of attack routes, are not modeled but rather are input created as part of the scenario generation process. Engagements are assumed to happen. Target choice, open fire, and terminate fire decisions are programmed in the models. I believe these are models of doctrine (which I think we will agree is questionable) and not combat behavior, i.e., how military personnel behave in combat, and I think the assumptions are unrealistic.

4.3 Large-Scale Warfare

Figure 3 portrays my impressions of the state of modeling large-scale warfare activities, divided into the division-to-corps level and the theater level.[1] Within each of these categories the row headings reflect different types of warfare activity. The column headings depict the combat and non-combat processes as well as the management processes associated with large-scale warfare. The partial tests indicated under firepower and movement processes in the offense/defense engagement reflect the basic firepower score attrition tables and firepower score FEBA movement rate tables supposedly based on World War II data.

Four conclusions can be drawn from figure 3 - three of them are explicit from the figure and the fourth is an implicit one based on my subjective evaluation which I believe is consistent with those of many practitioners in the field.

(1) Essentially the only modeling that has been done in the large-scale warfare area is the offense/defense activity on a single front. I do not know of the existence of any models which consider other important combat activities such as deep penetration, exploitations, sieges, or multiple front warfare in which the FEBA loses its integrity, nor the effects that these activities have in determining the type and frequency of small unit actions that occur. The trend appears to be one of making more efficient models of perhaps the wrong process.

(2) There are almost no models describing the management or decision processes associated with large-scale warfare. A significant amount of the tactical decision making is not modeled but rather input based on the scenario generation process. Tactical decisions that are modeled have not been tested, and have highly questionable assumptions. They are, I believe, supposed to be descriptions of doctrine and are not actual tactical behavior. In fact

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[1]The reader is reminded that my remarks do not consider some of the significant accomplishments in the US since 1972 (such as the development of the VECTOR, IDAGAM, DIVOPS, a simulation version of DIVWAG, Air Allocation Models) nor some current research (such as modeling penetration phenomena, large scale intelligence, tactical decision behavior, and terrain LOS modeling) which will be either formally presented or discussed at this conference.

one would question if doctrine is being modeled since, as I understand it, the PACT wish to penetrate, avoiding engagements to do so. Yet we devoted most of our development and study efforts to the engagement process.

(3) With rare exception, the models that do exist have not been tested against any historical or experimental data. The exception is contained in the offense/defense-breakpoint cell, where historical data was compared to existing models of breakpoints and the null hypothesis rejected.

(4) Essentially all the large-scale warfare models employ the "firepower score" concept of attrition and FEBA movement. I think these are questionable. I will not go into many of the problems associated with these models (which are well documented elsewhere); however, it is important to note that (a) these models are based on World War II data which is questionable for today's and future systems, and (b) they cannot realistically determine who is attritted in the war since the theory is not structural. Although the many problems associated with this theory are well known, it has been frequently employed because of the absence of other model structures to analyze this scale of warfare activity. In my opinion, we will some day think of the firepower score models of large-scale campaigns as the phlogiston theory of warfare.

In summary, I would like to abstract three main conclusions from the figures.

(1) Through 1972, as the organizational level of the combat activity increases, the number and quality of the models decrease. The amount of test data also decreases in this direction. The assumptions underlying the model structures get more tenuous the further removed we are from the physical process; i.e., at the individual firer level of activity we can somewhat rely on the "natural laws of physics" as underlying model structures, but we have not evolved similar "natural laws of combat" as we move up the scale of combat activity.

(2) The operations research community has studied and modeled only the classical firefight, with little attention given to other combat activities and noncombat processes. In my opinion, the problem in developing model structures for these other activities is not "how" to model them but rather "what" to model.

(3) There have been few or essentially no efforts to understand and model the behavioral decision and management processes associated with the combat activity.

5.0 Trends

Some of the formal papers that will be presented by US participants and discussions with them will, I believe, indicate some methodolical trends that are starting to evolve in the US. This section briefly notes some of the major trends.

(1) Recognition that a large number of different factors (weapon system characteristics, weapon system mixes, tactics, terrain, etc.) can significantly affect the results of small unit actions (thus requiring extensive parametric analyses in studies) coupled with the long preparation and running times of Monte Carlo simulations, has led to the development of hybrid analytic-simulation

models of small unit combat engagements (e.g., BONDER-IUA and related differential models, COMAN, IHA). In such models the attrition and acquisition (and sometimes allocation) processes are modeled in an abstract mathematical way while the movement process is included in a simulatory manner. Two development directions are being pursued to supplement, complement, and perhaps replace the monte Carlo simulations:

(a) Freestanding or independent analytic model: As the name implies, this type of analytic model can be run independently of any detailed Monte Carlo simulation model of the same combat process. That is, one designs such a model so that it can use the same type of inputs as the Monte Carlo simulations of the same process and hopefully predict similar outputs in an efficient and easily interpretable manner. An example of this type of model is the BONDER-IUA differential model which was first used in the US in 1969 and the many enriched versions of it since then, the latest being the BLDM (Battalion Level Differential Model).

(b) Fitted parameter analytic model: This is an analytic model of the combat process which must be used in conjunction with the Monte Carlo simulation (or appropriate data from the actual process). The data or outputs of the simulation model are used to fit one or more free parameters in the analytic model so that the latter predicts results comparable to the simulation model.[1] Examples of free parameter models that have been developed are COMAN and LORSUM. These models, in contrast to statistical regression functions, are structured on a physical basis with only a minimum number of parameters to be estimated. This permits a larger amount of extrapolative sensitivity analyses which are highly questionable if all of the parameters in the free parameter model are estimated.

(2) Over the past two to three years it has become increasingly clear that it is not sufficient to analyze weapon system and weapon mix combined arms questions in battalion or lower unit combat engagements and that the higher level division and corps level war games are not responsive to perform the extensive parametric analyses needed to address such questions. This has motivated the development of a first-cut hybrid analytic-simulation of division operations (the DIVOPS model in which the attrition, maneuver unit element and fire support sensor acquisition, and terrain line of sight processes are modeled analytically) and some research for next-generation analytic models of division-to-corps operations. Additionally, efforts have been devoted to reducing the player participation in war games (e.g., modification to the DIVWAG war game) and to get more weapon system attrition details into the games by using small unit action models in division level games

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[1]An obvious example of such a model, of course, is the classic statistical regression function, where essentially every parameter of the model is fit according to the data. These, however, are usually inadequate for analysis purposes and are usually based on ignorance of the process rather than knowledge.

in a hierarchical fashion (e.g., the DBM game uses the COMANEX free parameter analytic model to assess battalion actions, where parameters of COMANEX are estimated from runs of the CARMONETTE Monte Carlo simulation).

(3) More detailed force structure questions, requests for net assessments and net technical assessments, MBFR questions, and other force planning problems are generating the requirement for more disaggregated and credible theater level campaign models. This disaggregation is being accomplished in a number of ways:
   (a) The development of hybrid analytic-simulation models in which structural detail of small unit actions (e.g., battalion level and below) and other combat activities are directly played in the campaign model through the use of analytic submodels.
   (b) The development of campaign models in which results of brigade or division engagements are used in look-up tables and called for when assessments of such battles are needed.
   (c) Disaggregation of the "firepower score" theater level models so that attrition assessments and movement are performed at division or brigade level.

(4) After many years of giving lip service to the need for experimental data to verify land warfare models, there appears to be a slight, but none-the-less positive, trend to generate data for this purpose. The recent TETAM tests, which generated data to examine the predictive capability of our battalion level Monte Carlo simulations and their component terrain LOS models is the most prominent effort. If the tentative negative conclusions regarding the terrain LOS models are substantiated, I expect we will see increased emphasis on this verification activity through the conduct of more tests directly for this purpose and the use of existing and future test data generated for other purpose (e.g., HITVAL, SEEKVAL).

I believe you will see signs of these trends both in the formal papers presented by US participants and in discussions with them throughout the conference.

CONSTRAINED FORCE DEVELOPMENT

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INTRODUCTION

Constrained force development is a generic term applicable to the definition of force structure related problems and applies to short, mid, or long range planning and programing. The term assumes a three part structure associated with force structure problems: an initial object state; a goal state; and rules of transformation.

A problem's initial object state is its current environment, for example, the currently approved Army Force Program as exemplified by the Five Year Defense Program (FYDP). A goal object state is an explicit statement of a transformed initial object state. In the Planning, Programing, and Budgeting System (PPBS) the Program Objective Memorandum (POM) is developed prior to a FYDP update and can be considered a FYDP goal state. The POM identifies a future force structure and the specific unit related actions (activations, inactivations, reorganizations, and changes of assignment) required to transform explicitly the initial object state (the old FYDP) into the new goal state. These unit related actions express the rules of transformation capable of transforming the initial object state, via a sequence of intermediate states, into the goal state and are presumed to be feasible in light of known constraints.

This paper argues that the constrained force development problem is well defined when there exists a systematic method of deciding that a candidate for the problem's solution is acceptable. The existence of a well defined problem is a necessary and sufficient condition for initiation of the decision making process.

Force structure decision making is the process of differentiating between alternative sets of unit actions to find the set most acceptable. If current conditions, desired conditions, and alternatives which can produce desired conditions are known, then a problem becomes one of choice. The full range of operations research techniques may augment this choice process. Conversely, operations research techniques are marginally applicable to ill-defined problems.

Mathematical programing models require defined initial object states represented by objective functions and constraint equations. Goal states are represented by statements such as "maximize". Transformations which satisfy problem constraints in the initial object state are acceptable in our definition of problem solving. If doubt exists concerning definition of an initial object state, problems become stochastic. If doubt exists concerning goal states, i.e., force developers do not know whether they want to maximize or minimize, the problem is unsolvable. In linear programing, the simplex algorithm obviates the necessity of explicitly enumerating all possible transformations. That is, the linear programing method takes one simultaneously through the problem solving and decision making stages in such fashion that the solution produced by problem solving is the best decision making choice.

THE FORCE STRUCTURE PROBLEM

The consequences of failure to distinguish between the three states of problem definition and decision making are often serious. Decisions made when the constrained force structure problem is ill-defined (e.g., we do not know what we want to do, what we currently have, or the rules for changing things) may be damaging in the short run and may produce catastrophic results in the future. Today's decisions largely shape the constraints upon tomorrow's processes.

The Army has difficulty defining its initial object state, let alone its goal state. Frequently, the detailed description of "today's" Army can only be accomplished by examination of information which was developed in the distant past. Extension of this information into the future compounds inherent inaccuracies and little success has been achieved in acquiring detailed information concerning planned actions. This problem has been studied in detail and a management information system, to cope with it, is being designed. This effort is described in the next section.

Complexity has caused the force development process to become diffuse. The result is that decision makers seldom receive more than "one and one quarter" alternatives from which to select. Not only does solution search tend to cease with the first feasible solution, but such an initial solution is sometimes never found. This problem is exacerbated by the time constraints inherent within the PPBS cycle.

The Army must define future force structure in a fashion which permits implementation of strategy subject to known constraints. Furthermore, the Army must be able to describe accurately such force structure in sufficient detail to permit asset procurement and distribution.

As previously indicated, programing force structure decisions from an initial object state to a goal state is amenable to many operations research techniques. However, difficulty arises when one attempts to define the "cost coefficients" required by these techniques. "Cost coefficients" are the data needed to translate force goals into appropriate resource costs and encompass the broadest possible definition, e.g., people, dollars, equipment, facilities, strategic lift, etc. Though the Army receives and processes force structure guidance in terms of "cost coefficients" there is little capability to translate force structure goals into a useable format for analyses.

Consequently, the historical impact of force structure decisions is unknown except at the highest levels of aggregation and the validity of using currently available data as "cost coefficients" is questionable. A major Army task is the establishment of an audit trail from original guidance to appropriate authorization changes at unit level. Such historical data would then be available to determine authorization "cost coefficients" for use in operations research models.

A purpose of constrained force development is translation of force requirements into appropriate resource costs, comparison of these resource costs with projected resource availability and, finally, development of a viable program to transport the Army from any point in time to any selected goal state.

THE INITIAL OBJECT STATE

The major problems inherent in defining the initial object state are translation of highly aggregated force data into detailed unit actions and re-aggregating the effect of these detailed unit actions reflecting mission accomplishment. In terms of this paper, the Army must identify its goal state, compare the goal state's requirements with those of the initial object state (the approved force program) and define rules of transformation (unit actions) in sufficient detail that asset procurement/distribution agencies can support them. In practical terms, this means unit actions must be translatable into projected requirements for personnel in grade, branch, military occupational specialty (MOS), level detail, and equipment at line item number (LIN) detail over a five year period. The rules of transformation must be disseminated as guidance to the Army in the field for implementation, and the detailed field response to this guidance must be fed back to Department of the Army (DA) in sufficient time to support asset procurement and distribution. A two year projection is required to initiate asset distribution programing.

It is tacitly impossible for the Army in the field to accomplish such projections and, consequently, DA makes them. However, the qualitative accuracy of these projections is directly dependent on field input for reasons described in the ensuing paragraphs.

Guidance, as received by DA, is normally general in nature. The rule used in issuing guidance to major commands (MACOMs) is not to constrain excessively subordinates' ability to allocate resources in consonance with their concept for mission accomplishment. The practical effect is that guidance remains at a high level of aggregation until it reaches the unit which must implement it.

Detailed information is developed at unit level where the qualitative decisions are made regarding how the unit will be changed. The results of these changes (in grade, branch, MOS detail) are documented in a change to the unit's Army Authorization Documents System (TAADS) document. When equipment authorizations also change, these changes are noted in the TAADS document in LIN level detail. The proposed document changes are then forwarded, through commands, to DA for approval. These documents are the basis for projecting asset requirements associated with units. As previously indicated, DA projects force structure authorizations seven years into the future. The Structure and Composition System (SACS) provides a capability for computing force structure equipment and/or personnel requirements and authorizations for a real or hypothetical force, for the current year and each of a series of future years. It does this by mathematically factoring strengths in existing TAADS documents to match future personnel and equipment authorizations. The basis for this factoring is the authorization data contained in the Force Accounting System (FAS). Equipment requirements are determined in a similar fashion, utilizing routines to account for modernization.

It is necessary to describe how the authorization data is developed which provides the basis for mathematically factoring the TAADS document. As implied, the field normally tries to document authorizations in the short run (current year), while the Army Staff is making projections from these documents up to seven years beyond the current year. Although the guidance passed to subordinates deliberately is kept as broad as possible, it is necessary to make detailed changes in data bases for planning, programing, and budgeting purposes. A statement that a budget could not be presented because detailed field input was lacking would be unacceptable. Consequently, data bases are changed on the basis of "assumptions" regarding how subordinates will implement generalized guidance.

This guidance information is not normally at unit level detail and must be translated to that level in order to maintain a valid Army troop list. Since field responses are not timely enough, DA action officers make "program assumptions" at unit level, describing how they think the field will respond. This information establishes the programed data base used to factor TAADS documents mathematically and project asset requirements for Army procurement and distribution.

The assumption/command plan procedure is designed to mitigate the effect of the relatively long lead time it takes for DA to receive an approved TAADS document change.

This process mathematically adjusts current authorization documents to meet future projections and provides the basis for detailed acquisition of people and equipment. Distribution of people and equipment is based upon the most recently approved authorization document--which is different from the mathematically factored document used to create the "people and equipment pool" from which distribution is made. This problem, which impacts upon unit readiness and morale, should be alleviated as system response times improve and more users can review the systems' data.

An integrated management information system is being defined for development which will service all customers (from DA through unit) with an automated force development capability and centralized, edited data. As this system tracks guidance, maintaining an audit trail of force structure decisions, information concerning the detailed impact of force guidance will become available. This information should prove invaluable in defining the cost coefficients required by constrained force development. Furthermore, such a system will facilitate the timely and accurate flow of detailed information regarding future actions between DA and the field. This will permit use of operations research techniques to program force structure with attendant savings of money and manpower.

It is important to realize that the management information system being designed is more than a collection of computers and computer programs. It is an organized method of providing past, present, and projected force structure information relating to the internal operations of each using headquarters and provides externally generated information from each headquarters' subordinate elements. The system must support the planning, programing, budgeting, control, and operational functions of force development by furnishing uniform information in the proper timeframe to assist decision makers.

TOTAL FORCE - AN ARMY GOAL STATE

The Total Force concept has its origin in national policy statements which directed greater reliance on Reserve Components. The Reserve Components were always considered in force planning, but previously insufficient attention was devoted to their full integration in a Total Force concept. Much analysis was done on risk assessment of combat units but little was done of combat service support units. Many real constraints on the rules of transformation were ignored due to their complexity and due to the inability of the process to recognize them.

A giant step toward correcting these force planning deficiencies and developing a methodology to prevent their recurrence is the Army Total Force study effort. The following discussion highlights the current study methodology and describes on-going efforts to relate Total Force resource requirements with resource availability.

The process begins with definition of the combat units around which the study is based. This force is specified as guidance by the Chief of Staff. From this, the study develops support requirements. Combat unit requirements are not addressed, other than in fine tuning the injection of the given combat units into a theater subject to strategic lift constraints. These combat units are initially analyzed in the Force and

Weapon Analysis Project (FOREWON) system. The FOREWON system was developed for Army use by the Research Analysis Corporation (formerly RAC, now General Research Corporation, GRC) and is currently operated by the Army's Concept Analysis Agency (CAA). The FOREWON system consists of five separate but integrated models. Four of these models are used in Total Force analyses.

A lift model, the Preliminary Force Designer - Simulation Allocation Model (PFD-SAM) deploys units to a theater of operations and generates arrival dates. This model provides a preliminary allocation of the force and the available lift, and uses linear programing and computer simulation techniques.

A wargame model, A Tactical Logistical and Air Simulation (ATLAS) model employs combat units against an assumed enemy as the units arrive in the theater. ATLAS is a computerized theater wargame designed to determine quickly the outcome of an extended combat period.

The force wargamed in ATLAS consists of combat and combat support units. Based on the results of the wargame a logistics or force round-out model, Administrative and Logistical Support (FASTALS), is used to develop the combat service support required to support the combat forces.

Finally, a force aggregation model, Objective Force Designer (OFD) is used to develop an aggregated troop list to support the strategy being examined for all theaters of interest.

The results of this process are then subjected to more detailed analysis through use of the Concepts Evaluation Model (CEM) created by GRC and operated by CAA. The CEM is a theater-level combat simulation similar to ATLAS but which includes the additional features of combat at the brigade level and a more sophisticated logistics sub-model. The CEM permits analysis of the weapons system mix on the battlefield through a FEBA trace. A process of iterating between the SMOBSMOB (a more refined lift model than PFD-SAM) and the CEM permits fine tuning of the deployment schedule to improve warfighting subject to lift, combat unit and logistical constraints. The deployment schedule is viewed as an explicit statement of the Army's prioritized need for units as determined by their warfighting contribution. This prioritization is the key to applying constraints and developing rules of transformation. Furthermore, through the CEM's logistics sub-model, the study analyzes the effects of war reserve availability on the Army's needs for type units.

Described thus far has been a methodology for defining a relatively unconstrained force. A first step in assessing the resource requirements of this force is the translation of the force into Army budget and FYDP terms.

To initiate this process, the goal state is converted into detailed personnel and logistical information through use of the automated SACS. The SACS process has been discussed in the preceeding section. Personnel and logistics agencies are asked to evaluate the programed force structure changes postulated in the rules of transformation and assess their impact, on a unit by unit basis, in their areas of interest. Prior to this assessment, these agencies have validated the requirements for each unit in the goal state. Consequently, this analysis identifies needs for trade-offs and provides relative measures of cost and benefits with which to accomplish them. The Force Stratification Model, developed by the Engineer Studies Group (ESG), is concurrently used to analyze and compare the goal state and initial object state in terms of internal unit structure.

Relevant costs associated with the force change scenario are developed. These costs are staffed with the appropriate Army budget and FYDP program directors. Again, the result improves the quality of trade-off analysis and resource management.

Total Force data developed will be used for the PPBS cycle of 1977-1981. Concurrently, a methodology for synchronizing the PPBS products with the Total Force (goal state) is being developed. Essentially, this methodology is based upon a comparison of the Target Total Force (goal state) with the programed force (initial object state) and the recommendation of force structure actions required, on a unit for unit basis, (by FY over the POM years 77-81) to align the programed with the target force (rules of transformation). These force structure actions will be activations, inactivations, reorganizations, changes of command assignment, and/or geographic location changes. An attempt will be made to assess explicitly the projected impact of these changes on selected criteria such as personnel and fiscal feasibility. The Constrained Force Model (CONFORM) developed by GRC and operated by USAMSSA will be used for this purpose. These recommended force structure changes are essentially a scenario to map the Army today into the Total Force goal state at selected future points. In this regard, the scenario may be considered an explicit statement of rules of transformation. However, inherent in these rules are priorities which reflect the relative contribution of each unit to war-fighting. These priorities provide a mechanism for applying constraints.

CONCLUSION

Constrained force development has become an omnibus effort interwining previously disjointed actions in a symbiotic manner. The desired result is increased systems synergy and reduced process diffusion. A corollary objective is an integrating link comprised of a meta-language for defining problems which transcends technocratic jargon.

Two on-going projects have been described from the standpoint of constrained force development. Their description, in terms defining force structure problems, is intended to make their mutual dependence apparent. Defining the initial object state (the Army now) provides the basis for projecting future force structure requirements. If our definitions of the initial object state are faulty, projections from that base compound the problem and impose undesirable constraints upon future force options.

Providing visibility to planning factors and other unit related information will help purge bad data from the system and result in improved information. Tracking force development guidance and documenting its implementation allows use of sophisticated force programing techniques, improves process accuracy, reduces manpower requirements, and makes process constraints more explicit. By overturning the rock under which the force program is currently developed, process diffusion will be reduced and the mutual dependence of force related actions will become more apparent.

Inherent in making good short run force structure decisions is a defined goal state. A methodology for defining support requirements and relating future force structures to resource availability has been discussed. This methodology ignores civilian manpower and in so doing makes impossible detailed analysis of the general support force. Little analysis is devoted to special mission forces and a method for accomplishing such analysis using existing techniques is not apparent. No discussion has been devoted to defining requirements for combat units under constraints. These are major shortcomings in our attempts to define the force development goal state.

All of the information needed to make force development decisions (assuming there is a defined goal state) will not be provided by the management information system described earlier. Readiness, equipment availability, personnel availability, and fiscal information has been excluded from the data base.

Despite these shortcomings, significant improvements in constrained force development are being accrued.

Acceleration of processing time through automatic data processing and concurrent use of operations research models will make development of multiple alternatives possible. These alternatives will represent more accurate rules of transformation and, being explicit, will focus attention upon tight constraints. These actions make possible the integration of functional force development activities performed by the Army Staff.

The Total Force study effort operates outside of, and precedes, a PPBS cycle (POM-Budget-Execution) in terms of force development. Consequently, analysis of the goal state, with respect to the Total Force, is not constrained by PPBS milestones and can be conducted in a more relaxed atmosphere.

Finally, and perhaps of most importance, constrained force development stresses the logic which should exist between troop lists generated by the Army Staff. If the best military judgment determines that the Joint Strategic Objectives Plan (JSOP) force can satisfy the Army's strategic requirements, there should be a good explanation for requiring a unit in the Total Force (more constrained than the JSOP) which was not stated as a JSOP requirement. Using the same logic, there should be a good explanation for requiring a unit in the POM force (more constrained than the Total Force) which was not stated as a Total Force requirement. The same analysis holds for the Budget force.

TITLE: General Purpose Force Potentials

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For some time we at IDA have been conducting research, the objective of which is to provide analytic tools for force-capability comparisons of NATO and Warsaw Pact forces in Central Europe. We believe the methodology should be sensitive to important qualitative differences in weapons and to differences in force composition. At the same time, the methodology should be mathematically defensible, yet conceptually simple enough that it is heuristically justifiable. While it is instructive to compare the opposing forces in terms of relative numbers of personnel, tanks, artillery pieces, aircraft, etc., the neglect of potentially significant differences in weapon quality limits the utility of such assessments.

At the other extreme in the spectrum of methodologies are "simulations" or "war games," nearly always implemented as computer programs. Such methodologies vary greatly in scope and level of detail. There are detailed simulations of battles between small ground units, tank-vs-tank duels, and training-aid games for the simulation of combat commanders' decision environments, but these detailed models were not intended for use in force-balance assessments or for aggregation into a larger-scope model, which would be prohibitive in terms of time, cost, and the demand for data.

There are also "global" war game models which can be quite useful for "one-sided" analyses, such as assessing logistic requirements, air defense needs, capacity of communications systems, etc., but which suffer from inscrutability when used in assessing relative force capabilities. The necessity for built-in assumptions (to allow the computer to execute its calculations) and the mystique of the data-preparation process limit the ability of the user to verify the validity of predictions by such models.

In attempting to develop comparative measures of combat potential that are intuitively recognizable as useful indices, consideration was given to previous efforts of the military analytic community. Review of Index Measures of Combat Effectiveness by D.M. Lester and R.F. Robinson contains descriptions of much of that work, viz., Firepower Potential, Weapons Effectiveness Indices, Index of Combat Effectiveness, Weighted Unit Value, Combat Power Scores, and Quantified Judgment Method.

This paper presents several measures of force capability that reflect the quantity of major equipment items and some aspects of their quality. In order to provide the means for comparing NATO and Warsaw Pact in Central Europe, these measures, which are called "attriting potentials," are defined so that they represent the theater-wide capability of each side or the total potential to do a particular job. Thus, as nearly as possible, these measures of potential are scenario-independent and do not purport to represent how a battle would progress in a particular sector of the battleground. Rather, such measures give an impression of relative capability of one side with respect to the other, theater-wide.

The worth of many types of equipment is represented herein only by a net potential capability to defeat typical targets presented by an opponent. To obtain a relative comparison of the two sides, the measures are based on stylized targets within effective range of the weaponry whose potential effectiveness is being measured. Again, these measures do not represent the outcome of the local battle or engagement, but rather the relative total capability of each side to participate in a hypothetical engagement, given an abundance of targets already acquired. Clearly, in an actual battle, the full capability of either side would never be brought to bear. In short, these are measures of potential, not actual, capability. Measures of actual capability require a detailed understanding and modeling of target acquisition capability, command and control, and tactics, among many other factors, none of which is addressed by these measures. Nor do these measures take account of night and adverse weather effects on operations.

EXHIBIT 1 (U)

POTENTIAL MEASURES AND THEIR CHARACTERISTICS

MEASURES

PERSONNEL ATTRITING POTENTIAL	PAP
TANK ATTRITING POTENTIAL	TAP
BASED AIRCRAFT ATTRITING POTENTIAL	BAAP
POL ATTRITING POTENTIAL	POLAP

CHARACTERISTICS

- THEATER-WIDE
- INVOLVE PRIMARY ARMS & TARGETS OF WARFARE
- RELATE QUANTITY & QUALITY OF MANY DISSIMILAR WEAPONS TO A SINGLE GOAL
- MEASURE POTENTIAL CAPABILITY RELATIVE TO PROBLEM
- INTUITIVELY UNDERSTANDABLE

The stylized targets against which the capability of the forces of the two sides is to be expressed are personnel, tanks, based aircraft (i.e., aircraft in shelters, in revetments, and parked in the open), and POL storage. These targets were chosen (1) because they are important elements in modern warfare, (2) because the effectiveness of weaponry in attacking these targets is calculable, and (3) because the impact of attriting these targets is directly recognizable. Other targets, e.g., communication nodes, might have been chosen; however, attrition of such targets still leaves a more fundamental question to be addressed, viz., the impact of their loss on the relative balance. The chosen targets appear so fundamentally important that the ratio of their losses would appear to be indices of relative strengths. Unfortunately, other fundamental elements are not included in this analysis. Air-to-air effectiveness and ground defenses against aircraft, for example, have not been addressed. They are very important interactions in an assessment of relative strength of opponents; nevertheless, limitations of both imagination and effort prevented reduction of these interactions to simple measures.

I will now discuss each attriting potential separately, the equation we use in calculating it, the types of data needed, and assumptions made and some comments about intermediate level calculations. First, the Personnel Attriting Potential.

EXHIBIT 2 (U)

PERSONNEL ATTRITING POTENTIAL

WORKING EQUATION

GROUND-GENERATED

- THE PERSONNEL ATTRITING POTENTIAL (PAP) FOR A SPECIFIC WEAPON TYPE IS DERIVED AS FOLLOWS:
  - FOR EACH TYPE OF AMMUNITION EXPENDED BY THIS WEAPON,

$$\left(\text{LETHAL AREA PER DAY PER AMMO TYPE}\right) = \left(\text{EXPENDITURE PER DAY OF THIS AMMO TYPE PER WEAPON}\right) \times \left(\text{LETHAL AREA PER ROUND}\right)$$

  - ADD THESE QUANTITIES TO GET LETHAL AREA PER WEAPON PER DAY THEN,

$$\left(\text{LETHAL AREA FOR THIS WEAPON TYPE PER DAY}\right) = \left(\text{NUMBER OF THIS TYPE OF WEAPON}\right) \times \left(\text{LETHAL AREA PER WEAPON PER DAY}\right)$$

- ADD THESE QUANTITIES FOR ALL WEAPON TYPES TO GET TOTAL GROUND-GENERATED LETHAL AREA PER DAY
- PERSONNEL ATTRITING POTENTIAL $= \left(\text{TOTAL LETHAL AREA PER DAY}\right) \times \left(\text{TROOP DENSITY}\right) \div \left(\text{ENEMY PICU}\right)$

The potential of ground-delivered (or air-delivered) weapons to incapacitate personnel in the combat area by indirect fire is the potential fraction of the enemy personnel in combat units (PICU) that the weapons of the opposite side's forces could potentially incapacitate in a day. The target base of personnel we assume is 1/3 standing, 1/3 prone, and 1/3 in foxholes, at a concentration of 300 troops per km^2. This troop density is an average density of a U.S. mechanized infantry company on defense and a Soviet motorized rifle company in attack.

It should be pointed out that the equation for Personnel Attriting Potential involves a sum over all weapons of the product of effectiveness per round (or sortie) and the ammunition expenditure rate (or sortie rate). The effectiveness is rather straightforward to calculate and difficult to alter arbitrarily, whereas the rates are soft and can easily be changed. Thus, the product and the attriting potential are sensitive to uncertainties and arbitrariness of these rates. (This is a problem which, explicitly treated or not, all models share at least in principal.) Nevertheless, ammunition expenditure rates and sortie rates are important elements in the balance of strength (and, presumably, in the outcome of battles).

EXHIBIT 3 (U)

PERSONNEL ATTRITING POTENTIAL

TYPES OF DATA USED

TARGET	TROOP DENSITY TROOP POSTURE NUMBER OF PERSONNEL IN COMBAT UNITS
WEAPONS	NUMBER OF EACH TYPE WEAPON MUNITION TYPE FOR EACH WEAPON MUNITION RESUPPLY RATES
	NUMBER OF A/C OF EACH TYPE MUNITIONS LOADS FOR EACH A/C MUNITIONS STOCKPILE SORTIE RATES

CALCULATIONS

	LETHAL AREA/DAY FOR EACH WEAPON "STYLIZED" LOAD FOR EACH A/C LETHAL AREA/DAY FOR EACH A/C
	TOTAL LETHAL AREA/DAY TOTAL PERSONNEL POTENTIALLY KILLED/DAY

FINALLY,

$$\text{PAP} = \frac{\text{PERSONNEL POTENTIALLY KILLED PER DAY}}{\text{PERSONNEL IN COMBAT UNITS}}$$

As could be deduced from the previous equation, the types of data (or assumptions) needed for the calculations of the Personnel Attriting Potential are shown on this exhibit.

The calculations are rather straightforward. For aircraft we have developed a "stylized load" which is a mix of the various types of munitions available, the nature of the mix being adjusted such that the stockpile of munitions is uniformly drawn down.

Next I will discuss the Tank Attriting Potential.

EXHIBIT 4 (U)

TANK ATTRITING POTENTIAL

WORKING EQUATION

GROUND-GENERATED

- TANK KILLS FOR A SPECIFIC WEAPON TYPE
  - FOR A SINGLE WEAPON OF EACH TYPE

$$\begin{pmatrix}\text{POTENTIAL}\\ \text{TANK KILLS}\\ \text{PER WEAPON}\end{pmatrix} = \sum_{i=1}^{L} \begin{pmatrix}\text{FRACTION OF TARGET}\\ \text{FIRST DETECTIONS}\\ \text{PER RANGE INTERVAL}\end{pmatrix} \times \begin{pmatrix}\text{PROBABILITY}\\ \text{OF HIT GIVEN}\\ \text{AN AIMED SHOT}\end{pmatrix} \times \begin{pmatrix}\text{PROBABILITY OF}\\ \text{KILL GIVEN}\\ \text{A SHOT AND HIT}\end{pmatrix}$$

WHERE

$$\sum_{i=1}^{L} \begin{pmatrix}\text{FRACTION OF TARGET}\\ \text{FIRST DETECTIONS}\\ \text{PER RANGE INTERVAL}\end{pmatrix} = \text{1.0 WITHIN L RANGE INTERVALS OUT TO 3000 METERS}$$

  - ADD THESE TO OBTAIN POTENTIAL TANK KILLS PER WEAPON TYPE

$$\begin{pmatrix}\text{POTENTIAL}\\ \text{TANK KILLS}\\ \text{PER WEAPON}\\ \text{TYPE}\end{pmatrix} = \begin{pmatrix}\text{POTENTIAL}\\ \text{TANK KILLS}\\ \text{PER WEAPON}\end{pmatrix} \times \begin{pmatrix}\text{NUMBER}\\ \text{OF THIS}\\ \text{TYPE}\\ \text{WEAPON}\end{pmatrix}$$

- ADD ALL THESE QUANTITIES TO FIND TOTAL TANK KILLS BY GROUND WEAPONS
- TANK ATTRITING POTENTIAL = $\begin{pmatrix}\text{TOTAL TANK}\\ \text{KILLS}\end{pmatrix} \div \begin{pmatrix}\text{TOTAL NUMBER}\\ \text{OF ENEMY TANKS}\\ \text{IN THEATER}\end{pmatrix}$

The potential of ground- or air-delivered weapons to kill enemy tanks in the combat area is the potential fraction of the enemy's medium tanks standing in the open that the weapons of the opposite side's forces could incapacitate in a day by inflicting a mobility or firepower kill. It is measured in enemy tanks killed by a single aimed shot from each of a force's tank guns and ATWs divided by the total number of enemy tanks in theater.

It should be pointed out that the Tank Attriting Potential (unlike the Personnel Attriting Potential) is not defined in terms of the rate of expenditure of ammunition of the ground weapons involved. Each weapon is allowed one aimed shot because:

- Tank-antitank encounters are likely to be relatively short (a few hours) violent engagements without resupply.
- Vulnerability of direct-fire weapons to indirect fire and to fire from enemy direct-fire weapons differs markedly among the several types of weapons (e.g., portable ATWs are much more vulnerable than are tanks). Thus, vulnerability to enemy fire should be taken into account if tank attriting potential is to be based on a one-day period.
- Expected high attrition of antitank weapons--many will not survive one day of combat--is an important factor in decisions for equipping ground combat units. While an artillery weapon would generally be expected to fire thousands of rounds before it is put out of action by enemy fire, the expected life of direct-fire systems, such as tanks and ATWs, would likely be on the order of tens of rounds fired before attrition due to enemy fire. Thus, expected daily attrition should be considered if tank attriting potential is to be based on a one-day period.

Single sorties are used for Tank Attriting Potential generated by aircraft whose stylized loads include some ordnance which is not effective against tanks.

Thus, TAP, as defined herein, is sensitive only to quality (single-round or single-sortie kill probability) and quantity of weapon systems, not to rates of fire or sorties.

The types of data (or assumptions) needed in the calculations are shown in the next Exhibit.

EXHIBIT 5 (U)

TANK ATTRITING POTENTIAL

TYPES OF DATA USED

TARGET	MEDIUM TANK VULNERABILITY DATA NUMBER OF TARGET TANKS OF ALL KINDS
WEAPONS	NUMBER OF EACH TYPE TANK FIRING NUMBER OF EACH TYPE ANTI-TANK WEAPONS MUNITION TYPES FOR EACH WEAPON WEAPON KILL PROBABILITY VS. RANGE ENGAGEMENT PROBABILITY VS. RANGE (FIRST SITING PROBABILITY USED AS SURROGATE)
	NUMBER OF A/C OF EACH TYPE MUNITION LOADS FOR EACH A/C MUNITIONS STOCKPILE
CALCULATIONS	POTENTIAL TANK KILLS PER SHOT FOR EACH WEAPON "STYLIZED" LOAD FOR EACH A/C POTENTIAL TANK KILLS PER SORTIE
	TOTAL POTENTIAL TANK KILLS
	FINALLY,

$$\text{TAP} = \frac{\text{TOTAL POTENTIAL TANK KILLS}}{\text{NUMBER OF TARGET TANKS IN THEATER}}$$

The Based Aircraft Attriting Potential is calculated in a way similiar to the two already mentioned, as is shown in the next Exhibit.

EXHIBIT 6 (U)

BASED AIRCRAFT ATTRITING POTENTIAL

WORKING EQUATION

THE BASED AIRCRAFT ATTRITING POTENTIAL IS DEFINED AS:

$$\left(\begin{array}{c}\text{TOTAL NUMBER OF TARGET}\\ \text{AIRCRAFT KILLED PER DAY}\end{array}\right) \div \left(\begin{array}{c}\text{TOTAL NUMBER OF TARGET}\\ \text{AIRCRAFT IN THEATER}\end{array}\right)$$

THE TOTAL NUMBER OF TARGET AIRCRAFT KILLED PER DAY IS CALCULATED BY SUMMING, OVER ALL THE ATTACKING AIRCRAFT, THE PRODUCT:

$$\left(\begin{array}{c}\text{NUMBER OF TARGET}\\ \text{AIRCRAFT KILLED}\\ \text{PER SORTIE FOR}\\ \text{EACH AIRCRAFT TYPE}\end{array}\right) \times \left(\begin{array}{c}\text{SURGE SORTIE}\\ \text{RATE FOR EACH}\\ \text{ATTACKING AIR-}\\ \text{CRAFT TYPE}\end{array}\right) \times \left(\begin{array}{c}\text{NUMBER OF ATTACK-}\\ \text{ING AIRCRAFT OF}\\ \text{EACH TYPE}\end{array}\right)$$

CALCULATE THE NUMBER OF TARGET AIRCRAFT KILLED PER SORTIE BY AN ATTACKING AIRCRAFT OF EACH TYPE, BY MAKING THE SUM, OVER ALL THE MUNITION TYPES CARRIED BY EACH AIRCRAFT, OF THE PRODUCT:

$$\left(\begin{array}{c}\text{NUMBER OF UNITS OF EACH}\\ \text{MUNITION TYPE CARRIED}\\ \text{ON A SORTIE}\end{array}\right) \times \left(\begin{array}{c}\text{EXPECTED NUMBER OF TARGET}\\ \text{AIRCRAFT KILLED PER UNIT}\\ \text{OF MUNITION}\end{array}\right)$$

$$\left(\begin{array}{c}\text{EXPECTED NUMBER OF}\\ \text{TARGET AIRCRAFT KILLED}\\ \text{PER UNIT OF MUNITION}\end{array}\right) = \left\{\begin{array}{c}\text{FRACTION OF TARGET}\\ \text{AIRCRAFT IN}\\ \text{SHELTERS}\end{array}\right\} \times \left\{\begin{array}{c}\text{PROBABILITY OF}\\ \text{KILLING AIRCRAFT}\\ \text{IN SHELTER WITH}\\ \text{UNIT OF MUNITION}\end{array}\right\}$$

$$+ \left\{\begin{array}{c}\text{FRACTION OF TARGET}\\ \text{AIRCRAFT IN}\\ \text{REVETMENTS}\end{array}\right\} \times \left\{\begin{array}{c}\text{PROBABILITY OF}\\ \text{KILLING AIRCRAFT}\\ \text{IN REVETMENT WITH}\\ \text{UNIT OF MUNITION}\end{array}\right\}$$

$$+ \left\{\begin{array}{c}\text{FRACTION OF TARGET}\\ \text{AIRCRAFT PARKED IN}\\ \text{OPEN}\end{array}\right\} \times \left\{\begin{array}{c}\text{PROBABILITY OF}\\ \text{KILLING AIRCRAFT}\\ \text{IN THE OPEN WITH}\\ \text{UNIT OF MUNITION}\end{array}\right\}$$

The Based Aircraft Attriting Potential is defined as the potential of an air force to destroy an opposing force's aircraft, assuming that they are on the ground.

It is the fraction of the opposition's aircraft on the ground that can potentially be destroyed beyond repair (K-kill) in one day when one air force, unopposed by air defense, strikes the opposition's airfields. It is measured in aircraft killed per day divided by the total number of the opposition's aircraft in theater.

As can be seen in the exhibit, based aircraft are accounted for in three postures--in shelters, in revetments, and parked in the open--because their vulnerability to various types of munition are so vastly different in these postures.

Again, the data required for such a calculation are shown in Exhibit 7.

EXHIBIT 7 (U)

BASED AIRCRAFT ATTRITING POTENTIAL

TYPES OF DATA USED

TARGET	VULNERABILITY OF SHELTERS & REVETMENTS SPACING OF SHELTERS & REVETMENTS NUMBER OF SHELTERS & REVETMENTS NUMBER OF TARGET A/C
WEAPONS	NUMBER OF A/C OF EACH TYPE MUNITION LOADS FOR EACH A/C MUNITIONS STOCKPILE SORTIE RATES

CALCULATIONS

FRACTION OF TARGET A/C IN EACH BASING OPTION

NUMBER OF POTENTIAL A/C KILLS PER SORTIE FOR EACH BASING OPTION

TOTAL NUMBER OF POTENTIAL A/C KILLS PER DAY

FINALLY,

$$\text{BAAP} = \frac{\text{TOTAL NUMBER OF POTENTIAL A/C KILLS PER DAY}}{\text{TOTAL NUMBER OF TARGET A/C IN THEATER}}$$

Finally, I will discuss the POL Attriting Potential.

Again note that POL storage is accounted for in three postures--in surface tanks, horizontal subsurface tanks, and in vertical subsurface tanks--because their vulnerability is quite different.

The POL Attriting Potential is defined as the potential of an air force to destroy the opposition's POL storage capacity at fixed installations.

It is the fraction of the opposition's military and civilian POL which can potentially be destroyed in one day when one air force, unopposed by air defense, strikes the opposition's POL storage areas. It is measured in barrels of POL storage capacity destroyed per day divided by the total barrels of POL storage capacity in theater.

EXHIBIT 8 (U)

POL ATTRITING POTENTIAL

WORKING EQUATION

- THE POL ATTRITING POTENTIAL IS DEFINED AS:

$$\left(\begin{array}{c}\text{TOTAL POL STORAGE}\\\text{CAPACITY DESTROYED}\\\text{PER DAY}\end{array}\right) \div \left(\begin{array}{c}\text{TOTAL POL STORAGE}\\\text{CAPACITY IN}\\\text{THEATER}\end{array}\right)$$

- THE TOTAL POL STORAGE CAPACITY DESTROYED PER DAY IS CALCULATED BY SUMMING OVER ALL THE ATTACKING AIRCRAFT, THE PRODUCT;

$$\left(\begin{array}{c}\text{POL STORAGE CAPACITY}\\\text{DESTROYED PER SORTIE}\\\text{BY EACH ATTACKING}\\\text{AIRCRAFT TYPE}\end{array}\right) \times \left(\begin{array}{c}\text{SUSTAINED SORTIE}\\\text{RATE FOR EACH AT-}\\\text{TACKING AIRCRAFT}\\\text{TYPE}\end{array}\right) \times \left(\begin{array}{c}\text{NUMBER OF AT-}\\\text{TACKING AIR-}\\\text{CRAFT OF EACH}\\\text{AIRCRAFT TYPE}\end{array}\right)$$

- CALCULATE THE POL STORAGE CAPACITY DESTROYED PER SORTIE BY EACH ATTACKING AIRCRAFT TYPE, BY MAKING THE SUM, OVER ALL THE MUNITIONS TYPES CARRIED BY EACH ATTACKING AIRCRAFT, OF THE PRODUCT.

$$\left(\begin{array}{c}\text{NUMBER OF UNITS OF}\\\text{EACH MUNITION CARRIED}\\\text{BY A SORTIE}\end{array}\right) \times \left(\begin{array}{c}\text{EXPECTED POL STORAGE}\\\text{CAPACITY DESTROYED PER}\\\text{UNIT OF MUNITION}\end{array}\right)$$

- AND

$$\left(\begin{array}{c}\text{EXPECTED POL}\\\text{STORAGE CAPACITY}\\\text{DESTROYED PER}\\\text{UNIT OF MUNITION}\end{array}\right) = \left\{\begin{array}{c}\text{FRACTION OF}\\\text{SURFACE POL}\\\text{TANKS}\end{array}\right\} \times \left\{\begin{array}{c}\text{PROBABILITY}\\\text{OF DESTROYING}\\\text{A SURFACE POL}\\\text{TANK WITH ONE}\\\text{UNIT OF MUNI-}\\\text{TION}\end{array}\right\} \times \left\{\begin{array}{c}\text{AVERAGE}\\\text{CAPACITY}\\\text{OF A SUR-}\\\text{FACE POL}\\\text{TANK}\end{array}\right\}$$

$$+ \left\{\begin{array}{c}\text{FRACTION OF}\\\text{HORIZONTAL}\\\text{SUBSURFACE}\\\text{POL TANKS}\end{array}\right\} \times \left\{\begin{array}{c}\text{PROBABILITY}\\\text{OF DESTROYING}\\\text{A HORIZONTAL}\\\text{SUBSURFACE}\\\text{POL TANK WITH}\\\text{ONE UNIT OF}\\\text{MUNITION}\end{array}\right\} \times \left\{\begin{array}{c}\text{AVERAGE}\\\text{CAPACITY}\\\text{OF A}\\\text{HORIZONTAL}\\\text{SUBSURFACE}\\\text{POL TANK}\end{array}\right\}$$

$$+ \left\{\begin{array}{c}\text{FRACTION OF}\\\text{VERTICAL}\\\text{SUBSURFACE}\\\text{POL TANKS}\end{array}\right\} \times \left\{\begin{array}{c}\text{PROBABILITY}\\\text{OF DESTROYING}\\\text{A VERTICAL}\\\text{SUBSURFACE}\\\text{POL TANK WITH}\\\text{ONE UNIT OF}\\\text{MUNITION}\end{array}\right\} \times \left\{\begin{array}{c}\text{AVERAGE}\\\text{CAPACITY}\\\text{OF A}\\\text{VERTICAL}\\\text{SUBSURFACE}\\\text{POL TANK}\end{array}\right\}$$

The data needed for such a calculation is shown in the next exhibit.

EXHIBIT 9 (U)

POL ATTRITING POTENTIAL

TYPES OF DATA USED

TARGET	VULNERABILITY OF ABOVE & BELOW GROUND STORAGE TANKS SPACING OF STORAGE TANKS NUMBER OF EACH TYPE STORAGE TANK AVERAGE CAPACITY OF TANKS TOTAL STORAGE CAPACITY
WEAPONS	NUMBER OF A/C OF EACH TYPE MUNITIONS LOADS FOR EACH A/C MUNITIONS STOCKPILE SORTIE RATES

CALCULATIONS

FRACTION OF STORAGE CAPACITY IN EACH TYPE STORAGE
AMOUNT OF STORAGE DESTROYED OF EACH TYPE STORAGE PER DAY

TOTAL AMOUNT OF STORAGE POTENTIALLY DESTROYED PER DAY

FINALLY,

$$\text{POLAP} = \frac{\text{TOTAL AMOUNT OF STORAGE POTENTIALLY DESTROYED PER DAY}}{\text{TOTAL TARGET STORAGE CAPACITY}}$$

Using these four measures of the relative balance, illustrative calculations have been made for the Central Front in Europe. These calculations are presented in a classified report, "Comparison of Military Potential: NATO and the Warsaw Pact," (IDA S-435). One should note that the calculations presented in the report only illustrate the methodology. The data base upon which the calculations were based was not "official," but one which personnel at IDA have put together for this purpose. We tried to obtain realistic estimates of all the many kinds of data used; however, these may or may not be the same in detail as those used by our negotiating team in MBFR. We did not attempt to reconcile the data bases, which would be no small task.

In summary, we have developed four potential measures of effectiveness which might be used as analytic tools for force capability comparisons. They include both measures of weapon quality and force composition. They are neither as simple as a comparison of numbers of personnel, tanks, etc., nor as complex as "war games" or "simulations."

SUBJECT: The Heavy Lift Helicopter Cost and Operational Effectiveness Analysis

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AGENCY: USA Concepts Analysis Agency

I. INTRODUCTION

Background. - The Heavy Lift Helicopter Cost and Operational Effectiveness Analysis was performed by USA Concepts Analysis Agency to fulfill the requirements for a Concept Formulation Package contained in Army Regulation 1000-1, "Basic Policies for System Acquisition by Department of the Army." The objectives of the analysis were to:

Create mission profiles hinged to a set of three scenarios which highlight logically occurring transportation networks in order to determine the value added to the force by the heavy lift helicopter.

Describe the force structure, possible trade-offs, and implications of introducing several reasonable and effective levels of heavy lift helicopters into the Army.

Determine the net marginal cost over time of adding heavy lift helicopters to the force for comparison with the approved budget plan.

Missions. - The missions analyzed are depicted in Figure 1. These missions allowed the assessment of the complementary and competitive aspects of all modes of transportation in both logistical and combat support roles.

a. Logistics-Over-The-Shore. - The logistics-over-the-shore mission deals with the offloading of cargo ships using lighterage or helicopters. The cargo, which is either break-bulk or containerized, is moved over the beach to an inland marshaling area. In the three geographic areas specified by the scenarios, there are sufficient deep-water ports to support the movement requirement. A logistics-over-the-shore operation is necessary only if use of the ports is denied.

b. Port and Airfield Clearance. - The port and airfield clearance mission deals with the movement of containers and break-bulk cargo from a port or airfield to either a forward depot or a corps general support service area. The alternative transportation systems for this movement requirement are trucks and helicopters. If rail or pipeline assets are available to perform a portion (or all) of the movement, then analysis is limited to the portion which is not delivered by rail or pipeline.

c. Retail Delivery. - The retail delivery mission deals with the movement of containers and break-bulk cargo from the forward depots and corps general support service areas to the division rear areas. This mission occurs concurrently with the port and airfield clearance mission. The alternative transportation systems for this mission are trucks and helicopters. The retail delivery of bulk petroleum products is not examined.

d. Tactical Support. - The tactical support missions are other possible combat support and combat service support missions for the heavy lift helicopter which are distinct from the logistical missions discussed previously. A distinguishing characteristic of these missions is that time is an important consideration in determining how the movement will be performed. An example of this type of mission is the necessity to rapidly displace artillery.

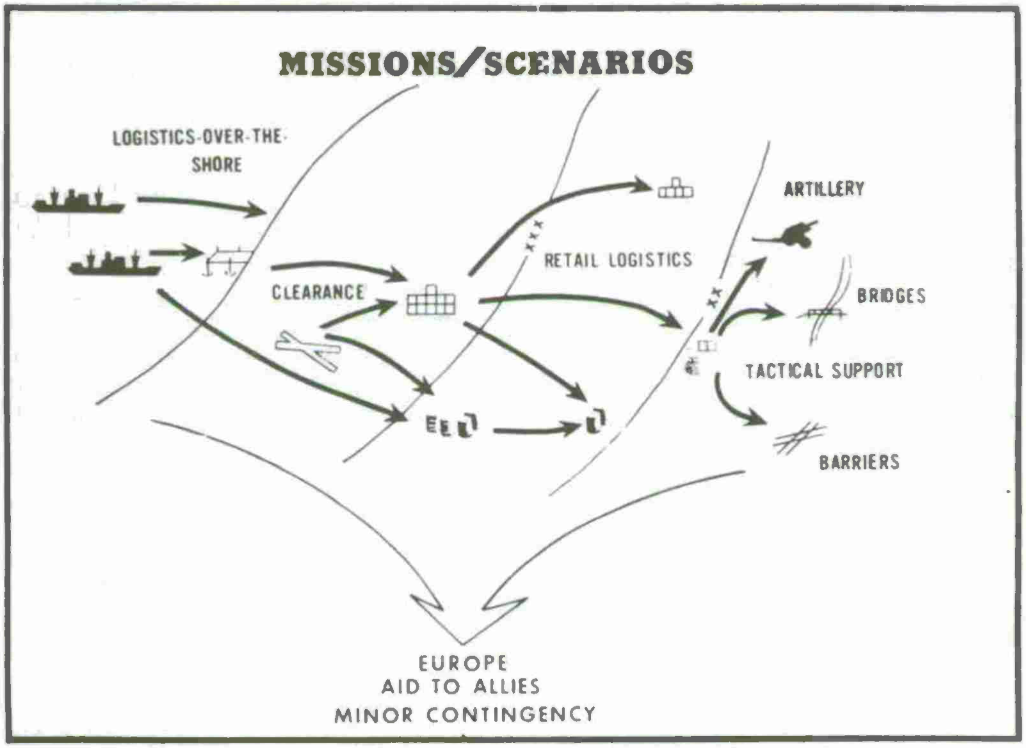

FIGURE 1, Missions and Scenarios

Scenarios. - The study directive required that three scenarios provide the environment for the mission analyses. The scenarios were generally stated as:

a. A major operation in either Europe or Northeast Asia.

b. A situation where assistance to allies is being provided.

c. Conduct of a minor contingency.

An analysis was first made to determine where each required scenario might realistically occur in the 1980-91 time frame. This was done in coordination with elements of the Army Staff and the combat developments community. Based upon Army plans and projected possible political developments, we selected Europe as the site for a major operation, the Middle East for an assistance to allied situation, and Latin America for a minor contingency. The force bases for the three scenarios were the planned forces for a conventional war in Europe during the 1980-91 time frame, a three-division force in the Middle East, and a one-division force in Latin America.

II. THE STUDY APPROACH

Evaluation Criteria. - We conducted a literature search and reviewed existing models to determine what evaluation criteria already existed for transportation systems. With this background, we formulated the following evaluation criteria:

a. The cost of transporting required amounts of cargo from given sources to desired destinations during a specified time period. The outcome is expressed as the family of transportation systems which minimizes the cost of accomplishing the movement requirement.

b. The time required to move a specified amount of cargo from given sources to desired destinations. The outcome is expressed as the family of transportation systems which minimizes the time required to accomplish the movement requirements.

c. The impact of adding heavy lift helicopters to families of transportation systems performing each of four missions under normal (steady-state) conditions.

d. The impact of adding heavy lift helicopters to families of transportation systems performing each of four missions under changing (transient) conditions.

e. The relative productivities and costs of competing helicopters.

f. Mission flexibilities provided by heavy lift helicopters which are not provided by other systems.

g. The relative vulnerabilities of the competing systems.

h. The impact of the heavy lift helicopter on the force structure.

i. The impact of the heavy lift helicopter on a constrained budget.

Development of the Methodology. - At the same time that we were establishing the missions and scenarios to be analyzed, we developed the study methodology. The study methodology called for 116 separate study tasks. These tasks ranged from defining vehicle productivity to modeling the system, performing sensitivity analyses, and writing the final report.

a. PERT Analysis. - A PERT analysis of the study tasks revealed that the time allowed for the study (ten months) made use of an existing model mandatory. There was not sufficient time both to develop a model capable of handling all the missions and scenarios and to perform the subsequent analysis. Therefore we intensified our review of existing models to identify the ones most applicable to our analysis.

b. Model Selection. - Our review lead us to the European Theater Network Analysis Model (ETNAM). This model is essentially a linear programing formulation of military theater logistic problems. It was originally developed for the European theater to insure that the model would be large enough to handle any other theater, regardless of the size or complexity of its transportation network. We had to modify ETNAM slightly to expand its capability. We called the modified model the Theater Network Analysis Model (TNAM).

Requirements for Additional Models. - The Theater Network Analysis Model provided the outputs necessary to satisfy the evaluation criteria relating to the minimum cost and time families of transportation systems operating under normal conditions. Additional models were required to develop inputs for Theater Network Analysis Model, to give an insight into the impact of HLH on families operating under non-steady-state conditions, and to determine the relative vulnerabilities of the competing helicopter systems. The actual models used are listed below:

a. ATLAS. - A Tactical Logistical and Air Simulation Model. A low-resolution computerized theater combat model.

b. Battalion Slice. - A Modular Force Planning System. Determines theater logistics/administrative workloads and units required to accomplish these workloads, based on a battalion-size theater slice.

c. CEM. CONAF Evaluation Model. A low-resolution computerized theater combat model; simulates command decisions on unit employment.

d. FASTALS. - Force Analysis Simulation of Theater Administration and Logistics Support Model. Computes time-phased logistics/administrative workloads for an active theater and rounds out the force with units to perform these workloads.

e. SMOBSMOD. Strategic Mobility Simulation Model. Inter-Theater movement capability estimator.

f. TNAM. - Theater Network Analysis Model. A modified version of the European Theater Network Analysis Model that provides a linear programing formulation of intra-theater logistics systems.

g. Aggregating Model. - Provides an analysis of the impact of network degradation on the costs of fielding a particular transportation family.

Interface Among the Models. The interface among the models is shown in Figure 2. These models were used for the European and Middle East scenarios only. The Latin America scenario did not require computer-aided analysis.

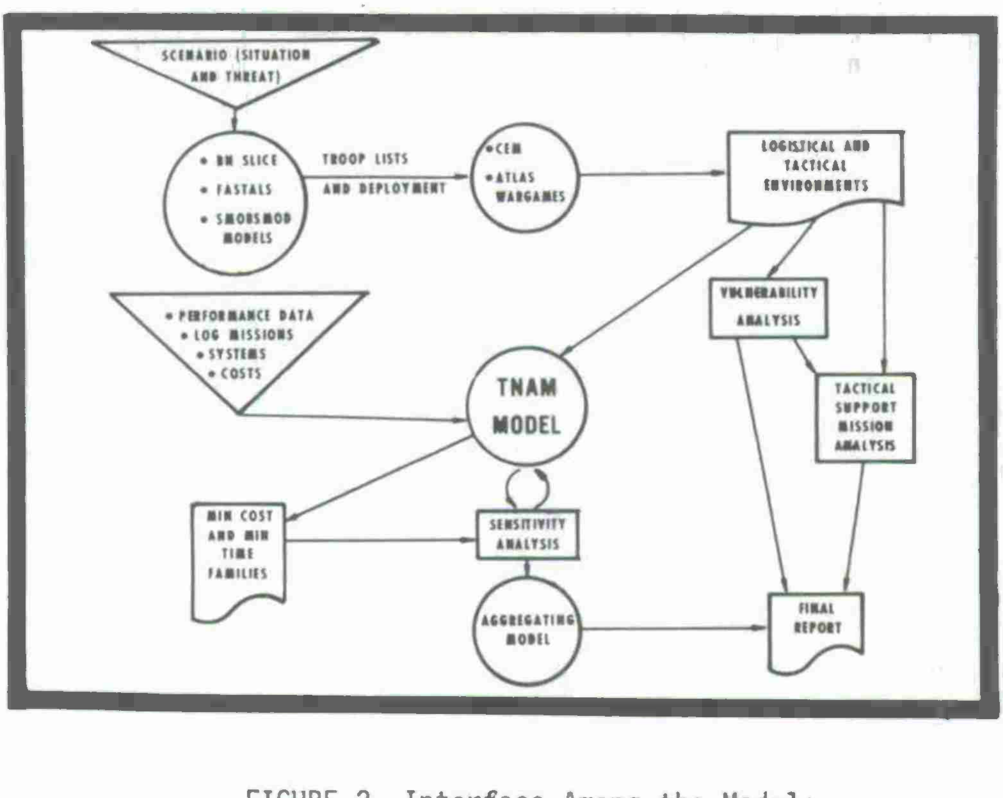

FIGURE 2, Interface Among the Models

a. Europe. - The Battalion Slice and FASTALS models were used to round out troop lists and provide logistical data for the European theater. These results were input to the CEM to obtain logistical locations for the placement of combat service support activities. This information, when combined with data on systems capabilities, costs and missions to be performed, formed the input to the Theater Network Analysis Model.

b. Middle East. - We used the SMOBSMOD for the Middle East analysis. It provided the times when the force elements closed and began requiring supplies, and the time-phased arrival of supplies into the theater by location. This data was input to the ATLAS wargame to determine the location of friendly and enemy forces, the combat activity each day, and the logical locations for combat service support acitivities. As in the European theater analysis, this information was combined with data on transportation systems and missions to form the input to the Theater Network Analysis Model.

c. Sensitivity Analysis. - The outputs from the Theater Network Analysis Model were those families of transportation systems that minimized either the cost or time of performing a particular movement requirement. The particular families selected by the model were highly dependent upon assumptions concerning the physical condition and availability of the highway network. As long as good roads were available, trucks were more economical than helicopters. When roads were severely degraded, helicopters were more economical than trucks. The problem was the determination of the frequency and duration of network degradation. To help us with this problem, we developed the Aggregating Model.

d. The Aggregating Model. - This model casts the transportation network as a two-state Markov chain with stationary transition probabilities. By varying the probabilities of network degradation and restoration, we were able to determine the circumstances that would cause us to be indifferent in our choice among transportation systems. That is, we could describe the circumstances that would make the long-run expected costs of the different systems equal to one another. The insights provided by this model formed the basis for our final report.

e. Other Analyses. - We supplemented the analysis of logistics missions with vulnerability analyses (air-to-air and ground-to-air) and the analysis of the capability of the heavy lift helicopter to perform tactical support missions. These analyses provided insights on the practicable uses of the heavy lift helicopter in a combat theater.

III. FORCE STRUCTURE IMPLICATIONS

Possible Quantities of Heavy Lift Helicopters. - The analysis showed that a decision to procure heavy lift helicopters could not be linked to a foundation of routine utility. Instead, these helicopters provided a hedge to extend the range of the transportation system to meet surge requirements. With this in mind, we identified reasonable quantities of heavy lift helicopters capable of supporting the forces in the three scenarios. When considering the possible missions for the heavy lift helicopter, the maintenance manpower and other support requirements, the aging of the current fleet, and the quantities that we had identified, we found that the heavy lift helicopter could be integrated into the force structure with virtually no increase in personnel spaces.

Force Capabilities. - Recall that one of our evaluation criteria was the value added to the force by the heavy lift helicopter. We were interested principally in how the heavy lift helicopter contributed to winning the war. We found that the contribution could be measured in only the Middle East scenario. There was no visible impact in the other two scenarios. The following paragraphs discuss our analysis of the Middle East scenario.

a. Base Case Analysis. - The Middle East scenario demanded early deployment of combat power, properly supported by logistics, against an enemy force advancing with some momentum. Crucial to the operation was the need to hold the forward destination airfield. The results of the ATLAS wargame showed that the necessity to deploy both combat and support units to the theater caused the combat power of the force to be marginal during the early days of the war. The enemy force was able to advance almost to within artillery range of the forward destination airfield before he was stopped. The depth of the enemy advance indicated that the planned deployment carried a high degree of risk. Therefore we examined two alternative ways to increase the combat power of the force earlier in the deployment schedule. The first alternative involved using heavy lift helicopters wherever feasible in lieu of other transportation systems. The second alternative was to increase the size of the strategic lift force with the quantity of C-5 aircraft equal in cost to the number of heavy lift helicopters used in the first alternative.

b. Use of Heavy Lift Helicopters. - The heavy lift helicopter has sufficient range to self-deploy to the Middle East from the United States. It does not require strategic lift support. Its use in the Middle East scenario eleminated the need for 22 support organizations and allowed the arrival of 7 additional support units to be deferred. The strategic lift capability freed by removing these units from the deployment list or deferring their deployment enabled combat units to be deployed at a faster rate. To assess the magnitude of the increase in combat power gained by use of the heavy lift helicopter, firepower scores for the combat elements of the force were computed for both the base case and the heavy lift helicopter case. The scores were then multiplied by the number of days that each combat element was in the theater until all combat forces had arrived. Measured in this fashion, the heavy lift helicopters case force had 15 percent more firepower then the base case force. Results from the ATLAS wargame, using the accelerated deployment schedule, indicated that the enemy advance would be stopped far enough from the forward airfield to prevent its interdiction by enemy artillery fire.

c. The Equal-Cost Alternative. - In this alternative, the strategic lift forces were increased by the quantity of C-5 aircraft equal in cost to the number of heavy lift helicopters used in the case just discussed. The increased lift capability did not provide as much increase in combat power as did use of the heavy lift helicopters because of sortie constraints at the destination airfields. That is, we had more strategic lift than could be accomodated. We did note, however, that if the sortie constraints were removed by either upgrading the airfields used or finding additional ones to use, the equal-cost quantity of C-5 aircraft provided the same increase in combat power as did use of the heavy lift helicopter.

d. Additional Considerations. - There are several points that a decision-maker must consider before choosing among the alternatives just discussed:

(1) The trade-off made between trucks and heavy lift helicopters was not a force trade-off. That is, the support units were not eliminated from the total force; they were eliminated from the deployment schedule. Should the war last longer than 45 or 60 days, it may be desirable to bring some of the original support units to the theater to avoid concentrating the logistical transport capability in a relatively small number of helicopters.

(2) Use of the heavy lift helicopters during the first 45 days of the war increased the theater requirements for petroleum products and maintenance manpower. The theater requirements for petroleum products were increased by 25%. The maintenance manpower requirements increased by 5500 man-hours per day. This latter requirement was within the organic capabilities of the heavy lift helicopter companies and did not necessitate provision of additional maintenance units.

IV. SUMMARY

Force Structure Implications. - The study showed that the heavy lift helicopter could be integrated into the force with little or no increase in required personnel spaces. It also showed that the capabilities offered by the heavy lift helicopter represented a hedge against a surge in requirements. These capabilities could not be considered as replacing any of the capabilities of the currently planned transportation systems.

The Value of Operations Research. - Operations research techniques were used extensively throughout the Heavy Lift Helicopter Cost and Operational

Effectiveness Analysis. Initially they were used to establish the study methodology and select the models to be used in the analysis. The PERT analysis of the study tasks showed that use of existing models was mandatory because of time constraints. Subsequently, within the study analysis itself, each model used and the integration of model outputs represented the application of operations research techniques. The use of these techniques allowed the value of the heavy lift helicopter to be measured for each of the evaluation criteria and provided a basis for presenting the results to the decision-makers in clear-cut management terms.

STUDY OF STANDARD ARMY MANAGEMENT LANGUAGE (SAML)

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BACKGROUND

The US Army uses several classification systems or management structures in the planning, programming, and budgeting of Army force structure, manpower, materiel and operating funds. These systems or structures, which may be characterized as management languages, comprise primarily those prescribed by the Office of the Secretary of Defense (OSD), i.e., the Five Year Defense Program (FYDP), Land Forces Classification System (LFCS), and the Defense Planning and Programming Categories (DPPC), as well as the Congressional budget appropriation structure (portrayed in the Army Management Structure (AMS)). These systems/structures all have different formats and purposes, resulting in a multiplicity and attendant incompatibility of languages in the management of Army forces and supporting resources.

Table 1 illustrates the four management languages. The FYDP is the basic OSD language for recording and controlling all approved forces, related resources, and budgetary data. The DPPC reflect an aggregation and different array of the same program elements (PEs) contained in the FYDP. The LFCS is a non-financial method for classifying Army force structure, manpower and materiel programs. The AMS, which includes a direct correlation in its coding logic between operations and maintenance budget appropriations and the FYDP, is the Army's internal resource management structure for programming, budgeting, accounting, and financial reporting.

The basic problem addressed in this paper derives from the fact that the Army is using three OSD languages for describing missions and functions of forces and activities. The FYDP and DPPC are closely related, but there is a lack of compatibility between the FYDP and LFCS. While the FYDP is the official program which summarizes approved plans and programs for the Department of Defense (DOD), Army forces have not been managed in their typical FYDP PEs but in force packages oriented to a functional or mission concept, such as is embodied in the LFCS. Although the LFCS is useful in planning and programming, it does not provide a meaningful bridge between programming and budgeting because it is a non-financial management language. The end result is a lack of standardization for management purposes within the Army, which complicates communication with OSD in various phases of the planning, programming and budgeting system (PPBS). There is a recognized need, therefore, for a management language to reflect Army roles, missions, organization and functions so that the working language employed by Army planners and programmers coincides with the financial management language to control resource application.

Table 1

PRINCIPAL MANAGEMENT LANGUAGES

FIVE YEAR DEFENSE PROGRAM

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Prog. 1 Strategic Forces	Prog. 2 General Purpose Forces	Prog. 3 Intel. & Communications	Prog. 4 Airlift/ Sealift	Prog. 5 Guard & Res Forces	Prog. 6 R&D	Prog. 7 Central Supply and Maintenance	Prog. 8 Training, Medical & Other General Personnel Activities	Prog. 9 Admin & Associated Activities	Prog. 0 Support of Other Nations

DEFENSE PLANNING AND PROGRAMMING CATEGORIES[a]

Strategic Forces	General Purpose Forces		Auxiliary Forces				Mission Support Forces				Central Support Forces							Individuals			Miscellaneous Costs	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
Def Forces	Land Forces	Mobility Forces	Intel & Security	Commo	R&D	Spt to Other Nations	Res Comp Spt	Base Opn Spt	Force Spt Tng	Command	Base Opn Spt	Med Spt	Pers Spt	Ind Tng	Command	Log	Fed Agy Spt	Transients	Patients and Prisoners	Trainees Students & Cadets	Ret Pay	Contingencies

LAND FORCES CLASSIFICATION SYSTEM

DIV FCS	SPECIAL MISSION FORCES								GENERAL SUPPORT FORCES								[illegible]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(15)
Division Force Packages	CONUS Air Defense Force	Defense Forces	Missile Forces	Strat Intel & Sec	Strat Commo	DOD & Joint Activities	Other Service Spt	Free World Spt	Trng Estab.	Spt Estab.	Log Estab.	Mvmts Spt	Cmbt Dev	R&D	Hq & Field Activities	Theater Spt	Individuals

AMS (BUDGET APPROPRIATIONS)

		PROCUREMENT APPROPRIATIONS													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
MPA	OMA[c]	Air-Craft	Missile	Weapons-Tracked Vehicles	Ammo	Other	RDTE	MCA	NGPA	OMARNG	RPA	OMAR	MCARNG	MCAR	NBPRP

[a]Excludes subcategories non-applicable to Army

PURPOSE AND OBJECTIVE

This paper presents a concept for a Standard Army Management Language (SAML) to be used for the planning, programming, budgeting and overall management of Army force structure, manpower, materiel, and operating funds. The objective is to improve peacetime management of Army forces and supporting resources in the light of the Army's wartime roles and missions and to standardize and simplify communications within the Department of the Army (DA) and between Headquarters, Department of the Army (HQ DA) and OSD.

SAML CONCEPT

The SAML concept is based essentially on absorption of the LFCS into the FYDP. The concept encompasses significant changes in the current PE structures and definitions of the FYDP (except those pertaining to Research and Development). These include establishment of a SAML PE coding logic which provides identification for geographic area location for Active Army forces, Reserve component identification for Army National Guard (ARNG) and US Army Reserve (USAR) forces, major force packages, and unit and functional support. Current FYDP PE definitions are expanded to portray the types of units in the force structure associated with each PE. PE definitions are categorized in accordance with the DPPC rather than current FYDP categories. Units are realigned at PE level within and between FYDP programs to provide a more meaningful distinction between combat and support forces. An audit trail is established from existing management languages to SAML at PE level for each Unit Identification Code (UIC) in the force structure.

The SAML PE structure for Active Army forces and related resources is illustrated in Table 2. It is based on the five numeric positions of the existing FYDP PE code and a sixth position "A", designated by DOD for all Army PEs. The first position provides major program identification at the highest level of information aggregation. The second position provides major subprogram aggregation by related groups of forces, activities, or functional programs. The third position provides for force aggregations coded by geographic area locations. The fourth position incorporates and codes LFCS force categories and, in the case of FYDP Programs 2 and 5, Force Plan (FPLAN) codes for the Division Forces category of the LFCS. The fifth position identifies the lowest level of FYDP aggregation, i.e., the specific types of units and functional support elements composing the force categories and force packages associated with the fourth position. The "A" in the sixth position indicates a DOD component identifier for the Army. In effect, the SAML concept provides a PE structure which utilizes the FYDP PE code to convey meaningful and standardized information at all levels of PE aggregation for use by Army force, manpower, and materiel planners as well as financial managers.

One of the features of the SAML concept is to realign Program 5, Guard and Reserve Forces, along the lines of Program 2, General Purpose forces, to enable a meaningful comparison in so far as possible between Active Army General Purpose Forces and counterparts in Army Reserve component forces. The SAML PE structure for Program 5 is comparable but not

Table 2

SAML PE STRUCTURE — ACTIVE ARMY

Position	Purpose
• First	Major program identifier
• Second	Major subprogram identifier
• Third	Geographic area identifier
• Fourth	Major force package identifier
• Fifth	Unit and functional support identifier
• Sixth	A - DOD component identifier for Army

identical to the structure shown in Table 2. While the second position of the PE code provides major subprogram aggregations, they are related to several pertinent FYDP programs for the Active Army. Also, the PE structure for Program 5 must be capable of differentiating between ARNG and USAR missions and elements, because these require separate identification in the AMS budget appropriation structure. Since all Reserve component units and activities can be related to the Continental United States (CONUS) or its non-contiguous states and territories, the third position of the PE code is used to provide Reserve component identification rather than geographic area location.

The SAML PE coding logic is applicable to all FYDP programs with the notable exception of Program 6, Research and Development, and a few subprograms contained in Program 2, General Purpose Forces, and Program 3, Intelligence and Communications. Program 6 contains approximately 200 PEs and would require an alphanumeric coding in the fifth position of the PE code for application of the SAML PE coding logic. While this does not pose an insurmountable problem from a data systems standpoint, it would represent a major deviation from overall FYDP as well as SAML PE coding logic. A more important consideration is the Congressional requirement to retain in the PE coding logic Research, Development, Test and Evaluation (RDTE) Budget Activities. These appear in the third position of the FYDP PE code and include: (1) military sciences, (2) aircraft and related equipment, (3) missiles and related equipment, (4) military astronautics and related equipment, (5) ships, small craft and related equipment, (6) ordnance, combat vehicles and related equipment, (7) other equipment, and (8) program-wide management and support. The other exceptions relate to the Unified Commands, Operational Systems Development, and Other subprograms of Program 2 and Program 3I, Intelligence and Security. PEs in these subprograms are either integral parts of DOD-wide subprograms or, in the case of Operational Systems Development, too numerous for adaptation of the SAML PE coding logic.

APPROACH AND METHODOLOGY

The basic operations research methodology employed in the SAML study included establishment of the FYDP as the basis for the SAML and subdivision of the effort into two phases. SAML I concentrated on restructure of FYDP Programs 2 and 5, comprising the General Purpose Forces of the Active Army and the Reserve Components, to establish a framework for the SAML. SAML II concentrated on restructure of the other FYDP programs to complete the development of the SAML.

In SAML I the initial effort involved collection and analysis of literature pertaining to the FYDP, DPPC, LFCS, AMS, and other basic features of the PPBS. The documentation included computerized output data related to force planning and accounting and budgeting for use in subsequent analyses. Concurrent effort entailed development of several alternative major program schemes, with selection of a scheme for further development into a detailed SAML PE concept based on absorption of the LFCS into FYDP Programs 2 and 5.

The next step in SAML I was to develop several alternative SAML PE structures in detail, with the objective of incorporating the LFCS into a revised structure for FYDP Programs 2 and 5. A concomitant objective was to realign Program 5 in such a manner as to bring the Reserve Components program structure into consonance with the Active Army structure. These actions were accomplished, in part, through the preparation of numerous tables throughout this phase of the study reflecting an overall PE structure for Programs 2 and 5 and establishing a correlation between the two programs. As problem areas were identified in the evolving PE structures, further fact-finding was conducted with particular reference to the delineation of combat and support forces and examination of functional areas that might be affected by changes in the FYDP structure or which could not be managed within the context of the current structure.

Basic decisions by the Army Study Advisory Group (SAG) led to development of proposed PE structures in detail, including preparation of PE codes and definitions applicable to the realigned structure for Programs 2 and 5. The logic of the proposed changes in FYDP language structure and content, called SAML, was examined empirically and an audit trail developed to permit correlation of the current FYDP with SAML at PE level. The proposed SAML was defined and documented in handbook form comparable to the OSD FYDP Handbook.

The principal task in the SAML II study was to develop a concept for restructuring FYDP programs other than 2 and 5, which would be compatible with the SAML I concept and absorb the LFCS in an acceptable manner to the Army Staff planners without adverse impact on language requirements of financial managers. The methodology included analysis in depth of each FYDP program from the standpoint of structure and content, using updated documentation from the Force Accounting System (FAS) and other sources to determine the application of Force Plan (FPLAN) codes, program element codes (PECODs), and AMS codes (AMSCOs) to each UIC in the Active Army force structure. A by-product of the analysis was identification of apparent data discrepancies. A related task was to realign assignment of Force Plan (FPLAN) codes to UICs in order to correct anomalies from a management standpoint and facilitate absorption of the LFCS into the FYDP. The concept was portrayed in tables displaying several alternative PE structures for certain FYDP programs and accompanying PE indexes of codes and titles. The effort involved editing and annotation of computer printouts prepared in accordance with General Research Corporation (GRC) specifications; preparation of analytical work sheets displaying rearrangement of data applicable to UICs within each FYDP program; and coordination with program managers, planners, manpower managers, and data systems staff personnel.

As in the case of SAML I the PE structures were then developed in detail, accompanied by preparation of PE codes and definitions and an audit trail depicting correlation of the current FYDP with SAML at PE level. The proposed completion of a standard management language was defined and documented in handbook form comparable to the FYDP Handbook.

APPLICATION OF THE SAML CONCEPT TO PROGRAMS 2 and 5

Program 2, General Purpose Forces

Table 3 displays the realigned SAML PE structure for Program 2. As stated previously, the first position provides the major program identifier. The second position provides four major subprogram identifiers. Although geographic areas (coded in the third position) are applied to the subprogram for Unified Command Headquarters, full application of the concept is used only in Subprogram 22XXX, Forces (Army). The third position provides for seven identifiers coded for geographic areas as shown. The fourth position provides force aggregations by major force packages (FPLAN) and codes the LFCS within the Program 2 structure for those force packages and PEs pertaining to General Purposes Forces. It also includes an "Other Forces" package to provide expansion capability for categorization of possible future force packages. The fourth position codes the three force categories of the LFCS: (1) Category A, Division Forces, (2) Category B, Special Mission Forces, and (3) Category C, General Support Forces (with a change in terminology to Theater/CONUS Support). The fifth position identifies the lowest level of FYDP aggregation, i.e., the specific elements comprising the three force packages of the LFCS which are aggregated in the fourth position. Division Forces packages are expanded in the fifth position to provide for explicit identification at PE level within each Division FPLAN not only for combat units but for functional type support units as well. This is done in order to preserve the integrity of the Division Forces concept. Certain force units, such as communication, intelligence, medical, and logistical, are shifted from FYDP Programs 3, 7, and 8 into Program 2. These units are identified as clearly and definitely falling within the category of "Division Forces," i.e., contributing directly and primarily to the support of Division Forces in combat.

Program 5, Guard and Reserve Forces

Table 4 displays the proposed realigned SAML PE structure for Program 5. It is possible to realign major parts of Program 5 (especially Division Forces) along the lines of Program 2 insofar as ARNG and USAR missions and elements are comparable to Active Army missions and elements in Program 2. However, since the ARNG and USAR have some unique missions, the proposed PE structure for Program 5 requires a different approach. First, included within Program 5 are certain missions and functional aggregations which for the Active Army General Purpose Forces in Program 2 are carried in other FYDP programs, i.e., 1, 7, 8, and 9. Second, the PE structure for Program 5 must be capable of differentiating between ARNG and USAR missions and elements, since these must be separately identified in the AMS budget appropriation structure. Third, although all ARNG and USAR units are located in CONUS or noncontiguous states and territories in peacetime, Reserve component General Purpose forces can be identified with more Division Force packages than can comparable Active Army elements in the light of wartime missions and deployments. Finally, the Theater/CONUS Support Category (called General Support in Program 5) of the Reserve components includes missions and elements that are not germane to Program 2. These unique activities include such

Table 3

STANDARD ARMY MANAGEMENT LANGUAGE - PROGRAM ELEMENT STRUCTURE, PROGRAM 2, GENERAL PURPOSE FORCES

1st Position	2nd Position	3rd Position	4th Position	5th Position	6th Position
Major Program Identifier	Major Subprogram Identifier	Command/Area Identifier	Major Force Package Identifier (FPLAN Code)	Unit and Functional Support Identifier	DOD Component Identifier
2 - General Purpose Forces	1 - Unified Command HQ Unified Command HQ are identified by COMMAND/AREA (3d Position) Special Mission Forces (4th Position) and 8 as an element identifier (5th Position) 21188A - ALCOM 21288A - LANTCOM 21289A - CINCLANT ABN CMD Post 21385A - USEUCOM - COMMO 21388A - USEUCOM 21488A - PACOM 21588A - USSOUTHCOM 21685A - USREDCOM - COMMO 21688A - USREDCOM	1 - Alaska 2 - Atlantic 3 - Europe 4 - Pacific 5 - South 6 - CONUS 7 - Worldwide	Division Forces 1 - Europe Force (ANE) 2 - Europe Reserve Force (ANC) 3 - Active Strategic Reserve Force (AVC) 4 - Pacific Reserve Force (APC/AFQ) 5 - Korea Force (AFK) 6 - Southeast Asia Force (APS) 7 - Other Forces (-)	Division Forces (4th Position Nos.1-7) 1 - Divisions 2 - Separate Bdes/Rgts 3 - Nondivisional Combat Units 4 - Division Forces Other Support 5 - Division Forces Communications Spt 6 - Division Forces Intelligence Support 7 - Division Forces Medical Support 8 - Division Forces Logistics Support 9 - Division Forces Administrative Support	A
	USEUCOM - COMMO and USREDCOM-COMMO are identified by COMMAND/AREA (3rd Position). Special Mission Forces (4th Position) and Base Communications, 5, in the 5th Position		8 - Special Mission Forces	Special Mission Forces (4th Position No. 8) 1 - Theater Air Defense Forces 2 - Theater Missile Forces 3 - Special Operations Forces 4 - Support to Other Services 5 - Defense Forces 6 - Special Mission Support	
	2 - Forces (Army) Includes all TOE/TD Units not included in other major programs		9 - Theater/CONUS Support	Theater/CONUS Support (4th Position No. 9) 3 - Force Related Training 4 - Logistic Support 5 - Base Communications 6 - Base Operations 7 - Medical Support 8 - Command 9 - Administrative Support	
	3 - Operational Systems Development (Aggregation 23XXX) Serially numbered in the 4th and 5th Positions and reflects dollars only.				

Table 3 (continued)

STANDARD ARMY MANAGEMENT LANGUAGE - PROGRAM ELEMENT STRUCTURE, PROGRAM 2, GENERAL PURPOSE FORCES

1st Position	2nd Position	3rd Position	4th Position	5th Position	6th Position
Major Program Identifier	Major Subprogram Identifier	Command/Area Identifier	Major Force Package Identifier (FPLAN Code)	Unit and Functional Support Identifier	DOD Component Identifier
	23018A - Shillelagh				
	23019A - Main Battle Tank				
	23023A - Land Combat Spt System				
	23024A - Heavy Antitank Assault Weapon System (TOW)				
	23025A - Cheyenne - AH-56A				
	23026A - Tactical Fire Direction System (TACFIRE)				
	23027A - Medium Antitank Assault Weapon System (DRAGON)				
	23029A - Surveillance, Target Acquisition and Night Observation (STANO) Operational Development				
	23031A - SAM HAWK/HAWK Improvement Program				
	23032A - CHAPARRAL/VULCAN				
	23033A - LANCE				
	23034A - PERSHING				
	23035A - M60 - A1 Tank Product Improvement Program				
	8 - Other (Current FYDP Nos.)				
	28010A - Joint Tactical Communications Program (TRI-TAC)				
	28011A - JCS Directed and Coordinated Exercises				
	28012A - Defense Special Projects Group (DSPG)				
	28014A - Combat Support Communications				
	28015A - Combat Developments				

Table 4

STANDARD ARMY MANAGEMENT LANGUAGE - PROGRAM ELEMENT STRUCTURE, PROGRAM 5, GUARD AND RESERVE FORCES

1st Position	2nd Position	3rd Position	4th Position	5th Position	6th Position
Major Program Identifier	Major Subprogram Identifier	Reserve Component Identifier	Major Force Package Identifier (FPLAN Code)	Unit and Functional Support Identifier	DOD Component Identifier
5 - Guard and Reserve Forces	1 - Strategic Forces (Defensive) 2 - General Purpose Forces 7 - Central Supply and Maintenance 8 - Training, Medical and Other General Personnel Activities 9 - Administration and Associated Activities	2 - US Army National Guard 3 - US Army Reserve (Or any two alternate numbers if required.)	Aggregation 512 Strategic Forces (Defensive) 1 - CONUS Air Defense Force Aggregation 52X Division Forces 1 - Europe Force (ANE) 2 - Europe Reserve Force (ANC) 3 - Active Strategic Reserve Force (AVC) 4 - Pacific Reserve Force (APC/APQ) 5 - Korea Force (APK) 6 - Reserve Components Europe Force (AVE) 7 - Reserve Components Pacific Force (AVQ) 8 - Reserve Components Other Theater Force (AVX) Aggregation 52X 9 - Special Mission Forces Aggregations 57X, 58X, 59X 9 - General Support	CONUS Air and Missile Defense (4th Position, No. 1, AGG. 512) 1 - Theater Air Defense Forces (ARNG ONLY) Division Forces (4th Position, Nos. 1-8, AGG. 52X) 1 - Divisions 2 - Separate Bdes/Rgts 3 - Nondivisional Combat Units 4 - Division Forces Other Spt. 5 - Division Forces Commo Spt. 6 - Division Forces Intel. Spt. 7 - Division Forces Medical Spt. 8 - Division Forces Logistics Spt. 9 - Division Forces Administrative Spt. Special Mission Forces (4th Position, No. 9, AGG. 52X9) Aggregation 52X9 3 - Special Operations Forces 4 - Support to Other Services 5 - Alaska Defense Force 6 - Caribbean Defense Force 7 - Iceland Defense Force 8 - Panama Defense Force General Support (4th Position, No. 9, AGG. 57X, 58X, 59X Aggregation 57X9 1 - Depot Maintenance Aggregation 58X9 1 - Individual Ready Reserve 2 - Recruit Training 3 - Force Related Training 4 - Flight Training 5 - Professional Training Aggregation 59X9 1 - Mobilization Base and Training Units 3 - Intelligence Support 5 - Base Communications 6 - Base Operations 7 - Medical Support 8 - Command	A

elements as Individual Ready Reserve and Mobilization Base and Training Units.

APPLICATION OF THE SAML CONCEPT TO OTHER FYDP PROGRAMS

The underlying concept of the SAML II study is to extend the overall PE coding logic adopted for FYDP Programs 2 and 5 in SAML I to the other programs to the maximum extent practicable to absorb the LFCS in toto and achieve standardization throughout the Army's portion of the FYDP. The concept also provides for additional or more explicit visibility in the FYDP structure for resources which are subject to intensive programming/budgetary review by OSD/Office of Management and Budget and the Congress, or which encompass management problems calling for structural changes in management language.

The SAML II concept encompasses a PE coding logic in which the first, third and fourth positions of the PE structure, i.e., major program, geographic area, and major force package identifiers, respectively — are relatively fixed. Since all Division Forces should have been accounted for in Programs 2 and 5, it appears that only digit 8, Special Mission Forces, or digit 9, Theater/CONUS Support, should be used in the fourth position of the PE structures for all other programs. Accomplishment of appropriate visibility in all programs is achieved by expansion of major subprograms in the second position in concert with use of discrete unit and functional support identifiers in the fifth position. Illustrations of application of the concept are shown in Table 5 for Program 1, Strategic Forces, and Table 6 for Program 7, Central Supply and Maintenance. Program 1 should comprise only Special Mission Forces; hence, the use of digit 8 in the fourth position. Program 7 should include only Theater/CONUS Support, calling for use of digit 9 in the fourth position.

AUDIT TRAIL

The audit trail from existing management languages to the proposed SAML at PE level is illustrated in Table 7. The table shows the current FYDP PE code (PECOD) and proposed SAML PECOD for each UIC in the force structure. All remaining data elements in Table 7, other than the Interim Force Identifier (INFID), are in broad use in Army ADP applications. The INFID was developed to code the DPPC. A letter is used in the first position of this three-character code to designate major category; the second position is the SAML geographic area identifier; the third position identifies subcategory within category. The INFID associated with the third PE listed in Table 7 is interpreted below to illustrate use of the code:

U - Auxiliary Forces
3 - Europe
4 - Support to Other Nations (the fourth subcategory within Auxiliary Forces in the DPPC)

Table 5

STANDARD ARMY MANAGEMENT LANGUAGE — PROPOSED PROGRAM ELEMENT STRUCTURE, PROGRAM 1 — STRATEGIC FORCES

1st Position	2nd Position	3rd Position	4th Position	5th Position	6th Position
Major Program Identifier	Major Subprogram Identifier	Geographic Area Identifier	Major Force Package Identifier	Unit and Functional Support Identifier	DOD Component Identifier
1 - Strategic Forces	2 - Defensive Forces (SAFEGUARD)	1 - Alaska 2 - Atlantic 3 - Europe 4 - Pacific 5 - South 6 - CONUS 7 - Worldwide	8 - Special Mission Forces	Special Mission Forces (4th Position, No. 8) Aggregation 12X8 4 - SAFEGUARD Defense System 5 - SAFEGUARD Communications 6 - SAFEGUARD Base Support 7 - SAFEGUARD Logistics Support	A

Table 6

STANDARD ARMY MANAGEMENT LANGUAGE - PROPOSED PROGRAM ELEMENT STRUCTURE, PROGRAM 7, CENTRAL SUPPLY AND MAINTENANCE

1st Position	2nd Position	3rd Position	4th Position	5th Position	6th Position
Major Program Identifier	Major Subprogram Identifier	Geographic Area Identifier	Major Force Package Identifier	Unit and Functional Support Identifier	DOD Component Identifier
7 - Central Supply and Maintenance	3 - Central Supply (Non-IF) 4 - Depot Maintenance (Non-IF) 5 - Supply, Maintenance, and Service Activities (IF) 6 - Other	1 - Alaska 2 - Atlantic 3 - Europe 4 - Pacific 5 - South 6 - CONUS 7 - Worldwide	9 - Theater/CONUS Support (4th Position, No. 9)	Theater/CONUS Support) (4th Position, No. 9) Aggregations 73X9, 74X9, 75X9, 76X9 Aggregation 73X9 1 - Supply Depot Operations (Non-IF) 2 - Inventory Control Point Operations 3 - Procurement Operations 4 - Second Destination Transportation 5 - Industrial Preparedness 6 - Base Operations 8 - Command 9 - Logistic Support Activities Aggregation 74X9 3 - Depot Maintenance (Non-IF) 4 - Maintenance Support Activities 7 - Training Aggregation 75X9 1 - Supply Depots Operations (IF) 2 - Revenues (Supply Depots) (IF) 3 - Depot Maintenance (IF) 4 - Revenues (Depot Maintenance) (IF) 5 - Armament Facilities (IF) 6 - Revenues(Armament Facilities) (IF) 7 - Missile Facilities (IF) 8 - Revenues (Missile Facilities) (IF) Aggregation 76X9 1 - Production Base Support	A

Table 7

EXTRACT FROM AUDIT TRAIL

FYDP PECOD	SAML PECOD	FPLAN	INFID	UIC	BR	UNTDS
12514A	12684A	CRC	S61	W2ZAAA		OFC SAFEGUARD SYSTEM
43112A	43692A	CKX	G69	W2DUAA		TML PAC NW OUTPORT
28013A	02381A	BME	U34	WGNFAA	FA	DET MSL WHD SPT-PERSH

CONCLUSION

The SAML concept provides a basis for a solution of the management language problem by amending and improving the PE structures and definitions of the FYDP in such a manner that it can be used by Army planners and financial managers for multiple purposes in various phases of the PPBS and accounting and financial reporting. With the elimination of the LFCS as a separate language, SAML is designed to standardize and simplify communications within DA and between HQ DA and OSD. It also affords a more purposeful delineation of peacetime manpower and dollar resources as they relate to the Army force structure on a wartime mission basis.

A VERY HIGH LEVEL LANGUAGE (VHLL) GENERATOR FOR APPLICATION TO ARMY PLANNING PROBLEMS

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INTRODUCTION

Systems analysis might be the nuclear weapon of the cold war between the services and OSD—it has never been used, but we couldn't survive without it. There can be no doubt that a great deal of systems analysis has been done in the last ten years—some very good work and some not so good (perhaps too few recognize the difference)—and much of this work has not been as useful as the time, effort, and money expended on it would suggest. In some cases study results have not reached those in authority to take the required action. In many cases the credibility of analytical results has been impaired by lack of understanding or communication between analysts and decision makers. Some analytical systems have taken so long to become operational that questions they were designed to address have changed or have been settled by other means.

This paper describes the use of very high level languages (VHLL) as one means of reducing the problems of communication, credibility and response time. Language generation techniques are described which reduce the effort required to implement and maintain a VHLL. Applications of very high level languages are discussed. Some observations relating to operations research-systems analysis are given. And recommendations relating to a unified Army planning structure are presented.

VERY HIGH LEVEL LANGUAGES

Very high level languages (sometimes called problem oriented languages) are characterized by their simplicity relative to high level languages such as FORTRAN or COBOL. They allow users with little training in the operating techniques of particular computer systems to successfully operate relatively large and complex modeling or data processing systems. They are usually custom designed for specific applications by specific users as in the case of the AFFORD and METOFOR system languages, discussed in this section. Such languages may be designed to use words or statements already familiar to analysts in their own fields of specialization.

The advantages of using very high level languages include significant reductions in the amount and the complexity of the programming code required of the user, with corresponding reductions in both the time required for programming and the number of errors introduced by the user in the process of setting up a program. A disadvantage of using VHLL in the past has been the time and effort required to develop the language initially, compared with the amount of use it is expected to have.

The ultimate goal of very high level languages is to give the end user direct contact with and access to the full analytic power of the computer. By analogy, electronics engineers have succeeded very well in giving the average American access to the Washington Redskins or the New York Jets in living color in his own living room and without the (continuous) aid of a technician. Three or four knobs control all of the complex circuitry behind the screen. Statements in a VHLL are the knobs which control the operations of large computerized analytical systems.

The AFFORD Force Planning Language

The AFFORD Force Planning Language (AFPL) was developed in 1971 by analysts at the Research Analysis Corporation and later implemented at the US Army Concepts Analysis Agency, Bethesda, Maryland, on their UNIVAC 1108 computer. The AFFORD system consists of three principal independent models which provide different phases of analysis in forming, applying and evaluating alternative US general purpose force structures.

The AFPL is implemented through the AFFORD Control Program [1] which incorporates the three independent models in overlay form. The user may execute any of the three models or he may enter, modify or report the input or solution data for any of the models through the relatively simple instructions of the AFPL.

Figure 1 shows the instruction set of the AFFORD force planning language. The action or operation initiated by each instruction is given in the column at the right. The user operates the system interactively by entering either the full name or the abbreviation of the instruction he wishes to execute. The DISPLAY and MODIFY instructions operate on variables or arrays which contain the input and solution data for each of the models. Data variables, arrays and subscripts have names familiar to force planners as illustrated in Fig. 2. The data are stored in labeled or NAMEed library files which may be created, loaded (LIBRARY), or SAVEed as desired. The REPORT and DISPLAY instructions provide a variety of reporting and documenting options using input and solution data. One interesting feature of the AFFORD System is that in some cases, solution data from one model becomes input data to another model processed automatically through the data library by the Control Program.

Figure 3 shows an example AFPL program.

THE METOFOR FORCE EVALUATION LANGUAGE

The METOFOR Force Evaluation Language (MFEL) was developed in 1974 by General Research Corporation for use with the VGATES II force evaluation model. This language includes an arithmetic processor and special input/output operations which allow the user to read, reformat and write standard data files. The user may also create, save, restore and/or modify catalogued library files. The MFEL is an interactive interpretive language currently operating on the UNIVAC 1108 computer.

Instruction	Abbreviation	Function
NAME.	N.	Specify a name or title for a library
LIBRARY.	L.	Specify a library to be created or loaded
DISPLAY.	D.	Display data from the current library
INDEX.	I.	Print an index of the current library
MODIFY.	M.	Enter, write out or modify data (Default instruction)
SAVE.	S.	Save (store) the current library
AFG.	A.	Execute the Alternative Force Generator (AFG)
FORCAP.	F.	Execute the Force Application Component (FORCAP)
VGATES.	V.	Execute the VGATES Combat Simulation
REPORT.	R.	Print specified AFFORD reports
END.	E.	Terminate Control Program execution

COMMENTS ARE INSERTED BY LEAVING THE FIRST COLUMN BLANK

Fig. 1 Instruction Set of the AFFORD Force Planning Language, AFPL

IPRIOR (MSSN, SITU)

IPRIOR is the priority associated with each mission situation.

MSSN is a subscript class containing missions 1 through 10.

SITU is a subscript class containing situations 1 through 6.

GPFCON (GPFS, 2)

GPFCON contains the lower and upper bounds for each general purpose force component.

GPFS is a subscript class containing each general purpose force - e.g.:

ADVA Army Divisions Active.

ADVR Army Divisions Reserve, etc.

Fig. 2 Example AFFORD Force Planning Language Data Arrays

```
        LOAD THE LIBRARY OF RUN V FROM THE HIGH LEVEL
        THREAT SCENARIO.

LIBRARY.     RUN V

        CHANGE THE LOWER AND UPPER BOUNDS ON ACTIVE
        ARMY DIVISIONS TO 1.0 AND 4.0, RESPECTIVELY, AND
        ELIMINATE THE RANGE ON ACTIVE MARINES.

GPFCON( ADVA MCVA ) = 1.0, 4.0, 2*0.0

        EXECUTE THE AFG (ALTERNATIVE FORCE GENERATOR)
        TO GENERATE A NEW SET OF ALTERNATIVE FORCES.
        THEN EXECUTE THE FORCAP (FORCE APPLICATION MODEL)
        ON THE FIRST FORCE (THE LEAST COST FORCE)
        TO DETERMINE THE STATIONING, READINESS AND
        MISSION ASSIGNMENT OF EACH GENERAL PURPOSE
        FORCE COMPONENT.

AFG.
FORCAP. 1

        REPORT THE RESULTS OF BOTH RUNS AND DISPLAY
        THE LIBRARY FOR DOCUMENTATION.
        FINALLY, SAVE THE LIBRARY AS RUN V (REVISED).

REPORT. AFG FORCAP.
DISPLAY.
NAME.   RUN V (REVISED)
SAVE.

END.
```

Fig. 3—Example AFFORD Force Planning Language Program

Figure 4 contains a summary of MFEL operations. These operations are performed interactively by the user at a computer terminal with immediate response.

The METOFOR force evaluation language is of particular interest in this paper because it was created by a language generator.

THE LANGUAGE GENERATOR

The language generator is a program which writes or generates the source code for a second program which interprets and executes statements of a very high level language. The first program, the generator, is executed to create a new VHLL or to modify an existing one. The second program, called the interpretor, is executed whenever the VHLL is used. Figure 5 shows a diagram of the procedure used to generate the METOFOR force evaluation language interpretor.

Arithmetic Operations:

addition	+
subtraction	-
multiplication	*
division	/
exponentiation	** or !

Parentheses (optional) may be nested to eight levels.

Variables and arrays created and stored as used.
(Variable and array names up to 18 characters long)

Arrays may have up to ten subscripts of total size ≤10000.

Subscripts may be numbers or variables, or

Subscript classes may be entered by statements such as:

SUBSCRIPTS. PLACES: HOME, OFFICE, STORE, THEATER

Read data from disk or tape files - example:

DISTANCE (PLACE, PLACE) =:TAPE (1 3 5 7)
(5X, 4F 10.2) — creates DISTANCE with sixteen values and reads from file labeled TAPE, four values from each of four records 1, 3, 5 and 7.

Write data onto disk or tape files - example:

:TAPE = DISTANCE — writes sixteen binary values from DISTANCE to tape.

Matrix arithmetic examples:

NUMBER (6) = 1 6 — creates NUMBER with six values, 1 through 6.

TIME (PLACES, PLACES) = DISTANCE/SPEED
creates TIME and enters sixteen computed values.

SPECIAL OPERATIONS:

REWIND. TAPE	to rewind file TAPE
SAVE. N	to save current library on file N
ATTACH. N	to attach or restore library on file N
TITLE. xxxx	to enter title xxxx for current library
DELETE. N	to delete variable, array or subscript class N from current library
MOVE. N ± I	to move read pointer on file N forward or back
HELP.	to print tutorial description of language operations.

Fig. 4 Summary of the METOFOR Force Evaluation Language, MFEL.

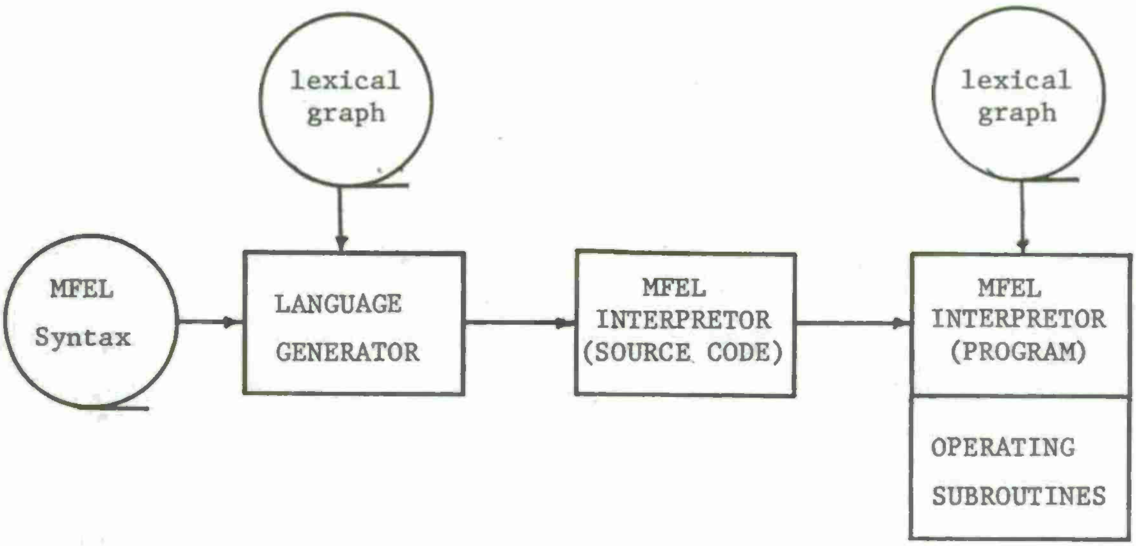

Fig. 5—Diagram of the Language Generation Procedure for the METOFOR Force Evaluation Language

This diagram shows the language generator in the block at the left. Input to the generator includes a lexical graph, shown at the top, and the syntax rules for the MFEL, shown at the left. The center block shows the source code (FORTRAN) for the MFEL interpretor which is output from the language generator. The block on the right shows the completed interpretor program formed by combining the compiled version of the MFEL interpretor source code with prepared operating subroutines. A second lexical graph is input to the MFEL interpretor program at execution time. This graph describes the lexical atoms of the MFEL language, while the lexical graph on the left side of Fig. 5 describes the lexical atoms of the MFEL syntax specification entries.

Lexical Analysis

Lexical analysis is performed by a table-driven lexical analyzer. Figure 6a shows a portion of the directed graph which describes the lexical atoms of the METOFOR force evaluation language.

The nodes of the graph may represent functions or character tests. Solid arrows represent success paths, dotted arrows represent failure paths.

Each node is given a sequence number for coding purposes. The graph is shown in pencil because this is the way it is normally prepared.

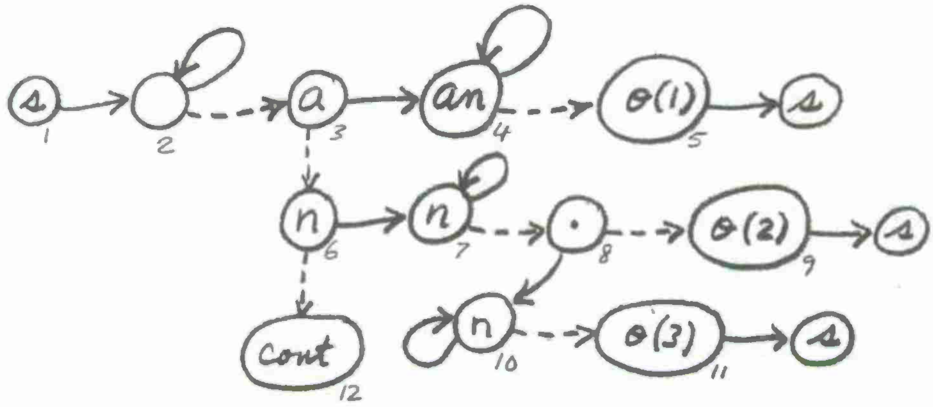

Fig. 6a—Example Lexical Graph

The following functions are used in Fig. 6a.

Code	Symbol	Description
1	s	start
2	a	test for any alpha character a through z
3	n	test for any numeric character 0 through 9
4	an	test for any alpha or numeric character
5	o(1)	output a name of any length beginning with an alpha character followed by alpha or numeric characters
	o(2)	output an integer number
	o(3)	output a decimal number

Character tests are shown with the character itself inside the node; the blank at node 2 and the decimal at node 8 are the only character tests shown in this example.

Figure 6a shows about one fourth of the complete lexical graph for the MFEL which recognizes a total of 18 lexical atoms including the arithmetic operators (+,-,*,/,** or !), integer or decimal constants, variable names and other special symbols. The first line of the example graph in Fig. 6a recognizes and outputs an alphanumeric name, the second line outputs integer numbers and the third line outputs decimal numbers —these are the most complicated atoms.

The simplicity of this graph is its most important characteristic. As you might expect, the complete graph for the 18 lexical atoms of the MFEL was originally set up in less than an hour.

Figure 6b shows how the graph of Fig. 6a is represented in tabular form for input to the interpretor program.

Node	Type	Fn	Par	Succ	Fail
1	2	1	0	2	2
2	1			2	3
3	2	2	0	4	6
4	2	4	0	4	5
5	2	5	1	1	1
6	2	3	0	7	12
7	2	3	0	7	8
8	1	.		10	9
9	2	5	2	1	1
10	2	3	0	10	11
11	2	5	3	1	1
12	continue				

Fig. 6b—Lexical Graph in Tabular Form for Input to the METOFOR Force Evaluation Language Interpretor Program

The first column (Node) contains the number of the node. The second column (Type) contains 1 for a character test or 2 for a function. Column three (Fn) contains the character, for a character test, or the function number. Column four (Par) contains a function parameter (if any) or may contain a repetition limit for a character test. Column five (Succ) contains the success path and column six (Fail) contains the failure path.

To change the lexical atom structure, the user makes a change in the table corresponding to the lexical graph. For example, the user could require all names to begin with a dollar sign ($) by changing node 3 to a character test for $.

Syntax Specification

The syntax, shown as input to the language generator in Fig. 5, consists of a few lines of specifications in BNF (Backus-Naur or Backus Normal Form). Figure 7 shows an example of the type of specification used for the MFEL.

```
<EXPRESSION>    ::= <OPERAND> [5|6|7|8|9] <OPERAND>
<OPERAND>       ::= <CONSTANT> | <VARIABLE> | <SUBEXPRESSION>
<CONSTANT>      ::= <INTEGER> | <DECIMAL>
<INTEGER>       ::= 2
<DECIMAL>       ::= 3
<VARIABLE>      ::= 1
<SUBEXPRESSION> ::= (<EXPRESSION>)
```

Fig. 7—Example Syntax Specification in BNF for the METOFOR Force Evaluation Language

The syntax specification in Fig. 7 is readily interpreted with some practice. The first line defines the term EXPRESSION as a statement beginning with an OPERAND, followed by one of the lexical atoms 5, 6, 7, 8 or 9 (the arithmetic operations +,-,*,/ or **), followed by another OPERAND. The second line defines OPERAND as a CONSTANT, a VARIABLE, or a SUBEXPRESSION. The fourth line defines INTEGER as atom number 2 (see Lexical Analysis above). The last line defines SUBEXPRESSION as EXPRESSION enclosed in parentheses. This last entry illustrates the recursive capability of the BNF specification and of the language generator. Notice that every term on the right hand side of Fig. 7 is ultimately defined in terms of lexical atoms.

The complete syntax description for the MFEL requires only 25 lines of BNF statements similar to those in Fig. 7. This syntax includes the distinction between integer and real constants or variables, subscripted arrays with integer or variable subscripts, matrix arithmetic (in addition to the arithmetic shown above), input and output functions, and all of the special command functions shown in Fig. 4.

Again the simplicity of the BNF syntax specification is its most important characteristic. Errors, not often made, are readily corrected in these specifications. Even more important is the flexibility which the system designer has in producing a language to fit the exact requirements of the user—almost independent of the computer operations to be performed. Once the computer operations are determined, the language may be designed to suit the user or users involved. Two or three versions of the language might even be generated for users at different levels of experience with the system.

Source Code Generation

Once a language is described by its lexical graph and the syntax specification, the language generator automatically produces the FORTRAN code required to recognize and control the execution of statements made in the language. When this code is combined with the operating programs or subroutines of the system, the language interpretor becomes a functional system.

The process of generating the code for the MFEL requires about 20 seconds of CP computer time and produces about 1500 lines of FORTRAN code (about half of which are comments).

APPLICATIONS

The METOFOR force evaluation language was selected as a test application for the language generator since it seemed to require a representative selection of language capabilities—viz arithmetic operations, data storage and retrieval, subscripted arrays with matrix operations, special purpose command operations, etc. Yet the application was on a small enough scale to be quite manageable for developing and testing.

The language generator is designed to be used in conjunction with almost any computerized analytical system to provide a very high level language operating capability. The generator produces FORTRAN code, but could be modified to produce assembly code for specific computers if desired.

Further and more specific applications are suggested in the next two sections.

OBSERVATIONS ON OPERATIONS RESEARCH AND ARMY PLANNING

To an observer in my position it appears that army planning processes (specifically, computerized modeling and systems analysis) go on concurrently with, but have rather little noticeable influence on, decision making processes. Well established political traditions and procedures have not yielded much to the super reasoning power of computerized analysis.

Of course no one would suggest that we should turn decision making over to the machines, or even that we should rely on computerized analyses so heavily that human factors lose the advantage in the decision making processes. Studies, modeling systems, etc., should never be expected to yield ultimate or optimal solutions to complex planning problems—unless all the relevent factors pertaining to the problems have been fully and accurately represented in the analyses. This can seldom be the case where problems include even the lightest interface with human institutions.

Not that all analysis is inadequate, but there is no systematic, dependable means of determining what is and what is not reliable. Buried in models and modeling systems (so deeply that the model builders themselves are often unaware of the extent of it) are built in assumptions, untried logic paths, potential contradictions, etc. How does the decision maker, unskilled in computer techniques and certainly unfamiliar with all of the details relevant to a system application, determine how to use the products of computerized operations research-systems analysis? Or, in other words, what is the proper role for operations research-systems analysis in support of army planning operations? This role, I submit, is and must always be, particularly at the highest levels, a subordinate supportive one.

The Supportive role

The supportive role, wonderfully matched to the potential capabilities of computerized analytical systems, becomes one of probing alternatives—what if questions—given the assumptions and limitations which must be well understood by the user. The user should not look for definitive solutions or ultimate answers, but rather he should look for insights into potential alternatives and for indicators of relative values to aid his own judgment and to suggest areas for further consideration.

To serve this function well, the products of analytical systems must be available during the primitive formative stages of decision making; they must be flexible—able to respond to questions and options as wide ranging as the imagination and curiosity of the planner; they must be capable of moving quickly with the planner down one line of alternatives and then just as quickly change direction to another line of alternatives as the situation requires. Some forms of analytical support should be as accessible to the high level planner (and at least as reliable and useful) as the dictionary on his bookshelf or the calculator on his desk.

VHLL Provides the "Knobs"

As planners and decision makers at higher levels gain more direct access to analytical systems through the "knobs" of very high level languages their understanding of what these systems can produce will increase and the systems and the products of operations research and systems analysis will take on greater significance.

It is hoped that in this and in other ways, language generation techniques will make a positive contribution to the future value of operations research to the US Army.

A UNIFIED ARMY PLANNING STRUCTURE

The Problem

The "proliferation of models" is a phrase commonly heard among army and defense planners. It seems to indicate a lack of direction or at least a lack of coordination in the development of planning systems. It suggests that new models have been developed where old ones might have been used, or worse, that new models were developed where none was required. Certainly some degree of redundancy and experimental development is healthy. But perhaps we would do well to examine means of promoting the widest possible application of existing software to current problems—to examine techniques for adapting existing software to new and different applications with minimal effort—and finally to develop some guidelines for future software design to enhance the opportunity for wide applications of new software and to maintain an overall balance and direction to software development.

With hundreds of models and systems doing their own thing in army planning applications, it is time to think about some unification of the structure in which these systems operate to provide an environment, some common ground, within which they begin to support and add credibility to each other and in the process enhance the image of systems analysis in general.

Army Standard Models and Data Bases

To begin some movement in this direction, I offer three recommendations.

1. Make a comprehensive survey of existing models, modeling systems and computerized data files. Establish a management information system which will give army planners immediate access to descriptions at general levels of detail of any model, system or data file available for application to army problems. NIH has developed an effective MIS which could provide a valuable guide for the development of such an army system.

2. Establish Army Standards for models and modeling systems developed with army funds for army applications. These standards should include access to standard army data sources. Relative to these standards, create three categories of modeling systems:

I Army Standard
II Partially Army Standard
III Non Standard

Category I to include modeling systems designed to access established army computerized data sources <u>directly</u> for all required data. Category II to include modeling systems which access established army computerized data sources directly for all required input data, with the exception of data of a subjective or arbitrary nature not appropriately maintained in standard army sources. Category III to include modeling systems which access little or no required data as described above.

Such a classification system provides immediate communication of the general character of a model or system to a potential user. A category III model is probably of such a specialized nature that it has little chance of application outside its immediate environment. A category II model may require a significant data generating effort to be useful, while a category I model may be ready for immediate application with an existing standardized data base. When results are presented from an Army Standard system, there is immediate understanding of the data sources (a significant credibility factor), the basic planning assumptions are known and the results can be described and understood from this common reference point. Having such a classification system implies the need to encourage and, in some cases, require the development and use of Army Standard Modeling Systems.

3. Promote the conversion of useful existing models and modeling systems to Army Standard form. This would be accomplished in two ways. First, where an existing system already requires and maintains a large data base, this data base might be formalized and incorporated by definition into the Army Standard system and be made available to other systems and users as appropriate. Establish general, readable documentation on the content and accessibility of these data. Second, provide software for existing models or systems to process, format, combine or generate the required inputs from standard data sources.

These ideas are not new. Work on unified data bases has been going on for years. But new emphasis is needed now on methods of increasing the value and the credibility of systems analysis. At a time when many are questioning the value of systems analysis, when the Department of of Labor classifies systems analysts as non-professionals [2] along with librarians and historians, it is time to reassess our priorities and to find ways of making our product more valuable and more responsive to the real problems of the community we serve.

Very High Level Language Application

Families of models or analytical systems may be brought together to operate under the umbrella of a single very high level language. Software developed for the two VHLL examples discussed in this paper provides the capability to create and maintain data libraries and gives the user convenient control over data storage, input, output and formatting operations. These capabilities suggest the use of very high level languages implemented by language generation techniques to bring new tools to bear in the process of unifying army analytical systems.

CONCLUSION

Very High Level Language (VHLL) is a term which describes what is usually a very simple language created to perform specific functions by a user who may be unfamiliar with ordinary high level computer languages such as FORTRAN or COBOL. Such languages are also useful to analysts who may have a number of complicated procedures to be executed frequently. In this case, simple statements in the VHLL reduce the time required to set up and perform these procedures and minimize the opportunity for inadvertent input errors.

A disadvantage of VHLL is the time and programming effort required to create the language initially, with the realization that such special purpose applications are often temporary in nature or evolve over time in such a way that the associated VHLL may become obsolete before it is implemented. Hence this approach has not been generally used for analytical modeling systems in the past.

We now have the capability to generate automatically most of the code required to implement a VHLL. This capability virtually eliminates the major disadvantage of using VHLL, since the time required to implement a working version is minimal and the VHLL can be changed as quickly and as often as the problem, system or environment requires.

[1] Research Analysis Corporation, AFFORD System Description and User's Manual - Volume III, Control Program and Reporter, RAC-R-144, August 1972.

[2] Newsletter of Military Operations Research, PHALANX, Vol 9, No. 3, September 1974.

SUBJECT: Wartime Active Replacement Factor (WARF) System Design

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1. Background. The Army plans equipment procurement based upon their expectation of loss in both a peacetime and a wartime active posture. These losses are cojoined to compute the Authorized Acquisition Objective (AAO) which strongly influences the POM and Budget cycle. The data used to compute WARF's was contractor-derived from WWII and Korean loss data and therefore does not show the changes in weaponry, mobility, and electronics that future armies will have. Vivid proof of a current inadequacy lies with the tank WARF now computed to be 8.62 percent per 30 days of battle in a mid-intensity theater conflict. My guts tell me that is wrong. Improved WARF's will provide a better Army position for the distribution of procurement dollars among the services.

2. The Basic WARF Structure. The WARF basic structure uses a contractor developed system called SYMWAR. For each piece of equipment a loss rate matrix is prepared. (Figure 1)

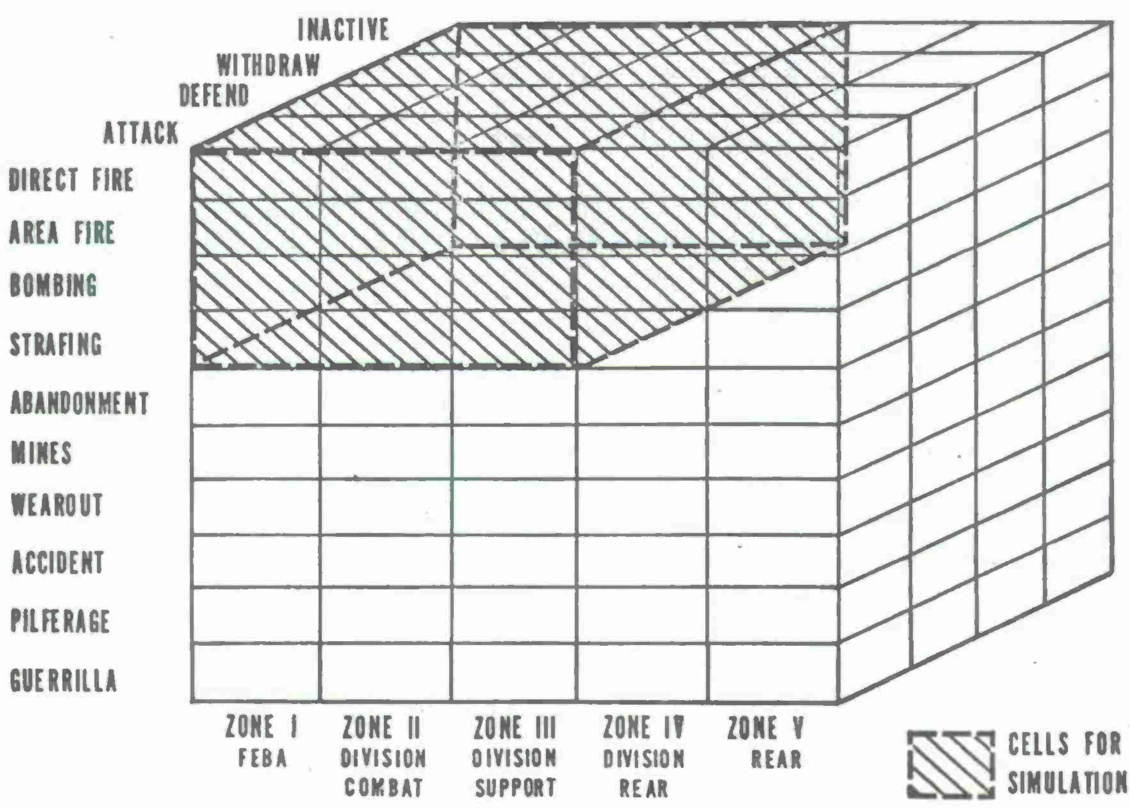

FIGURE 1. SYMWAR (WARF) Loss Rate Matrix

This three-dimensional matrix with 4 battle postures, 10 causes of loss and within 5 zones of the theater was filled with historically developed loss rates (those that produced the 8.62 percent WARF for tanks). Theater Zones I, II and III are those within normal artillery. Over the years, computerized war games were developed that project battle outcomes along with associated casualties and consumption. Taking one cell in the matrix, say direct fire losses to tanks on the FEBA; rather than extrapolate from another war with many conditions changed, one could use loss rates from simulations to relace the loss rate to tanks from direct fire at the FEBA. As a matter of fact, the shaded portion of the matrix could be relaced with loss rates from simulations and contains 48 of the 200 cells in the matrix. Cost-wise, the 48 cells will cause more than one-third of the theater cost losses.

Given the distribution of equipment within the theater zones and the combat postures over time, the loss rates for MIE are rolled-up in an accounting model. The problem for the WARF project therefore, was to design and operate a system wherein simulated loss rates would replace historic rates wherever possible in the matrix.

3. Models used in WARF. After reviewing several models at various levels of resolution, the Concepts Evaluation Model (CEM) and the Artillery Models from within the AMMORATES system were selected as loss simulators to provide the loss rates for the shaded portion of the WARF matrix.

a. The Concepts Evaluation Model (CEM). CEM is a fully automated, theater-level wargaming model that considers

(1) Weapon and Personnel Casualties

(2) Force Mix

(3) Logistics and resupply

(4) Personnel replacement and evacuation

(5) Air and Air Defense

(6) Artillery

(7) Terrain

(8) Commander's Decisions

(9) Massing against penetrations

It may play 50 blue divisions against 125 red divisions, thus it may portray a theater, and for WARF purposes, 41 different kinds of high cost tactical major items of equipment (MIE). Figure 2 shows in more detail the 48 cells of the 200-cell WARF matrix wherein simulated loss rates from CEM will replace historic ones.

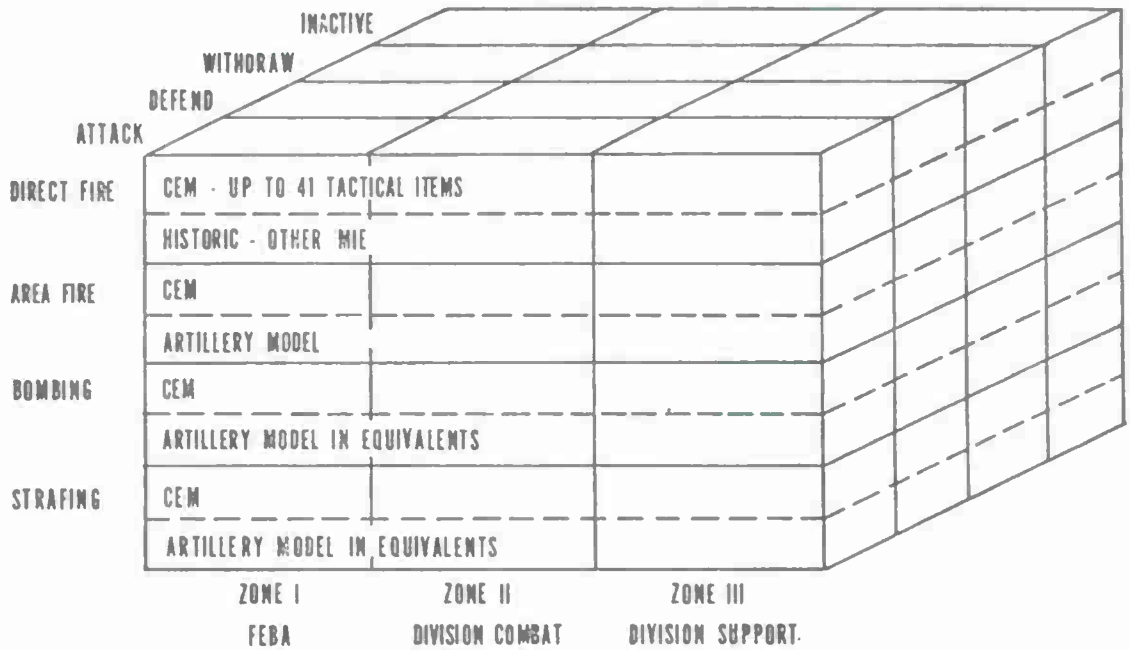

FIGURE 2. WARF Cells Containing Simulated Loss Rates

Realizing that CEM considers only tactical firepower producing MIE, there remained a large number of costly items located within the first three zones of the theater subject to loss from artillery. These items are characterized as engineer equipment, trucks, electronic equipment and the like.

b. The AMMORATES ARTILLERY Models. The three AMMORATES Artillery models are the Target Acquisition Model (TAM), the Fire Planning Model (FPM) and the Casualty Assessment Model (CAM). These models in their original configuration were designed to cause personnel casualties in 16 combinations of personnel and battle postures. WARF required artillery losses to equipment and it was found that a small finite number of equipment classes would suffice; thus, reprograming and a slight expansion of the TAM, FPM, and CAM was accomplished. The selection of a small finite number of equipment class was pursued. All existing equipment classification schemes were based upon mission or function, whereas WARF artillery casualties would be necessary based upon the hardness of targets. A detailed analysis of all MIE expected within red artillery range (Zones I-III) was conducted. The results of that analysis are seen in Figure 3. Any item of equipment found in the theater forward area could be equated to 1 of the 22 determined vulnerability classes. For each class of equipment, a notional item was selected that best characterized the class. As an example, class 2, Light Armor was notionalized by armored carriers because they made up 85 percent of all light armor population in that class.

1	LIGHT AIRCRAFT	12	POL TRANSPORTERS
2	ARMOR, LIGHT	13	AMMO TRANSPORTERS
3	ARMOR, TRACKED, MDM HVY	14	SMALL ARMS & PYROTECHNICS, INDIVIDUAL
4	WHEEL: TRUCK LIGHT	15	WEAPONS & MISSILES, CREW SERVED
5	WHEEL: TRUCK MDM HVY	16	OPTICAL DEVICES & SETS
6	BOATS & SP AMPHIBIANS	17	COMMUNICATIONS & ELECTRONICS
7	TRAILER, TOWED LT	18	MECHANICAL, ELECTRICAL-MECHANICAL EQPT
8	TOWED EQUIP, ARTY	19	TOOL, SETS/KITS, SMALL
9	SEMI TRAILER, MDM/HVY	20	OPERATIONAL MAINTENANCE, MDM/LARGE
10	BOATS, PNEUMATIC, SP/RAFTS	21	STORAGE & DISPENSING EQUIPMENT, CL III, SMALL
11	BRIDGES, EMPLACED	22	SHELTERS & NON-POL STORAGE TANKS

FIGURE 3. WARF Vulnerability Classes

The next step was to determine what type of kill was necessary to cause replacement of an equipment item. The replacement kill ('r'-kill) is defined as a direct hit plus a fuel or ammunition standoff

or

$$LA = L \times W + 1/2\ \Pi \times (R_{pI})^2$$

L = Length of MIE

W = Width of MIE

R_{pI} = Radius where probability of ignition = 50%

These lethal areas (LA) for each type red artillery against each of the 22 vulnerability classes has been received from the Army Materiel Systems Study Agency (AMSAA).

Casualty assessment is precomputed by placing each equipment class in 7 targets diameters ranging from 50 meters to 350 meters. Red fires battery volleys into the target assuming random placement at 100 target elements with the target radius. For each LA overlaying a target element, a kill is recorded, then all kills averaged over the sample of 100. This generated a large number of tables which became look up tables for 'r' kills, an example of which is at Figure 4. To decrease computer running time and core size, a series of multiple linear regressions were performed as a function of lethal area, rounds fired and target diameter. The correlation coefficient of the multiple linear regressions was generally greater than .99 so it was possible to compute losses from a set of equations rather than execute a CAM run for each possible situation solely for the purpose of producing look up tables.

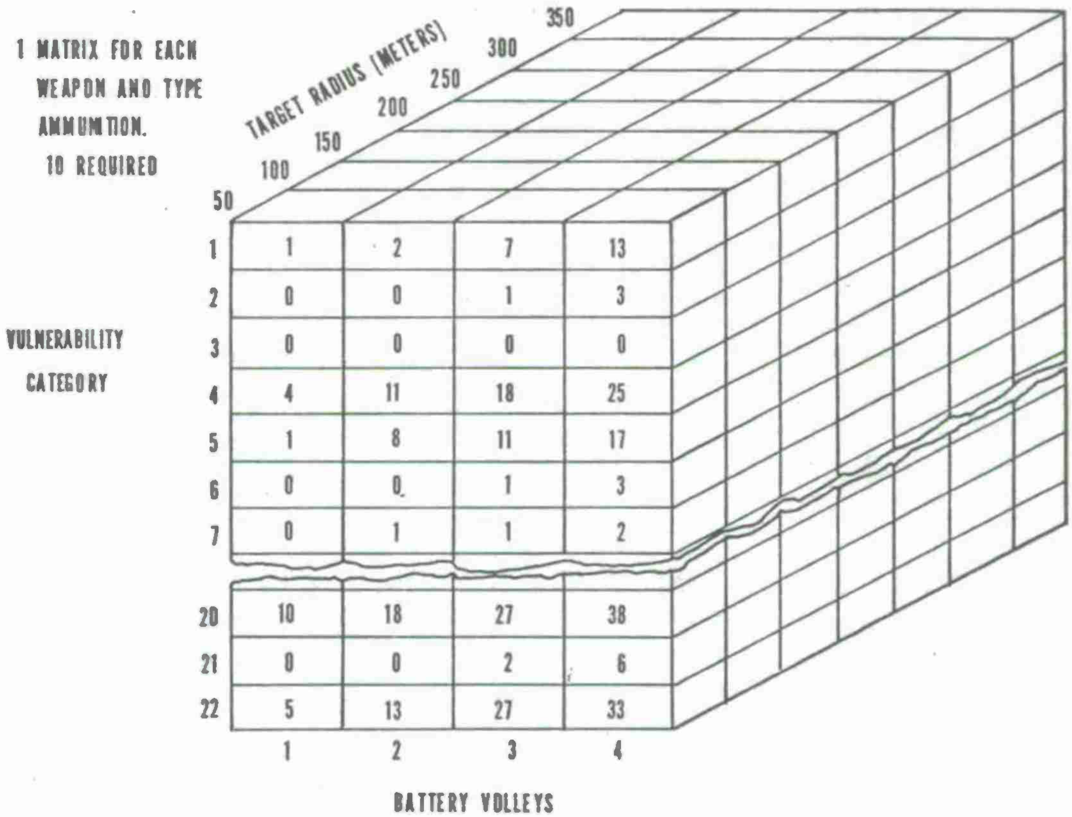

FIGURE 4. Casualty Assessment Matrix

The TAM uses detection probabilities to acquire targets based upon size, activity, terrain and distance. The list of probable targets is passed to the FPM which, using red firing doctrine, programs artillery fire against the targets. Knowing the number of rounds against each target, assessment of replacement kill is determined in the CAM as explained earlier in this paragraph. An example of this process may be seen at Figure 5.

In the case of the 50-meter target, assume there were 1 - 1/4 ton vehicle and 3 - 2½ ton vehicles and TAM thought it was an infantry platoon. The FPM planned to fire 1 battery volley of 152 mm at that target. Using the casualty assessment matrix for that situation with 1/4 tons being vulnerability class 1 and 2½ tons being vulnerability class 2, one finds 10 percent destruction of 1/4 tons and 7 percent destruction of 2½ ton vehicles.

The artillery assessment is accomplished for a 6-hour stylized period with 100 percent equipment strength for the attack, defend, delay and static posture. The loss rates to equipment are passed to the WARF matrix and entered as seen in Figure 2. The bombing and strafing loss rates will be generated with the artillery models by using artillery equivalents for bombing and strafing.

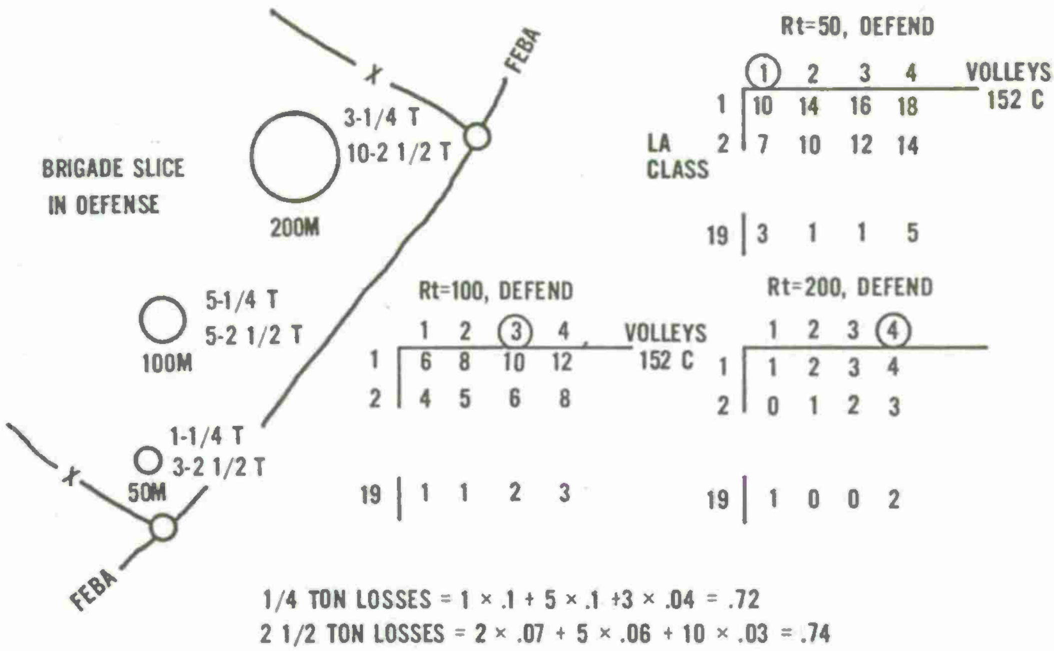

FIGURE 5. Casualty Assessment

4. Roll up. Referring back to Figures 1 and 2, the loss rates from simulations are moved into the matrix for each MIE. The postures throughout the war are determined in CEM so in a bookkeeping fashion, WARF's are computed by summing the losses over time in the theater. This produces the losses in the theater and does not yet tell planners what must be shipped from the CONUS base. Sea and air shipping loss rates are introduced as seen in Figure 6 and will insure that 100 percent of the theater requirements arrive in the theater.

5. Study Consistency. Figure 7 shows the relationship among three major Army studies, i.e., WARF, Force Design (CONAF), and AMMORATES. All use a common scenario, a maximum of common models and the same data base to the maximum extent. The only radical departure from their commonality is the difference in mode in simulating the theater battle for Force Design and WARF. For Force Design, CEM is operated in the capability mode, i.e., real-world limits are placed on resupply of both MIE and logistics, however, in WARF, the requirements mode is required meaning that each 12 hours of battle, blue will start at 100 percent strength. The impact on battle outcome and attrition is expected to strongly influence the WARF's--blue attrition should be much higher in requirements mode.

SEA

$$\text{LOSSES IN THEATER} \times \frac{\text{SEA LOSS RATE}}{\text{1-SLR}} \times \text{\% SHIPPED BY SEA}$$

AIR

$$\text{LOSSES IN THEATER} \times \frac{\text{AIR LOSS RATE}}{\text{1-ALR}} \times \text{\% SHIPPED BY AIR}$$

IF 100 TANKS ARE DESTROYED IN THE THEATER BATTLE, SEA LOSSES ARE 20% AND AIR LOSSES ARE 5% WITH 90% SHIPPED BY SEA:

SEA

$$100 \times \frac{.2}{1-.2} \times .9 = 22.5 \text{ LOST AT SEA}$$

AIR

$$100 \times \frac{.05}{1-.05} \times .1 = \frac{.5 \text{ LOST IN AIR}}{23 \text{ TOTAL INTERTHEATER LOSSES}}$$

FIGURE 6. Computation of Intertheater Shipping Losses

6. WARF's Impact on the AAO. Recalling the current WARF for tanks using historic loss rates is 8.62 percent. A sample AAO computation was conducted using a tank WARF of 20.1 percent per 30 days and the AAO increase was 273 million dollars. (The 20.1 percent is thought to be conservative.) There are about 400 MIE for which new WARF's will be calculated using simulated loss rates with models run in requirements mode. This should provide a multi-billion dollar increase in the Army's AAO and should place us in a stronger position to vie for a larger piece of the procurement dollars.

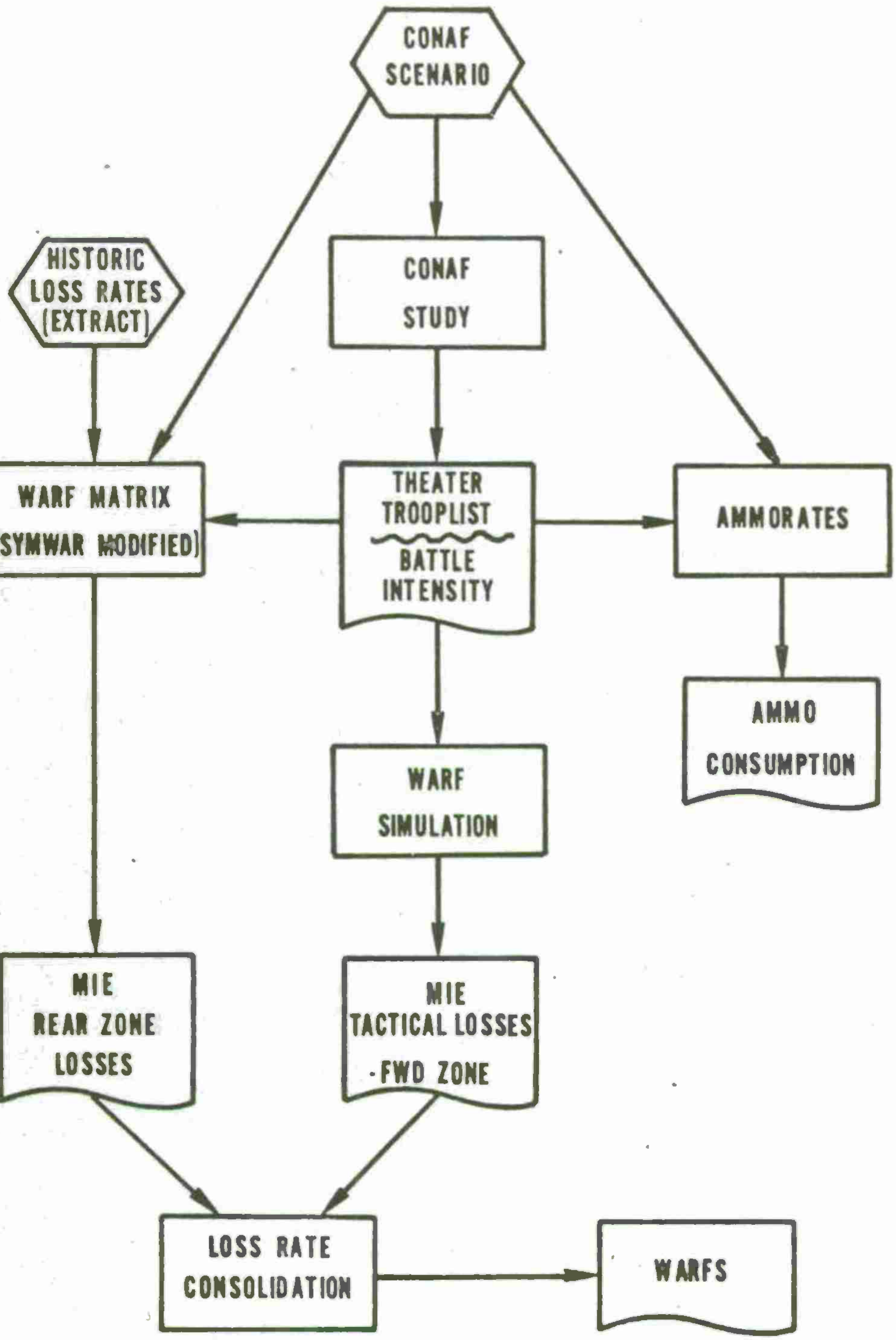

FIGURE 7. Study Consistency

COSTING THE CONCEPTUAL ARMY IN THE FIELD

by
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Concepts Analysis Agency

1. Introduction

a. Preparing for the future is a task particularly germane to the Army's Operation Research community. It is also an area which can be well served by the tools and techniques of OR. To those involved in force planning, the design of the field Army is a very real problem. Not only must we contend with countering a postulated threat, but also we must design the force so that it is affordable. Whether maintaining or modernizing existing units or fielding new ones an impact on manpower and dollar resources will result and must be addressed.

b. What is the best design for the Army in the 1980's? Should it be infantry heavy or should it have greater aviation or armor capabilities? The answers to these questions are related to another question: What can we afford? By applying the techniques of operations research to these questions, a set of reasonable, alternative force designs may be postulated. The objective is to find cost-effective solutions, i.e., forces with the necessary fighting capability at an acceptable cost. The Concepts Analysis Agency, in its study of the Conceptual Design of the Army in the Field, Phase III (CONAF III) addressed this issue. The study involved maximizing combat power in the mid-range time frame (to FY 86) based on realistic projections of resource constraints, materiel availability and the international situation as they relate to Division Forces.

2. Background

a. CONAF III is the latest in a series of studies on mid-range planning designed to provide Army leaders a rational basis for decisions which will come to fruition 5 to 10 years from now. This involves making the best use of scarce resources under current policies and constraints as well as preparing for modernization through force development and cost planning. In CONAF I, a basic methodology was developed for mid-range force design and evaluation. CONAF II compared forces of equal cost; it considered force alternatives which had the same totals for procurement plus 10 years of operation. The principle constraint in CONAF II was the procurement funds assumed available through FY 86. This constraint influenced the equipment that might be purchased for alternative forces but did not constrain the operating cost during the transition period.

b. In CONAF III, we addressed the most effective force which could be developed and maintained between now and FY 86 while remaining within annual fiscal constraints. Costs were estimated on a year by year basis for alternative forces taking into account modernization plans. The approach correlated estimated costs with the year in which obligational authority would be required. This limited the force designer to rates of change in force structure consistent with expected FY funding levels.

3. Resource Constraints

a. Assumptions. - In any realistic situation one is never at liberty to achieve his desires with impunity. Regardless of how much we want something, however worthy it may be time, money, some authority or maybe just a perverse universe acts as constraining device. The force designer must contend with constraints also. His constraints are resource limitations of manpower, material and money which may keep him from an objective of a particular force at a specific time. But being aware of constraints, it may be possible to achieve the same objective via another route. More on this later. The establishment of constraints derive from official sources and it must be recognized that these sources reflect policy decisions which are subject to change. Nevertheless, planning for the future based on present policy has got to be superior to planning without regard to possible limitations. With that as a premise, the following assumptions were used to establish resource constraints.

(1) peacetime operating conditions

(2) all costs would be expressed in FY 74 constant dollars

(3) the Program Objective Memorandum (POM) FY 75-79 and the Force Structure/Manpower Systems/Account Display (Form 1) were appropriate sources for developing resource constraints through FY 79.

(4) OMA and MPA constraints beyond FY 79 were assumed equal to those indicated for FY 79.

(5) Procurement constraints beyond FY 79 were reflected in the Materiel Procurement Priorities Review Committee (MPPRC) report.

b. Manpower Constraints. - The derivation of manpower constraints was established in the following manner. Active and Reserve military manpower constraints for Division Forces were considered the structure strengths shown in the POM (FY 75-79) or as updated in subsequent Form 1's. Civilians associated with the Division Forces worked either directly in support of the Divisions (as in TDA units) or indirectly (such as laborers or base operating personnel). The number of civilian direct hire were established in the Form 1 while division force civilian indirect personnel are shown only in the POM. By using the POM and Form 1, total civilian manpower constraints for division forces were established. These manpower constraints were identified by year for active and reserve forces as well as direct and indirect civilians.

c. Fiscal Constraints

(1) OMA and MPA Appropriation. - To determine dollar constraints for the OMA and MPA appropriations, the Force Cost Information System (FCIS)

developed by the Office of the Comptroller of the Army (OCA) was used to develop average cost factors. The FCIS, an extensive computer based information system, contains equipment, personnel and cost data on major combat and combat support units. With FCIS as a data source, average factors of OMA and MPA per man were derived. These average factors, based on similar units, were then multiplied by the manpower constraints previously calculated to derive dollar constraints.

(2) Procurement Appropriation Constraints. - Division forces have two separate forms of procurement costs associated with their operation. The first is a one time, nonrecurring cost of establishing a new unit or modernizing an existing unit. (Existing units not intended for modernization by new equipment incur no nonrecurring procurement costs.) The second type of procurement cost occurs on an annual recurring basis and consists of peacetime replacement costs plus those of annual service practice (ASP) ammunition, repair parts and secondary items. The calculation of the procurement appropriation constraints reflect the current plans for modernization of the division forces. The FYDP Procurement Annex and the MPPRC indicated the plans for acquisition of new or improved systems. Those documents, along with Selected Acquisition Reports (SARs) provided estimates of equipment costs.

(a) Nonrecurring Procurement. - The nonrecurring procurement appropriation constraints were based on approved plans for new or additional items. The constraint is expressed in the following equation:

$$C_{NR} = \sum_{i=1}^{n} (Q_i \times P_i \times 1.05)$$

where C_{NR} = Nonrecurring Procurement Constraint
n = number of different items intended to modernize division forces
Q_i = quantity of each item allocated to division forces
P_i = average price per item
1.05 = factor to allow for initial repair parts and secondary items.

The equation was taken directly from the OCA approved Army Force Planning Cost Handbook (AFPCH) and was therefore appropriate for use in CONAF. Again, the quantities of equipment involved and their costs came from DA approved planning documents.

(b) Recurring Procurement. - The calculation of the recurring procurement cost constraint involved all the equipment of the division forces not just new or additional items. The recurring expenses consist of peacetime replacement costs as well as repair parts and secondary items. The computation of the recurring procurement appropriation constraint is expressed:

$$C_R = \sum_{j=1}^{m} ((Q_j \times P_j \times 0.03) + (PR_j \times RF_j) + A_j)$$

where C_R = annual recurring cost constraint
m = number of different items in division forces

Q_j = Quantity of each item
P_j = average price per item
0.03 = 3 percent annual repair parts factor
PR_j = quantity of items assigned peacetime replacement factor
RF_j = annual replacement factor
A_j = annual service practice ammunition cost.

Again, the equation and factors were obtained from the AFPCH. The summation of the recurring and nonrecurring costs yielded the total procurement appropriation constraints.

(3) Constraints Document. - To summarize, the POM, Form 1, FYDP and MPPRC provided a basis for our development of manpower and fiscal constraints appropriate to CONAF III. The manpower constraints were used in establishing OMA and MPA dollar constraints and, to a large extent, the FCIS provided factors to translate manpower and materiel planning into appropriation constraints. Once the constraints had been established, they were documented and displayed by fiscal year. The constraints document was then available to the force designer in his evaluation of alternative division forces. He could design forces to meet specified threats and guage whether the cost of fielding and maintaining the forces were within the limitations of men and money which present policy indicated.

4. Force Costing

a. General. - In CONAF III the force designers considered several alternative forces. A so called "approved force" was the composition indicated in present programing documents such as the POM and FYDP and was used in calculating the constraints. Alternative forces involved:

(1) one with increased war reserves compared with present practice,

(2) a force with more infantry capability and

(3) a force with greatly increased aviation units.

Each of the alternatives required design refinements to maximize their combat effectiveness within the limitations imposed by the resource constraints. It thus was necessary to cost the alternatives (and their variants) as quickly as possible to support the force designer.

b. Assumptions. - A computer based model was developed at CAA to automate the calculation of the 1,300,000 data elements required to cost division forces for CONAF III. The assumptions used in estimating the force costs were, of course, compatible with those used in estimating the constraints.

(1) peacetime operating conditions

(2) FY 74 constant dollars

(3) Costs previously incurred were considered sunk and did not enter into the calculations.

(4) Only the variable portion of costs were computed. These are the costs which reflect the size and composition of the force. There is a fixed cost which is basically insensitive to the force design but that was excluded. The variable costs allowed the development of equal cost forces not exceeding the constraint.

(5) Direct costs (expenses incurred by the division forces like pay of assigned personnel and materiel consumed by the unit) and indirect costs (expenses incurred in support of the force like replacement training and medical costs) were estimated.

c. Computer Models. - The costing of division forces was accomplished through the use of the Force Costing System developed at CAA. The system consisted of ten separate but interactive computer programs which performed the functions of validation, unit costing and force costing. In general, the system extracted a troop list for each fiscal year from a file supplied by the force designer. Then the costs for each individual unit in the force was computed and the costs aggregated in terms of the major appropriation categories by fiscal year.

(1) Validation Programs. - These programs checked troop lists for valid TOE numbers and determined that the cost of the TOE units were contained in the cost data bank. Exception reports were provided so that steps could be taken to assure that all units of the troop list were costed or to notify the force designer that he had specified an invalid TOE in his troop list.

(2) Unit Costing Programs. - These costing programs updated the cost estimates of existing units in the cost data bank. Input was from FCIS tapes which were updated periodically by the Office of the Comptroller of the Army. This assured that the most recent cost estimates were used. These programs also developed cost factors for units in the troop list which did not appear in the data bank. The factors were calculated by taking the geometric mean of similar type units to derive a statistical average. The geometric mean was selected by observing that the frequency distribution of the factors associated with existing units had wide extremes. A characteristic of the geometric mean is that it is less affected by extremes and is a more typical average. The arithmetic mean, on the other hand, can be greatly distorted by extreme values and therefore it may not be a typical value. Based on the mean factors and descriptions of men and materiel for new and modernized units, costs for these units were computed and also stored in the data bank.

(3) Force Costing Program. - The work of validating existing units or costing new and improved units culminated in the force costing programs. These programs extracted cost information from the data bank for a given force and aggregated the costs by appropriation. In performing this function, factors were applied to reflect the theater of operation,

manning level and whether the unit is Active Army or Reserve Component; these options were defined by the force designer in constructing the force alternative.

d. Costing Process. - The preceding material outlined, in general, the costing procedures. The following illustrates in more detail how the systems worked.

(1) Existing Units, Personnel Costs

(a) The calculation of personnel costs began with either a TOE or TDA. In the case of civilian personnel, their number was multiplied by per capita factors, obtained from OCA to compute their contribution to the OMA cost. The factors provided estimates by theater of operation.

(b) Military personnel costs for existing active Army units were in the cost data bank by virtue of its update from the FCIS. In the case of Reserve Component units, OCA factors were applied to a like Active Army unit to reflect a decreased annual recurring cost; nonrecurring costs or costs of initially fielding a unit were assumed equal for active and reserve personnel.

(c) The personnel costs for existing units were computed according to the force design. They were accumulated by appropriation (MPA and OMA), type (recurring and nonrecurring as well as direct and indirect) theater (CONUS, Europe and Pacific) and fiscal year.

(2) Existing Units, Materiel Costs

(a) Materiel items which are in the inventory were costed according to the AFPCH guidance on annual replacement policy. The Supply Bulletin SB 700-20 also provided investment cost information.

(b) When an existing unit was expected to be modernized with new equipment, not presently in the inventory, another procedure was used. Sources such as approved SARs, DCPs and the MPPRC were used to obtain hardware costs. These were used to estimate the one-time (non-recurring) as well as the annual recurring procurement costs of forces. The equation describing the nonrecurring costs for equipment to support a unit is:

$$C_{NP} = \sum_{i=1}^{n} P_i \times Q_i \; (ORF_i + RCF_i + 1.05)$$

where C_{NP} = Nonrecurring procurement cost for new or additional unit equipment

n = number of new or additional pieces of equipment

P_i = Procurement cost of each item

Q_i = Quantity of each item

ORF_i = Operational Readiness Float Factor

RCF_i = Repair Cycle Float Factor

1.05 = Constant to reflect cost of initial repair parts and spares

All factors were obtained from the AFPCH.

(c) Recurring procurement costs accrue for all major equipment, not just the new or additional items. The equation which represents this annual expenditure is:

$$C_{RP} = \sum_{j=1}^{m} ((0.03Q_j + RF_j) P_j + A_j)$$

where C_{RP} = Recurring procurement cost for a unit
m = Number of items of unit equipment
Q_j = Quantity of each item in a unit
0.03 = Constant to reflect annual repair parts cost
RF_j = Annual peacetime replacement factor
P_j = Price of the item
A_j = Annual Service Practice ammo cost (if any)

There were similar equations for OMA expenditures extracted from the AFPCH. The just described process resulted in estimates of the materiel costs for existing units. Again, the costs were accumulated as direct and indirect costs both recurring and nonrecurring for the procurement and OMA appropriations.

(3) New Units. - The previous discussion related to estimating the costs of existing units which were either left unchanged or modernized with new or additional materiel. In the case of new units which the force designer envisoned, a different approach was used which relied much more on manual input. Starting with an equipment list and a deployment plan, items which were in inventory (such as trucks, radios and guns) were computed based on latest prices in the AFPCH or supply bulletin. New items of equipment were costed using the same relationships and references previously indicated. Personnel costs for new units were computed by searching the FCIS for similar types of units and deriving new personnel cost factors based on the geometric mean of the cost factors exhibited by the existing and similar units. Then, adding the material and personnel costs, the total estimated costs for new units were obtained.

5. Distribution of Costs. - The preceding material has described the methodology used in costing force alternatives for CONAF III. The distribution of these costs, annually, warrants additional explanation. The force designer provided the composition of his force alternatives by year. His design indicated when units were to be modernized and when new units would be activated. This information was necessary in order to allocate the one-time, nonrecurring costs of activating or modernizing a unit. Recall that the cost model calculated the nonrecurring costs as well as the recurring expenses. The nonrecurring OMA and MPA appropriation expenses occur at time of activation or modernization of the unit. But in order to allow sufficient lead times in manufacturing major equipment items, procurement funds are usually obligated in advance of receipt of the equipment. The number of years between obligation of procurement funds and unit activation or modernization varies with the type and complexity of the equipment,

however, based on an analysis of several weapons systems, the obligation for procurement of major equipment occurs, on the average, about two years prior to unit activation or modernization. The recurring costs, of course, are incurred in each year of operation.

6. Force Costing Summary. - A recapitulation is, perhaps, in order to clarify the complex approach used in costing the conceptual Army in CONAF III.

a. The force designer developed several force alternatives. The designs consisted of combinations of units which presently exist in the Army as well as new and/or modernized units. Also, the annual composition of the force alternatives were specified thus providing a basis for determining dates of activation for new and modernized units.

b. For each alternative, information on troop lists and equipment combined with data bases like the FCIS and other approved sources for personnel and equipment costs produced our cost data bank on all units used in CONAF III.

c. The force costing model then computed the costs for the alternative forces by adding the appropriate units.

d. The costs of each alternative resulting from the model were compared to the resource constraints. If necessary, changes to a force's manpower and/or materiel were made to bring the alternative within constraints.

7. Results. - The results of this process may be seen in Figure 1. The figure represents a typical output showing appropriations (MPA, OMA and Procurement) by fiscal year for the constraint and three alternatives. In FY 75, no force alternative exceeds the constraint but in FY 86, Force 1 exceeds all constraints except MPA, Force 2 exceeds the OMA and Procurement constraints and Force 3 exceeds only the OMA limit. Looking at the total costs for the FY 75-86 period an interesting situation confronted the force designer concerning Force 2. That force was below the total MPA constraint by about $3.5 billion; it exceeded the total Procurement constraint by about $2 billion; and its total, over all appropriations, was within the grand total constraint. The force designer was faced with the opportunity to trade-off equipment for personnel, bringing each appropriation closer to its constraint, or to apprise Army planners that a change in currently envisioned fiscal constraints may be necessary. His decision considered the change in force effectiveness resulting from manpower/materiel shifts. The CONAF III force cost system gave the force designer an analytical tool in his search for cost effectiveness.

8. Summary

a. In costing the Conceptual Army in the Field, a very detailed cost model was developed. The model centered about an automated data bank which stored cost information on new, modernized or existing units. Costs for alternative force designs were calculated using a methodology general

FIGURE 1
CONAF COSTING RESULTS

	Annual Costs in Millions, FY 75-86	
	FY 75 . . . FY 86	Total
Military Personnel Appropriation (MPA)		
Constraint	$4,863 . . . $4,795	$57,812
Force 1	4,766 . . . 4,699	56,524
Force 2	4,764 . . . 4,454	54,181
Force 3	4,768 . . . 4,719	56,795
Opn and Maint Appropriation (OMA)		
Constraint	2,078 . . . 2,017	24,448
Force 1	2,058 . . . 2,127	24,606
Force 2	2,058 . . . 2,108	23,889
Force 3	2,059 . . . 2,097	24,464
Procurement Appropriation (PA)		
Constraint	950 . . . 1,243	14,670
Force 1	817 . . . 1,254	14,435
Force 2	798 . . . 1,522	16,524
Force 3	865 . . . 1,199	14,023
Total		
Constraint	7,891 . . . 8,055	96,930
Force 1	7,641 . . . 8,030	95,565
Force 2	7,620 . . . 8,031	94,594
Force 3	7,693 . . . 8,015	95,282

enough for use in many studies requiring force costing. A sense of realism was added through the use of resource constraints which established limits of manpower and costs over the time span of interest. The approach was well received; costs were not at issue in staffing the CONAF III report. The same methodology will be used in CONAF IV now underway at the Concepts Analysis Agency.

b. It is felt that the use of annual resource constraints is a significant contribution to Army force planning. The force designer, using the force cost system, has an analytical tool to determine how design or schedule changes affect dollar resources and what the limits of those resources are likely to be. He may then effect trade-offs between manpower and materiel in order to establish a force design which is not only effective but also affordable.

AIR DEFENSE REQUIREMENTS FOR THE UNITED STATES ARMY

Mr. Clifton P. Semmens
Braddock, Dunn and McDonald, Inc.

OBJECTIVE

The objective of this paper is to suggest an approach which would substantiate U.S. Army air defense requirements and stabilize the air defense force structure to the same extent that force structures of other combat arms are stabilized.

The thrust of the paper is built around a conviction that a basic organization for air defense in the Army is more important than equipment requirements - at this time. Many equipment technical deficiencies can be compensated for by innovative tactical and operational procedures. Development of such procedures, however, cannot be accomplished in a void where no organization or environment of complementary systems exists. In contrast to determining weapon requirements within an organized force structure, the Army for years appears to have concentrated on the process of procuring rather sophisticated equipment with little regard to how it will be employed or the force structure within which it must operate. As a result, the adequacy of current and proposed air defense systems to meet a full spectrum of requirements is not known, and an adequate air defense force structure does not exist.

BACKGROUND

Examination of the history of the U.S. Army over the last fifty years discloses a "cyclic pattern" in the number of air defense units retained within the Army force structure. WWI, WWII, and the Korean War all saw the activation and deployment of numerous and varied air defense units to meet the then existing requirements. Following the war periods, the numbers of air defense units were reduced almost to the point of elimination of the capability. This general approach may have been acceptable under circumstances of a period of mobilization and military buildup and against the air threat extant at those periods. Continued application of the cyclic approach, however, in modern warfare could prove disastrous.

The necessity for immediately available, combat-capable forces has become a hallmark of United States military policy. The necessity also for immediately available Army air defense forces in adequate numbers appears obvious. Continued reliance on a procedure of obtaining these forces "after the fact" appears faulty. The simple logistics of procurement lead times and training alone invalidate reliance on such procedure. The numbers and types of Army air defense units should be correlated with the missions appropriate to the units; the air defense units should be included in the total Army force structure. Modern war will not offer a reasonable possibility of providing major portions of the defense against air attack as a part of the post D-day buildup. Recourse to such a method is valid only to the extent that the installations, facilities, or units to be defended are themselves created during the post D-day period.

The most recent lessons of history convey a clear message concerning air defense. Ground units are severely restricted in maneuver and effectiveness in the presence of modern air power. Even the smallest national powers now have modern air forces in sufficient sizes to influence strongly, if not control, the course of the battle. Air defense--particularly ground-based air defense means--has reached a point of effectiveness so as to deny hostile air power control of, or in some circumstances access to, the air space over the battle area. Air defense thus is an essential ingredient to successful ground operations. A method of sizing the required Army air defense ingredient by some logical, persuasive approach offers a challenge to military planners.

Recent actions have not fully addressed the overall problems of Army air defense. For example, recent indepth studies of Army air defense requirements have been concerned primarily with desired materiel characteristics and meet the needs of a research and development planner. In contrast the proposed study, is based upon a conviction that a basic organization for air defense in the Army is equally as important as equipment requirements. Many equipment technical deficiencies can be compensated for by innovative tactical and operational procedures. Development of such procedures, however, cannot be accomplished in a void where no organization or environment of complementary systems exists. Contrary to this thesis the Army for years appears to have concentrated on the process of procuring rather sophisticated equipment with little regard to how it will be employed or the force structure within which it must operate. As a result, the adequacy of current and proposed air defense systems to meet a full spectrum of requirements is not known, and an adequate air defense force structure does not exist.

None of the studies cited above addresses the problem of requirements for air defense units within the Army force structure. Further, in considering the areas in which Army air defense units may be employed, none of the studies considered COMMZ air defense requirements. In addition, many of the current deployment studies "beg the issue" of adequate air defense of committed U.S. Army forces by assumptions such as lines of communications through areas of other national states and that air defense of the areas of concern would be the responsibility of the friendly, foreign state exercising sovereignty.

It seems clear that a major effort should be undertaken to determine Army air defense requirements in relation to the total Army force structure. Preliminary to such a major analytical effort, an approach, i.e., a methodology, should be considered. It is to this preliminary goal that this paper is directed.

METHODOLOGY

Development of a force structure for Army air defenses, as with other forces, is a complicated and delicate process. It presents a challenge for aggressive innovative thinking and an exercise in restraint. The purpose of such a force structure is to provide U.S. forces the necessary balance to insure sufficient freedom of operation and maneuver to accomplish their assigned missions.

Accomplishment of an air defense force structure must be done in balance with the other assets in the theater of operation. In this respect, development of a force structure differs from developing specific deployments and an organization for combat. A force structure represents a normalized or average requirement for air defense forces to meet contingencies - worldwide. The number of units, by type, must be in balance with the other Army forces, in being.

Determination of the number of air defense units required is influenced by many factors. These factors may be categorized as either "standard" or "variable." The standard factors are those which remain relatively constant and lend themselves to quantitative measurement. Included are such items as:

- Priority of the defended unit/facility/installation; its military worth to blue forces
- Characteristics defined by the defended unit/facility/installation
    - Mission
    - Number
    - Typical size and relative location
    - Mobility, dispersion, and ease of concealment
    - Degree of damage it can sustain
    - Hardness and recuperability
- Characteristics of the postulated U.S. Army air defense materiel systems and the basic fire unit organization pertaining to that materiel
- U.S. Army air defense tactics which define the procedures for utilization of the materiel
- Characteristics of the red air threat in terms of magnitude (projected inventory numbers), performance capabilities, and typical tactics
- Roles and missions of Army air defense

The variable factors are those which will vary with the situation and do not lend themselves to quantitative measurement--except for the specific situation being considered. Included are such factors as:

- Terrain--particularly as it influences location of blue ground targets and the red air avenues of approach

- Contribution of the other blue air defense means to deter or reduce the red air threat. Such contribution may come from:
  - Other adjacent or associated ground-based air defense means
  - USAF
- The manner in which the available red air threat will be applied against blue ground targets, i.e., red intentions on the use of his air power
- Specifics of materiel performance related to the given situation, e.g., target handling capacity and single shot kill probability (SSKP)

Early, subjective analysis has indicated that the standard factors provide an adequate basis for defining overall Army air defense requirements in terms of troop units and the Army force structure. The variable factors apply only to a given situation. Measurement of their significance under the given situation is properly the subject of detailed wargaming to determine defense effectiveness.

The standard factors, within acceptable bounds, remain reasonably constant and, therefore, provide the basis for a methodology, which is not driven by a detailed situation scenario, for determining Army air defense force requirements. These standard factors are associated with what and how many of the U.S. resources in the field are to be provided ground-based air defense; the general characteristics of such resources--characteristics which remain generally unchanged regardless of where the Army is deployed; the characteristics and utilization of Army air defense materiel; and the numbers and capabilities of the red air threat. This latter factor is considered to establish a credible red air threat, a threat that red has the capability of using. The exact manner of utilization of the red air capability need not be established. Commitment to such an approach would define blue air defense requirements in terms of red intentions to apply its air capability.

Consideration of the standard factors will evolve a methodology for determining overall Army air defense requirements in quantitative terms, while detailed consideration of the variable factors by wargaming a number of typical scenarios will permit the validation and refinement of the numbers generated. To develop a force structure only the standard factors need be considered in detail. The goal is to establish a method of determining a standard ratio of Army air defense units to the total Army force structure. Modifications in numbers of air defense units associated with an army in the field, due to detailed consideration of the variable factors, may be made by decision at the time of such deployment. However, reliance should not be placed on the necessity to mobilize and train Army air defense units as a prerequisite to deployment. Required units should be a part of the Army force structure and be available for immediate deployment with the forces they are to protect.

Figure 1 illustrates the methodology for developing a force structure for Army air defense forces. Note that the end product is related directly to the number of divisions in the Army.

To develop a force structure it is necessary to define in some way the items that require defense. This requires definition of a situation or situations from which logical deployments of forces may be developed. In a recent study we elected to use one scenario in Central Europe involving a majority of the proposed Army 16 division force structure. We found that this scenario analyzed with respect to the standard factors provided adequate data for the development of Army air defense force structure planning factors. This step proved most important as it not only provided a list of assets for the theater but also an indication of where they would most likely be located.

An analysis of Army air defense roles and missions proved to be a critical step in the force structure development process. The role or function of Army air defense impacts on the missions to be accomplished and the missions in turn impact upon the equipment requirements as well as the tactics to be employed by Army air defense units. In other words, it soon became apparent that a defined role for Army air defense became the root from which the force structure grew. Simply stated the role of Army air defense is to defend the critical assets of the theater against air and ballistic missile attack.

This definition permitted development of a list of critical assets and (based upon their location the capabilities of the threat, and consideration of the contribution of area air defenses as well as their importance to the overall theater mission) arrangement in a relative order of priority. From these lists missions for Army air defense units were developed with respect to defending these assets under various operational conditions e.g., offensive, defensive, etc. By keying on the mission and location of the element being defended, it was also possible to analyze equipment requirements in terms of mobility, head-on engagement capability, etc., and to define, in broad terms, employment and deployment tactics. These, in turn, were used to develop specific deployments for Army air defense units.

Command, control and communications requirements were next examined in the context of existing Joint and Service doctrine to determine the necessary interfaces. This, in turn, led to a logical grouping of forces into organizations from which planning factors were developed.

An example of these planning factors is illustrated in Figure 2.

Related to a 16 division force the following number of air defense units would be required.

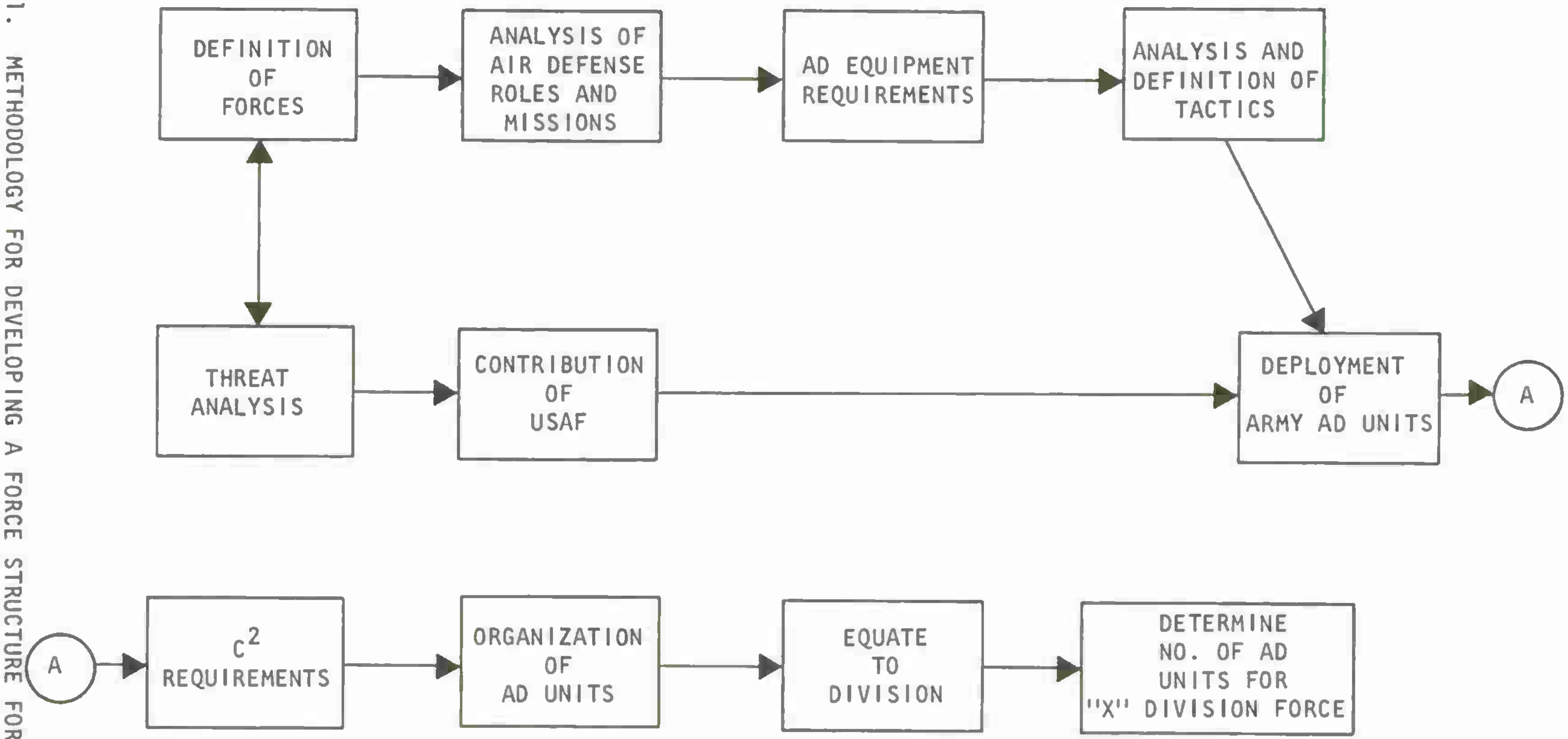

FIGURE 1. METHODOLOGY FOR DEVELOPING A FORCE STRUCTURE FOR ARMY AIR DEFENSE FORCES

REQUIRED NUMBER OF ARMY AIR DEFENSE UNITS
BY
TYPE PER DIVISION

TYPE UNIT	NUMBER
HQ & HQ BTRY, AIR DEF COMMAND	.083
HQ & HQ BTRY, AIR DEF BRIGADE	.333
HQ & HQ BTRY, AIR DEF GROUP	.917
C/V BATTALION (INCLUDES DIVISIONAL BATTALIONS)	1.833
HAWK BATTALION (SP)	1.000
HAWK BATTALION (TOWED)	1.833
HERCULES BATTALION (3 BTRY)	.250
HERCULES BATTALION (4 BTRY)	.250

FIGURE 2. PLANNING FACTORS

TYPE UNIT	NUMBER
HQ & HQ BTRY, AIR DEF COMMAND	1.0
HQ & HQ BTRY, AIR DEF BRIGADE	5.0
HQ & HQ BTRY, AIR DEF GROUP	15.0
C/V BATTALION (LESS DIVISIONAL BATTALIONS)	13.0
HAWK BATTALIONS (SP)	16.0
HAWK BATTALIONS (TOWED)	29.0
HERCULES BATTALIONS (3 BTRY)	4.0
HERCULES BATTALIONS (4 BTRY)	4.0

A comparison of these figures with those of other branches or major combat groupings in terms of the division slice is shown in Table 1.

These figures fall somewhat below the figures recommended by the Arms Board in 1952, which was appointed by General Mark W. Clark and apparently was the last organization to formally look at the air defense requirements of the Army. The Arms Board recommended that each division in the Army have one AW battalion organic to the division artillery. In addition, the Board recommended that 15.61 percent of the Army combat troops on M-day be nondivisional air defense units. In setting up a type Field Army, the Board allocated 31,448 troops to separate AAA, 9.11 percent of the strength of a type Field Army.

It must be emphasized that these planning factors are tentative and subject to further refinement. Specific scenarios in various possible areas of conflict need to be examined for the purpose of further validating and refining these figures. Once this is accomplished the Army will have a firm basis for a formalized air defense force structure. Such a force structure, if accepted and implemented, would include the following advantages:

- Provide a base of trained personnel from which to expand should the need arise. The base would be balanced and would consist of:
    - Active Air Defense Forces
    - National Guard Air Defense Forces
    - Reserve Air Defense Forces
- Support the development and acquisition of new equipment to fulfill specific roles and missions as the need arises

TABLE 1

DIVISION SLICE-MAJOR GROUPING

1	2	3	4	5	6	7
	WORLDWIDE SLICE (PERCENTAGE)		THEATER SLICE (PERCENTAGE)		COMBAT ZONE SLICE (PERCENTAGE)	
BRANCH OR OTHER MAJOR GROUPINGS	TOTAL (71,955)	CONUS PORTION (20,000)	TOTAL (51,955)	COMMZ PORTION (12,250)	TOTAL (39,705)	CORPS (21,743)
ARMOR	2.1	0.3	2.8	-	3.7	6.7
FIELD ARTILLERY	7.1	1.6	9.2	-	12.1	22.1
AIR DEFENSE ARTILLERY	5.7	1.3	7.4	-	8.2	15.0
ENGINEER	8.5	4.0	10.2	14.3	8.9	16.2
MAINTENANCE	5.1	1.4	6.5	7.9	6.0	10.9
S&S	5.7	2.6	6.8	14.8	4.3	8.0
TRANSPORTATION	6.2	5.0	6.7	16.3	3.7	6.7

- Provide the flexibility necessary to meet the needs of contingencies and permit the tailoring of forces to the extent necessary

- Enhance the air defense career field by providing:

  - Visible recognition of the air defense combat arm

  - Visible continuity for a career

  - A rotation base balanced with other combat arms

COST EFFECTIVENESS ANALYSIS OF ENLISTMENT/REENLISTMENT BONUSES

by
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1. Introduction

a. In force design, a general objective is to design the mix of the force that will maximize combat power against a specified threat. Great care is taken to insure that a proposed force is first, feasible in terms of weapons systems and secondly, can be achieved within given fiscal constraints and manpower authorizations.

b. Less consideration is usually given to whether the force is feasible in terms of the availability of personnel with the required skills; yet the personnel constraint may, in reality, be the first constraint to become active. In June of 1972 the Army found that it was necessary to pay a cash bonus to induce enlistments into the combat arms. The authorized Army force structure as it was then constituted could not be sustained through the normal flow of accessions which allowed enlistees a choice of occupations. The bonus had the effect of increasing the total number of accessions and the further effect of channeling them into the skills where they are needed.

c. The favorable results achieved from the combat arms bonus program caused the Deputy Secretary of Defense to request approval by Congress to "Provide the Secretary of Defense with the expanded authority to award an enlistment bonus across Service lines solely on the basis of critical skill determinations in order to fulfill existing accession requirements for enlisted personnel." In a letter to the Chairman of the Senate Armed Services Committee, Mr. Clements stated that the ". . .bonus would be employed only when demonstrated to be cost effective and only when other alternatives have been fully explored and exhausted."

d. The Assistant Secretary of the Army for Manpower and Reserve Affairs subsequently tasked the Concepts Analysis Agency to conduct a study to identify cost effective enlistment and reenlistment bonuses. The study is being conducted in two phases. Phase I concentrated on the enlistment bonus and has been completed. Phase II deals with reenlistment bonuses and is now in progress. The remainder of this paper provides a description of the work completed under Phase I.

2. Effectiveness - The Department of the Army authorizes enlistment bonuses only to individuals that enlist for four years. A key premise of the Phase I effort is that without the bonus individuals will enlist for two or three years and that a cost effective bonus to induce a four-year enlistment can be identified. Thus it is assumed that an MOS position

will be continuously filled and that each enlistment option e.g., two, three and four years, has a cost associated with keeping that billet filled. This allows a comparison of alternatives with equal output but unequal costs. The cost differentials provide a basis for determining the level of bonus which would be cost effective.

3. Costs - The developed methodology assesses the costs associated wtih the typical enlisted man during his initial enlistment. As indicated in Figure 1, the costs have two principal components: those costs that are independent of MOS and common to all enlistees and those costs that are unique to a specific MOS. Most of the cost categories need no explanation. A possible exception is the support cost, which represents a factor for variable medical payments and activities such as commissaries and PX's supported by the Operation and Maintenance, Army appropriation. Another is the income tax element which represents the estimated average additional income tax that would be paid if the allowance for quarters and subsistence were taxable. The primary data source selected to support the cost categories is the Department of Defense report on the Economic Cost of Military and Civilian Personnel. In cases where our enlistment bonus study's purpose required data different from that of the Defense report, or where a greater resolution of data was required, e.g., MOS unique costs, Army Staff or government agency sources were used. Figure 2 presents the data sources associated with each of the study cost categories.

Figure 1
Cost Categories

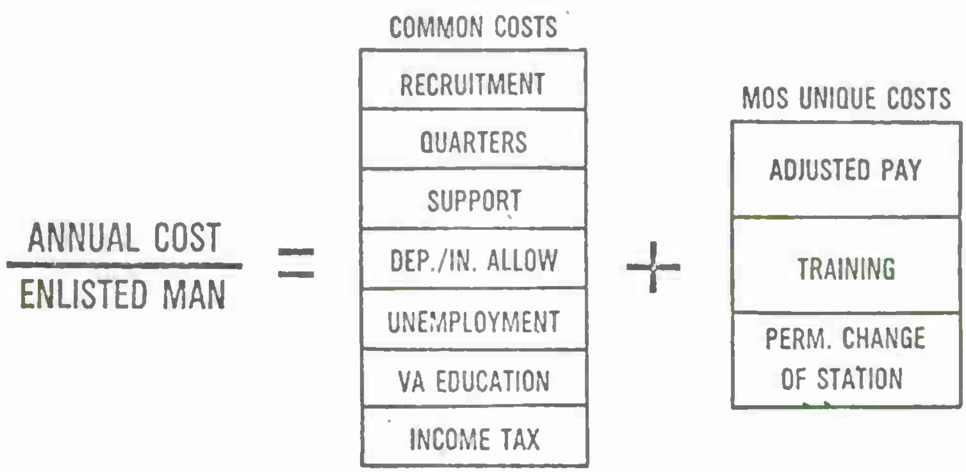


Figure 2
Data Sources for Cost Categories

COST CATEGORY	DATA SOURCE
Recruitment	US House of Representatives Report Conference: US Army Recruiting Command
Quarters	"Economic Cost of Military and Civilian Personnel in Department of Defense"
Support	Same as above
Dependence & Indemnity Allowance	Same as above
Unemployment Compensation	Same as above
VA Educational Benefit	Conference and Letter-Report: Veterans Administration Conference: DOD Staff
Income Tax Adjustment	"Economic Cost of Military and Civilian Personnel in Department of Defense"
Adjusted Pay	"Economic Cost of Military and Civilian Personnel in Department of Defense" augmented by Conference: ODCSPER and by DA Circular 611-19.
Training	"Military Occupational Specialty Training Cost Handbook-Enlisted" OCA.
Permanent Change of Station	"Program Objective Memorandum FY 75-79" "DCSPER Capability Study, RCS-926"

4. Study Methodology - The total cost for each MOS is computed by summing the applicable costs at MOS level. Individual comparisons are then made between the two or the three-year enlistee's productive man-year cost, respectively, with that of the four-year enlistee. Productive man-year (years of enlistment less training time) costs are the total costs of two, three or four-year enlistments divided by the associated number of productive man-years. The difference in productive man-year costs between a two or three-year enlistment and a four-year enlistment is the cost savings (or loss) per productive man-year which accrues from a four-year enlistment. This annual savings multiplied by the total productiv time of a four-year enlistment yields the total costs saved when compared to two or three-year enlistments. The result is the maximum bonus payment which is cost effective; i.e., the MOS bonus ceiling. An example of this process for a two-year versus four-year comparison can be illustrated with the use of Figures 3 and 4. In Figure 3 the "non-DOD" elements include those costs associated with: dependency and indemnity compensation, unemployment compensation, educational benefits and income tax adjustment, while the "other DOD" components include costs associated with PCS, quarters and support. The four step process, described below, applies to all MOS.

Figure 3
MOS 12B20 - Combat Engineer

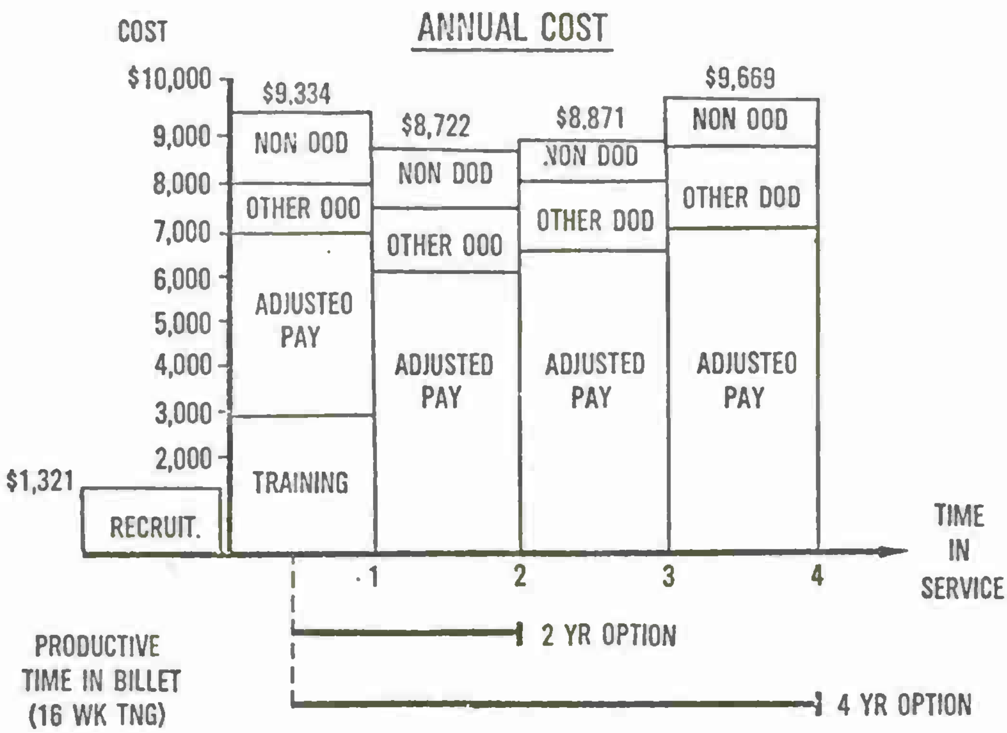
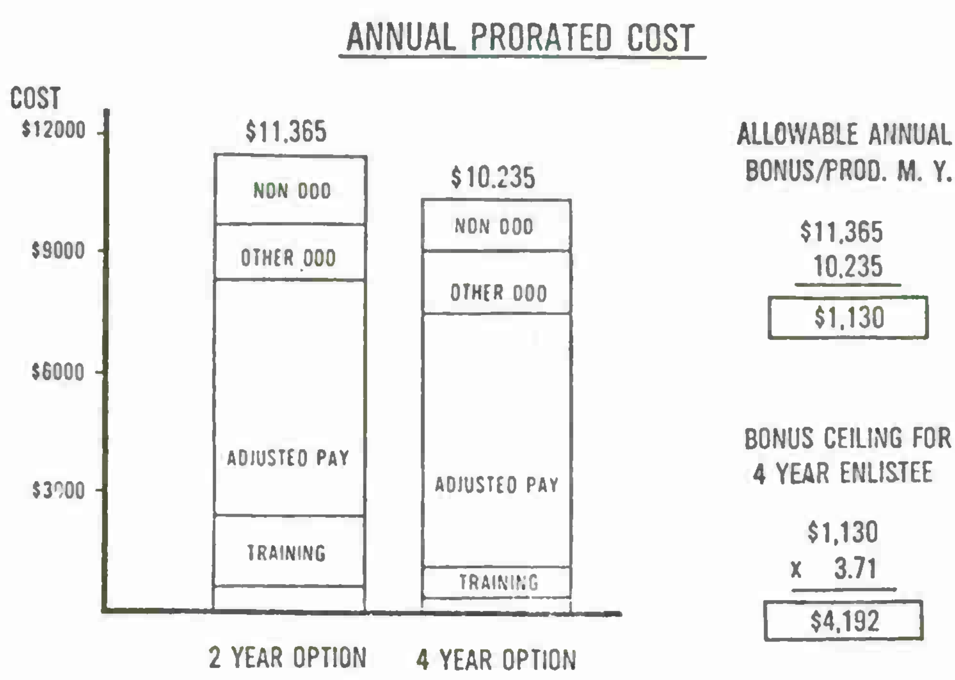


Figure 4
MOS 12B20 - Combat Engineer



a. Step 1 sums the total two-year cost for this illustrative MOS: 12B20, Combat Engineer, as that for recruiting ($1321), the first year costs ($9334) and the second year cost ($8722) for a total of $19,376.

b. Step 2 prorates this total over his approximate 1.7 years in billet to arrive at an annual prorated cost of $11,365 as shown in Figure 4. Similarly, the four-year prorated cost is determined.

c. Step 3 compares the four-year and two-year prorated costs as shown in Figure 4 reflecting a $1130 difference.

d. Step 4 multiplies this difference by the four-year enlistee's time in billet, establishing the cost effective bonus ceiling of $4,192 as shown in Figure 4.

5. The Model - Attendant to the analytical effort, a computer-based model was developed to calculate the cost effective bonus for each MOS at the four digit level. The model is deterministic with two optional report formats. The abbreviated format reflects only annual costs and bonus ceilings. This output provides a compact reference showing all the computed bonus limits and facilitates the comparison of potential savings among MOS. A detailed format provides information on how the individual cost categories contribute to the bonus ceiling. The model is written in FORTRAN V to run on the UNIVAC 1108 computer. Execution time to evaluate 510 MOS is less than two minutes and storage requirements do not exceed 20,000 decimal words.

6. Data - To facilitate assessment of changes, the model has been written to accept most endogenous and exogenous variables in data card format. This feature is useful in evaluating the effects of proposed policy changes. Specific data elements required to operate the model are the following:

a. Variable input parameters, which must be provided to initialize the model:

(1) Type of output desired.

(2) Remaining time in service required for promotion to E-5.

(3) PCS costs.

(4) Recruiting cost.

(5) VA educational cost and weighting factor.

(6) Average time in service for promotion to the next higher pay grade.

(7) Annual costs by grade for:

(a) Composite pay

(b) Quarters

(c) Support

(d) Foreign Duty

(e) Aircrew

(f) Dependency/Indemnity

(g) Unemployment

(h) Income Tax Adjustment

b. Variable input parameters which must be provided for each MOS.

(1) MOS number and title

(2) Specific MOS promotion sequence (optional)

(3) Length of training

(4) Variable training cost

(5) Overseas deployment

(6) Percent of MOS drawing proficiency pay

(7) Amount of proficiency pay

(8) Percent of MOS drawing aircrew pay

(9) Percent of MOS drawing hazardous duty pay

(10) Amount of hazardous duty pay

7. Externalities - The methodology developed in this study is concerned principally with quantifiable variables for which official cost data can be obtained and utilized. Although not included in the study methodology, several cogent factors are identified below for judgmental consideration in the management and application of the enlistment bonus. These are:

a. The added operational effectiveness of the individual inherent in the longer (four-year) enlistment.

b. The effect a bonus awarded to one MOS may have on another MOS. For example, a bonus awarded to one MOS might induce enlistments in that MOS to the detriment of others.

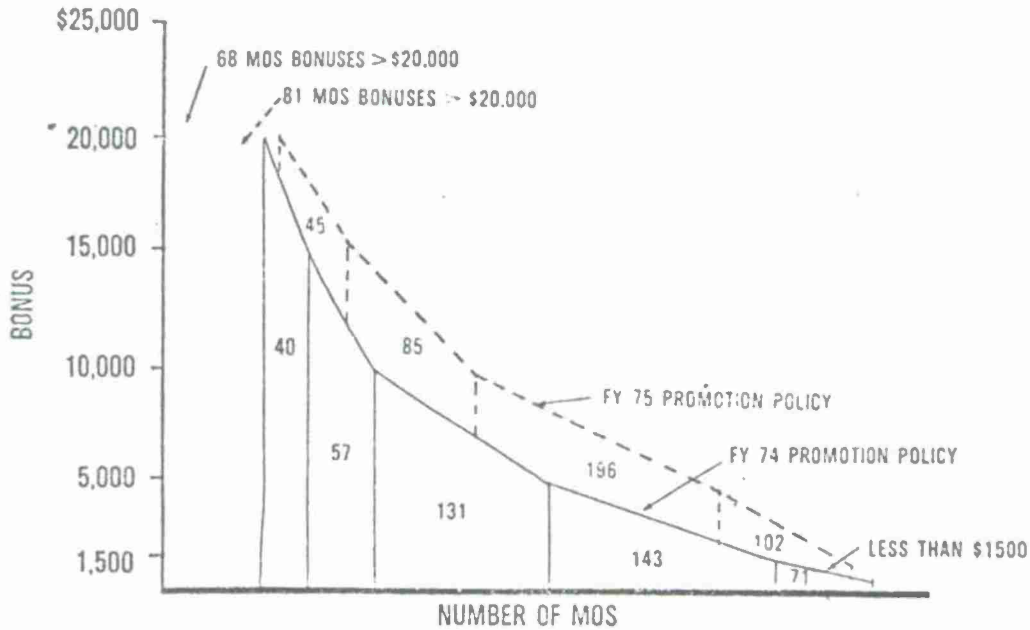
c. The ranking of critical MOS which are all bonus candidates in order to determine which should be authorized a bonus if money is constrained.

d. The improved management inherent in a force composed of a high proportion of enlistees under a longer (four-year) enlistment.

The model previously described calculates a cost effective bonus ceiling based on quantifiable factors. The decision of whether or not to award a bonus and what that bonus should be requires consideration of the non-quantifiable factors as well.

8. Sensitivity - The design of the model permits and facilitates assessment of the impact of changes to critical personnel policies such as promotion points and training time. For example, the model was exercised using FY 74 promotion policy and then iterated using FY 75 promotion policy which generally had increased time in service requirements for promotion. Figure 5 reflects bonus sensitivity as a function of promotion policy.

Figure 5
Bonus Ceiling Sensitivity to Promotion Policy
(Four vs Two-year Enlistment)



Note that 71 MOS have bonus ceilings of less than $1500 using FY 74 promotion points, but that all MOS are cost effective at the $1500 level when FY 75 promotion policies are used. This threshold is significant because it is the lowest bonus payment that the Army presently intends to offer. As is to be expected, the other factors which play major roles in establishing bonus ceilings are the length of training and the variable training cost. It is significant that MOS which require only basic training have bonus ceilings in the $2000 range while MOS 28Q20, which is a SAFEGUARD MOS, has a training time of 69 weeks and a variable cost of training of $62,492, and could support a bonus of up to $194,000.

9. Observations - The conduct of this study involved establishing a methodology, developing and documenting a model and employing the model to calculate a cost effective bonus level. Resulting from that process are the following significant observations:

a. The FY 75 enlistment bonus program is cost effective when comparing the two-year versus four-year enlistment.

b. It is cost effective for all MOS to offer a bonus to induce a four-year enlistment.

c. The bonus computation model provides useful insight into the actual costs incurred in staffing an MOS.

d. This study will serve as an aid in considering the cost effectiveness of enlistment bonuses; however, the determination of whether a bonus should be offered and the amount cannot be determined on the basis of currently quantifiable factors alone. Effective management of the enlistment bonus program involves the application of judgment to many simultaneous Army requirements and the need to operate within constraints. Weighting of these considerations rests with the manager of the bonus program and with decision makers reviewing the program.

10. The wide range of bonus ceilings from $2000 to nearly $200,000 suggests alternative uses for the bonus computation model. For example, MOS with very high bonus ceilings such as MOS 28Q20 may be excellent candidates for civilianization. Another alternative might be to retrain a career soldier from a surplus career field into the high cost MOS. The state of the art today allows us to cost a potential or an actual force. The direction of operations research in the personnel area in the future should be to manage those costs; to provide better service at less cost.

TITLE: The IDA TACNUC Model Study

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Institute for Defense Analyses (IDA)

IDA TACNUC Model Study

The IDA TACNUC Model Study is part of a larger effort that IDA/WSEG is undertaking for the JCS in the development of methodologies for evaluating the effectiveness of general purpose forces. Under the present effort, IDA is tasked with the development of a model, or models, that can be used to evaluate, on a theater-wide scale, the relative effectiveness of combat forces employing both nuclear and nonnuclear weapons.

At the present stage of development the TACNUC model structure considers the interactive effects of the various routines shown in Figure 1. Both the scenario information and the user supplied input are used to direct the model's operation. For example, the nuclear routine provides for the assignment and assessment of nuclear weapons on various targets throughout the theater. The assignment of weapons to combat units is either user specified or developed from user inputs by an internal assingment procedure. Assignment of weapons to fixed targets, at present, is directed by the user. On the other hand, the tactical air routine determines the allocation of aircraft to specific combat missions based on a user input allocation, then computes attrition to tactical aircraft from various ground and air sources, and finally provides combat air support missions for use in the ground combat routine. The overall model operation is guided and controlled by the theater combat routine. This routine allocates arriving resources to various areas within the theater, moves units into combat or into reserve based on input parameters and/or model logic, and in general, does detailed bookkeeping on the many resources that are required by the other routines. In most cases routines are oriented to indicate their effect on the ground combat routine. The ground combat routine determines unit movement and the level of unit effectiveness resulting from the interaction of this and other routines. (Presently, there are two development efforts on the ground combat routine: one effort to develop the movement and engagement rules of a maneuver-oriented ground combat model, and a second effort to extend the concept of IDA's sector-based, conventional, ground-air model (IDAGAM) to a model logic consistent with required features of the nuclear routine. Only the theater structure of this second approach is described here; other features, with minor exceptions, are documented in IDA Report R-199.)

A summary of the model components and assessments is presented in Figure 2.

Figure 1. GENERAL STRUCTURE OF THE TACNUC MODEL

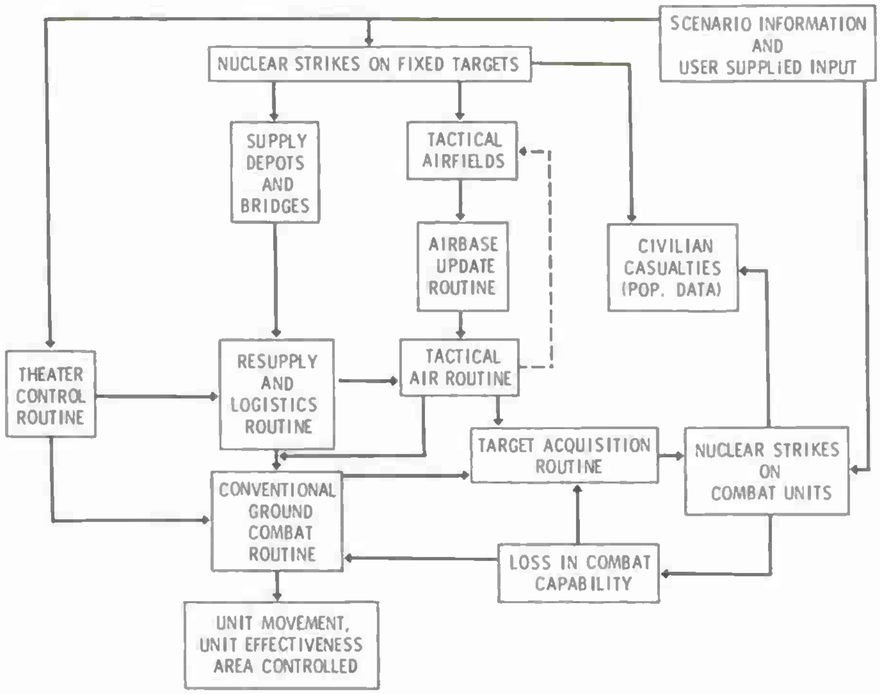

Figure 2. MODEL COMPONENTS AND ASSESSMENTS

A. Conventional Combat

1. Ground Combat

a. Executes movement of battle units
b. Develops combat engagements
c. Assesses personnel and weapon attrition

2. Tactical Air Combat

a. Develops multi-mission assignment of tactical aircraft
b. Determines allocation of tactical aircraft to target areas
c. Computes aircraft attrition by type mission

B. Target Acquisition

1. Computes the number of targets detected, by type, for each time period
2. Considers the availability and target detection capability of sensors
3. Considers the number of targets available and their environment

C. Nuclear Combat

1. Nuclear Weapon Assignment

a. User's guidance on damage criteria permits automatic weapon assignment
b. Assignments guided by employment options and employment criteria
c. Assignments consider friendly force and civilian population targeting constraints

2. Nuclear Damage Assessment

a. Expected damage expressed as a mathematical function
b. Damage assessed against fixed and mobile targets
c. Weapon, delivery system, and target characteristics considered

D. Theater Control

1. Assigns the replacement and augmentation units to battle areas
2. Handles theater wide basing of tactical aircraft to airbases
3. Accounts for the resupply and update of ground forces and air combat forces

I. THEATER STRUCTURE

The TACNUC model is designed to be a theater-level model that can play the delivery of conventional and nuclear munitions by both air and ground delivery means anywhere in the theater. The components of the theater structure include sectors, battle areas, regions, and the COMMZ. This theater structure forms the basis of the sector-oriented combat model. By ignoring the sector data, this structure is equally applicable to the maneuver-oriented ground combat model.

Geographical Sectors and Battle Areas--The theater structure is built around a series of non-intersecting geographical sectors that cover the theater area of interest. These sectors are considered as avenues of advance that run the length of the theater and are of variable width. Each sector is divided into a fixed number of subdivisions that are of equal depth but a width that varies in accordance with the sector width. (See Figure 3.) These subdivisions are called battle areas and are assumed to be of constant terrain features throughout the battle area. Within the sector, and hence within a particular battle area, specific impediments to movement (or barriers) may be located. Ground combat takes place in that portion of the sector near the line that separates the two sides. This line is traditionally called the FEBA. The battle areas within which combat occurs are termed active battle areas, with all others being inactive battle areas.

Regions--Regions consist of the rear portion of one or more geographical sectors, beginning at the rear of the active battle area and extending to a predefined depth. Each region is divided into two parts: a forward region and a rear region. These two parts are created to provide the tactical air routine with the capability of representing, in a stylized way, varying range capabilities of different aircraft.

COMMZ--The COMMZ is an area to the rear of the rear region that spans all sectors in the theater. The COMMZ is used for receiving the arriving combat units, tactical aircraft, supplies, and replacement weapons and personnel. The COMMZ serves as a holding area for combat resources and provides airbase facilities for long range tactical aircraft.

In summary, the theater structure of the TACNUC model provides for sectors, battle areas, regions, and a COMMZ. Any element played in the model can be located by its association with a specific battle area, either active or inactive. All the other elements of the theater structure, sectors, regions, and COMMZ, are used as controlling mechanisms to assign various resources to particular areas of the theater: sectors are used as controlling mechanisms for combat and subsequent movement of forces; regions are used as controlling mechanisms for the assignment of tactical aircraft to missions throughout the theater, and for assigning combat forces to sectors; and the

Figure 3. THEATER STRUCTURE - SECTORS AND BATTLE AREAS

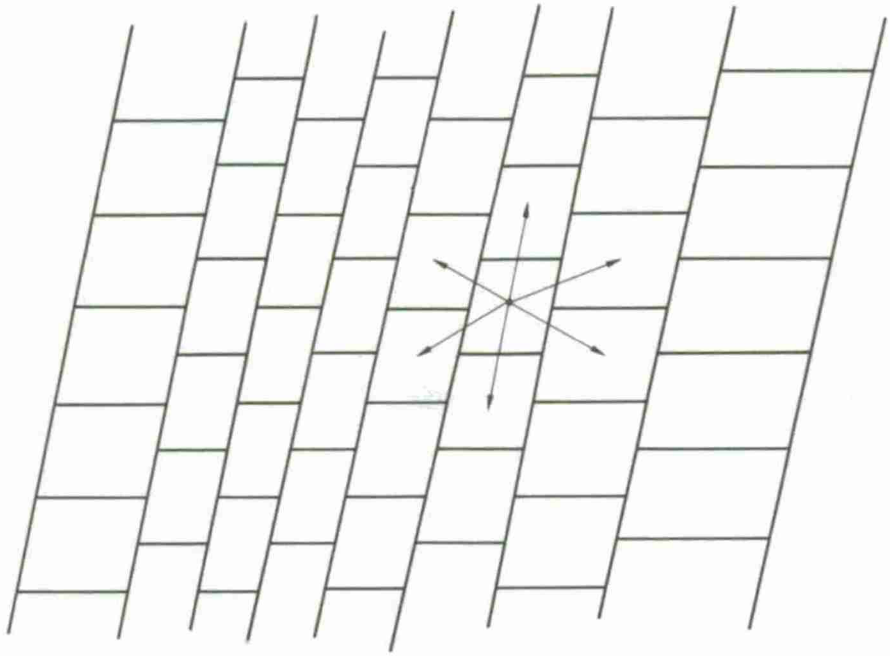

Figure 4. RESOURCES CONSIDERED WITHIN THE TACNUC MODEL

A. Ground Combat Resources

1. Division or Brigade sized combat units
2. Coordinate location for each combat unit
3. Number of people and weapons, by type, for each unit
4. Number of nuclear delivery systems, by type, for each unit
5. Subunits distributed by company, battery, and launcher level
6. Number of people and weapons, by type, for each subunit

B. Air Related Resources

1. Coordinate location of each airbase
2. Number of shelters, aircraft, SAMs and AAA at each airbase
3. Number and general location of notionalized airbases
4. Number of shelters, aircraft, SAMs and AAA at each notional airbase

C. Other Resources

1. Location, size, and nuclear weapon content of each SASP
2. Location, size, and number of missiles of non-divisional missile sites (SSMs and SAMs)
3. Location, size, and tons of supplies of logistics and resupply areas
4. Location, size, and total personnel of Corps, Army, and Theater headquarters units
5. Location, size, and total population of each high density civilian population area in the combat theater

COMMZ provides for the central control and storage of all resources entering the theater.

II. RESOURCES

The two opposing sides in the TACNUC model, denoted by Red and Blue, are represented in a symmetrical manner. Each side can have ground and air resources, with each type of resource having either a conventional capability or a nuclear capability, or both. All the resources considered in the TACNUC model are summarized in Figure 4. Items under the "other resources" category are resources that are affected by nuclear weapons either as a result of direct targeting or indirect effects.

III. ROUTINES WITHIN THE TACNUC MODEL

A brief discussion of certain routines within the TACNUC model is presented in the following sections.

A. A Maneuver-Oriented Ground Combat Model

Current Russian tactical doctrine emphasizes broad exercise of maneuver, exploiting the enemy's exposed flanks and gaps in his formation. Russian military leaders recognize that decisive results have rarely been achieved without a threat to the enemy's lines of communication or lines of retreat. Likewise, NATO doctrine seems to recognize the need for counterthreats to enemy penetrations. Given the importance of maneuver in modern tactics, it is remarkable that so few computerized ground combat models can accommodate it.

In contrast to models that slice the theater into numerous sectors, this ground model partitions the theater into "battle areas" of arbitrary size and shape. The only restriction is that each battle area not on the theater perimeter must have exactly six neighbors; one way to achieve this structure is to let the battle areas be equal-sized hexagons.

A unit's location is defined to be the battle area it occupies. A unit can move directly from the battle area where it is located to any adjacent battle area. Its rate of movement depends upon its type, the terrain on "the" route between the two battle areas, and the user-specified "basic transit time" for travel between them. A unit's actions--movement and change of posture--are governed by its mission--a sequence of timed orders.

Missions are input by the user or generated by one of the model's subroutines. Orders are basically instructions to change posture and location. The model logic is capable of interpolating between orders, so that a relatively short sequence of orders (a simple mission) can specify a long sequence of movements and attacks. Missions may only be provided at preset times, and in the interim the tactical situation may necessitate altering some of them; the alterations are made by two subroutines, both designed for easy modification. By an appropriate choice of missions (or the mission-generating subroutine), the user can force the war to develop along whatever lines he chooses. In particular, he can organize the battle areas axially into sectors and exclude attacks across sector boundaries, and the model will emulate a sector-based model.

The model recognizes four classes of unit postures: defense, withdrawal, march, and attack. Within each class there may be as many as ten postures; for example, defensive postures might be distinguished by degree of preparation and willingness to yield ground. Much of the model's temporal structure comes from delays in transitioning from one posture to another. Sometimes these result from combat (an attacker must defeat the defender before it can occupy the defender's battle area).

An engagement occurs when one side attempts to seize a battle area controlled by the other side. Such a contested area has a stylized FEBA, which measures the territorial progress of the engagement. The attrition suffered by each side and the rate of FEBA movement depend upon the battle area's "environment" (e.g., natural terrain and towns); in general, the environment characterizes all factors relevant to combat that are not simply expressions of the forces involved. The theater structure makes it possible to play simultaneous assaults on a battle area from different directions and to play encirclements. Thus, breakthrough and exploitation can be modeled at a level of realism impossible to achieve in sector-based models. However, by restricting mission generation, the user can force the model to emulate a sector-based model.

In many other models, the attrition process is the central component, reflecting a lack of balance in modeling effort between attrition and maneuver. In this version of the model, a force ratio is determined, based on weapon antipotential potentials, and is used to compute weapon losses (by type), personnel casualties, and movement of the battle area's stylized FEBA.

B. Tactical Air Routine

The TACNUC tactical air routine is designed to assess the effects of opposing tactical air forces interacting with an opponent's air and ground resources. The model logic allows aircraft to interact with opposing aircraft through airbase attack and air-to-air combat. The interaction between air and ground is modeled through the destruction of combat forces by the close air support mission. The attack on supply depots, on long range missile sites, and on combat forces in the rear, is modeled through the interdiction mission. Other air superiority missions such as escort, intercept, and air defense are assigned as required depending on enemy air activity. All assessments made by the tactical air routine are conventional weapon assessments. The nuclear missions are assigned either by the user or by the tactical air routine's automated logic but are assessed in the nuclear damage routine.

The assignment logic of the tactical air routine assigns the inventory of aircraft for a given day to various missions throughout the theater. The assignment is given in terms of the fraction of aircraft, by type, to be used on each of six combat missions. The six missions are: airbase attack, close air support, interdiction, escort, battlefield defense, and airbase defense. A seventh mission, tactical reconnaissance, is played also.

The assignment logic is designed for use in one of three ways.

1. Completely user input controlled such that all assignments are specified for the entire length of the campaign.

2. Completely dynamic in nature such that the assignment in a given period depends upon the assignment in previous periods as well as upon other selected factors; e.g., aircraft drawdown rates.

3. Some combination of 1 and 2 such that the user may specify given assignments for certain periods, but beyond that the dynamic nature of the model will prevail.

The dynamic portion of the model allows the user considerable flexibility in determining the strategy to be employed in assigning aircraft to missions. By specifying the appropriate values, the user can portray various sets of air strategy parameters and hence air strategies. With these input values as a guide, the decision logic determines the day-by-day assignment of type aircraft to type missions.

The number of aircraft types that are considered on each side is a user input. However, because of the allocation scheme used in assigning aircraft to missions, it is important that the aircraft be assigned to one of the following three categories: fighter, attack, or (dual purpose) fighter/attack. In addition, three separate range considerations of the aircraft are included: short, medium, and long range. With these six categories of aircraft capability available, it is possible to provide within the air routine assignments of short, medium, and long range fighter aircraft, attack aircraft, or fighter/attack aircraft to the six combat missions.

The TACNUC model also has available to it a data file describing, in detail, each of the active tactical airbases. This file is used when assessing the effects of nuclear strikes on specific airbases. However, for the conventional assessments, a reduction in the number of bases considered was in order. For these assessments notional airbases were created from the file of actual airbases with the objective that each combat sector would have two notional bases. Each notional airbase created in this manner is made up of one or more actual airbases that are known to exist in the sector area of interest.

Each notional airbase is characterized by its location, the number of aircraft of each type based on it, the number of shelters associated with it, and the number of SAMs or AAA protecting it. The aircraft on each notional airbase may or may not be sheltered depending on the number of shelters available and the sheltering priority scheme for type aircraft. As the enemy overruns certain actual airbases, the number of aircraft and air resources included in any one notional airbase is reduced.

C. Target Detection and Acquisition in the TACNUC Model

In a combat situation where tactical nuclear weapons can be used, the process of target acquisition is particularly important since nuclear weapons are a very expensive, very lethal resource, that should be applied only to the most militarily significant targets. Thus, in a model of tactical nuclear combat it is desirable that target acquisition be played in a realistic way so that we can effectively portray the capability of the opposing forces to acquire targets on which to direct nuclear fires.

The target detection model deals with probabilities of target detection because: (i) it is not certain that detection is possible under all environmental and physical conditions, and, (ii) even when detection of a target is possible, it is not certain to occur due to a number of interfering factors. In the model the probability of target detection is made a function of a number of environmental and physical variables.

It is assumed that the general location of the NATO and Warsaw Pact forces is known across the theater. Both sides operate sensors to acquire candidate targets for possible nuclear fires. The targets are positioned within range zones of stylized division arrays. Some of the sensors are located within a sensing division itself and move with the division (e.g., ground sensors), while others are associated with aircraft stationed at fixed geographical positions (e.g., air-carried sensors) and are allocated to different target divisions by sensor allocation rules.

The primary targets for nuclear weapons generally are combat maneuver units, nuclear delivery systems, command and control centers, and logistics areas. The specific targets considered in a typical Soviet array might be motorized rifle companies, tank companies, SSM batteries, conventional and nuclear artillery batteries, and division, regiment, and field artillery headquarters. Corresponding NATO targets would be acquired by the Warsaw Pact forces.

A convenient way to categorize the various sensors used in the model is by their mode of operation. A representative list might include the following:

Standoff (fixed)

- Visual: unaided or aided.
- Radar: counterbattery, countermortar, surveillance.

Standoff (moving)

- Helicopter or Mohawk with photo, infrared, and SLAR.

Penetrating

- RF-4C or Drone with photo, infrared, and SLAR.

Underlying Intelligence Sources

- ELINT Systems, Satellites, and POWs.

The probability that a target is detected over some interval of time is modeled so that it is a function of:

(a) The capability, number, location, and mode of operation (standoff fixed, standoff moving, or penetrating moving) of the sensors.

(b) The detectability, number, and location of the targets.

(c) Environmental factors such as terrain, ceiling, visibility, and time of day.

"The target acquisition routine calculates the probability distribution of the number of targets of each type detected within each target division" as follows: First, compute the probability that a single sensor detects a single target. Then, assuming that all sensors operate independently, compute the overall probability P that a target is detected. If the number of targets present is N, it then follows that the number x of targets detected has the binomial distribution.

$$\binom{N}{x} P^x (1 - P)^{N-x}$$

This information on target detection is then provided to the nuclear portion of the TACNUC model.

D. Nuclear Damage Assessment

The assessment of nuclear damage against military targets will fall into two general categories; blast damage to weapons equipment and personnel and cumulative effects of initial nuclear radiation against personnel. In each category effects against primary targets of interest and bonus damage to adjacent units will be evaluated.

All assessments are made in an expected value sense. Primary targets are assumed to be either uniformly distributed in value with a specified radius or normally distributed with a specified variance. Target elements of bonus targets will be assumed to be uniformly distributed over the fraction of the appropriate "range zone" which is not occupied by the primary target. For the case of multiple rounds delivered within a given division range zone the expected bonus damage level from blast to a particular target will be compounded probabilistically assuming mutual independence between damage probability predictions for each burst. The probability of surviving each round will be conditioned in the event that the target unit was not a primary target. For example, suppose two similar rounds are fired at type A units. Further, assume that there are N_1 type A units. If P is the expected destruction level against a type A unit given that it was not a primary target, then the total expected fraction of blast damage to accrue against type A targets in the form of bonus damage is

$$N_1[1 - \frac{N_1 - 2}{N_1}(1 - P)^2] .$$

Of course, these calculations would be made for each target element category (e.g., trucks, APCs, tanks, etc.)

As the effects of radiation are additive in nature, a different device is required for their estimation. The basic approach will be to maintain an estimate of the fraction of each battle unit which is in each of several cumulative radiation "states." The states might correspond to cumulative dose level or some appropriate surrogate such as the number of days remaining before becoming combat ineffective. Again, it will be assumed that successive weapons are delivered independently. With this assumption the cumulative radiation state of personnel within a given battle unit will be treated as a Markov process with the delivery of each weapon initiating a transition. Even with the assumption of independence, the requisite Markov property probably does not hold precisely. However, it is felt that this is a reasonable approximation.

A basic requirement for the calculations implied by this approach is an efficient means of determining the area covered by radiation of a specified level. This poses a problem since available radiation estimation algorithms calculate the radiation level at a specified range given appropriate weapon and target parameters. The approach which we shall use is to construct a subroutine which will utilize such an algorithm, along with a list of weapon yields, burst heights, protection factors, and various other effects assumptions to fit a number of curves. These curves, one for each yield, height of burst, and protection category combination will estimate effective biological dose as a function of range, but in a functional form which is invertible. In particular, the form chosen is:

$$\ell n(\text{dose}) = \frac{a_0 + a_1(\ell n\,\text{range}) + a_2(\ell n\,\text{range})^2}{b_0 + b_1(\ell n\,\text{range}) + b_2(\ell n\,\text{range})^2}.$$

This choice of approximating function was motivated by three factors:

1. Goodness of fit (5 parameters are available)
2. Invertibility
3. Ease of automation.

The third factor is important should a user wish to consider an alternative list of weapon or target characteristics or different effects assumptions.

To illustrate the above calculations indicated we make the following definitions:

1. p_i = the probability that a target element is in radiation state i
2. P = the transition probability matrix whose i, jth entry is the probability that a target element will transition from radiation state i to state j when one weapon of a given type is detonated. These values will depend on the definition of the states and on the curves described above.
3. N = the number of weapons of a given type to be fired
4. $\bar{p}_i$ = the updated value for p_i following an attack.

Then,

$$(\bar{p}_1, \bar{p}_2 \cdot\cdot, \bar{p}_i \cdot\cdot) = (p_1, p_2 \cdot\cdot, p_i \cdot\cdot)P^N$$

The effect of time which moves persons either closer to combat ineffectiveness or further away due to recovery depending on cumulative dose level is easily incorporated within such a framework.

E. A Supplies Network for the TACNUC Model

The basic concept of the supplies network proposed for the TACNUC model is discussed below.

(a) The node locations are chosen first over the breadth and depth of the theater. Likely node locations are key points in the actual transportation network such as ports and transportation centers. Another restriction is that nodes be chosen so that any arc which joins two nodes represents the distance supplies can be moved in one cycle. This distance must, of course, recognize the local terrain and be averaged over all modes of transport. The reason for this requirement is so that at the end of any cycle all supplies flowing in the network can be assumed located at a node.

(b) Once the network is chosen it will be necessary to associate each actual or notionalized supply pools and ports with a node of the network. Similarly, airbases and battle areas must each be associated with at least one node in the network. The end result of this step is a model of the supplies network of the theater, with all key locations included.

Once the network is constructed, one is faced with the problem of how supplies will flow within it. One approach, which is only sketched here, is as follows: For each node determine the net availability of or requirements for supplies at the node for the next cycle. A node having a net surplus is called a source, one having a deficit is called a sink. Some nodes will be neither. Then solve a transshipment problem to determine the flows from the sources to the sinks which minimize the total flow time required to satisfy all the demands. This procedure is repeated at the beginning of each cycle using updated supplies and demands. Since each arc has a transit time of one cycle, all supplies are automatically located at a node at the end of a cycle and this makes updating straightforward. (If capacities exist and can be associated with each arc, a capacitated transshipment problem can be solved to determine the time-minimizing flow pattern.)

There are a number of questions that must be answered in carrying out this procedure. Arc travel times and capacities are not clearcut and considerable judgment is required to determine their values. Supplies available at nodes must be generated from overall theater stockage policies as well as supplies already moving through the network. Demands required by nodes are a combination of supply consumption, supply losses due to interdiction, and desired inventory levels. Allocation policies must be generated to handle cases where theater demand exceeds theater supply since the transshipment algorithm requires that total supply be at least as large as total demand. In addition, the supplies model must interface properly with the ground, air, and nuclear models since they all have considerable impact on supplies.

METHODOLOGY FOR TOTAL FORCE PLANNING (METOFOR)

Mr. Lee G. Wentling, Jr.
General Research Corporation

Under sponsorship of the Deputy Chief of Staff for Operations and Plans, the General Research Corporation has developed and transferred to the Army staff the METOFOR System for application of the total force concept in the mid-range planning of conventional, General Purpose Forces (GPF) and the assessment of assistance programs. This paper outlines the system concept, illustrates system operation with a simplified example, and identifies areas of potential application.

The METOFOR system concept is illustrated in Fig. 1 in terms of the planning functions shown in the boxes, the variable planner input, and the intermediate and final system outputs. The basic categories of planner input are shown at the left. The US military strategy and the planning scenarios that exemplify its execution define the scope of the problem and identify those allies whose forces will operate in concert with US forces if deterrence fails and thus be instrumental in defining US requirements and objectives. The second category of input is the establishment of projected or reasonably attainable resources and the definition of planning constraints on force structures of the country forces that are represented. The third category of planner input is the definition of combined force goals or constraints for the total allied force to be assembled to oppose the threat in each of the planning scenarios. These goals or constraints are specified from the viewpoint of the supreme allied commander in each region and are not directly concerned with individual country contributions. The combined or total force characteristics that are desired do, of course, reflect the level, composition, and operating concept assumed for the threat in the respective scenarios.

The combined force determination function accepts these planner inputs together with the force component cost factors from the resource analysis function, and produces the outputs shown. These are feasible objective forces for the US and for each Free World country represented in the problem, US security assistance allocations to the eligible countries, and finally the attainable combined force in each planning scenario. The attainable combined forces become input to the force evaluation function that produces theater outcomes in terms of results on the ground. These results, however, reflect the relative contribution of all mission forces available in the region. The outcome in NATO center, for example, would reflect the contribution of mobility, sea control, and sea projection forces as well as those of the land forces and the land-based tactical air forces.

The combined force determination function is illustrated by means of a simplified example that is shown in Fig. 2. The rim of the figure identifies the basic elements of the model. At the left are indicated

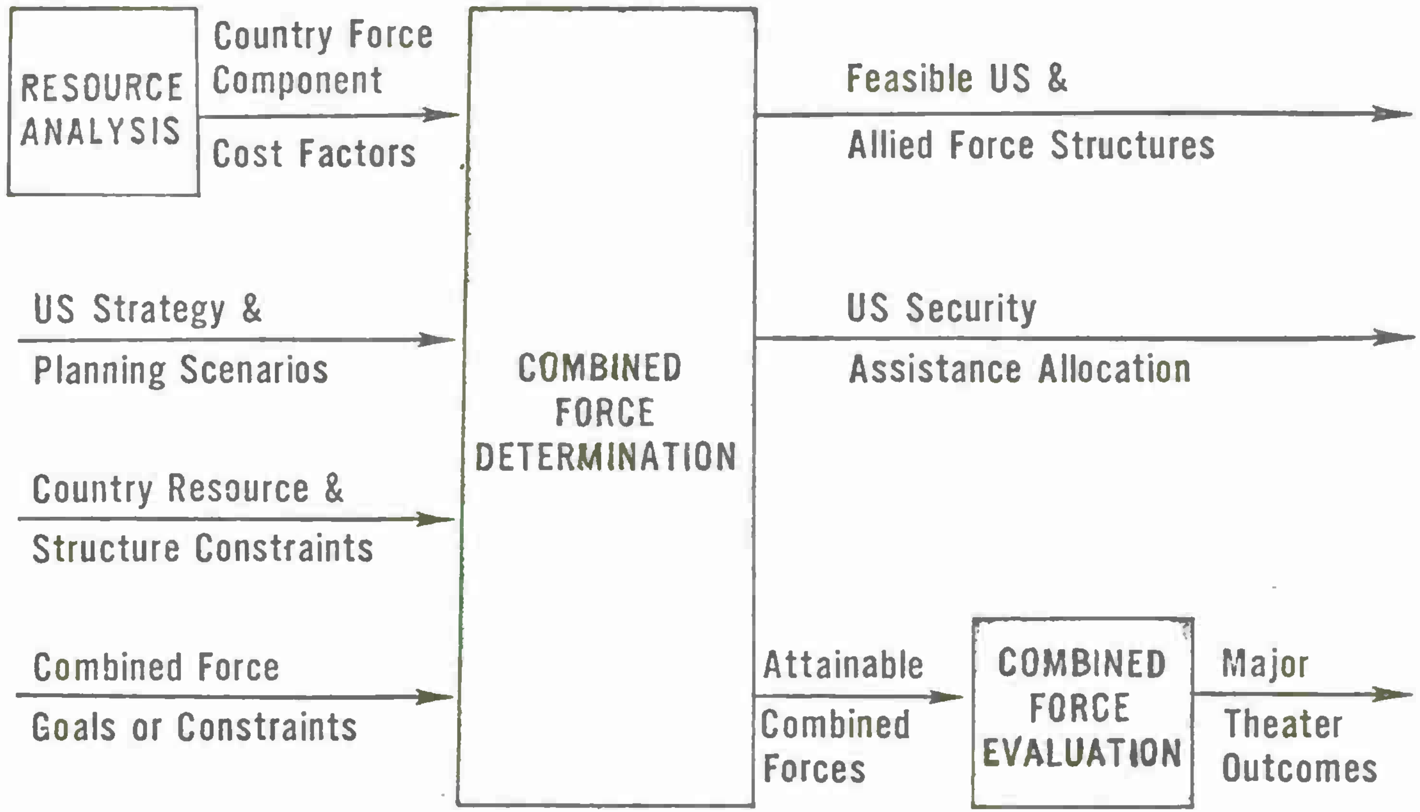

Fig. 1—The METOFOR System

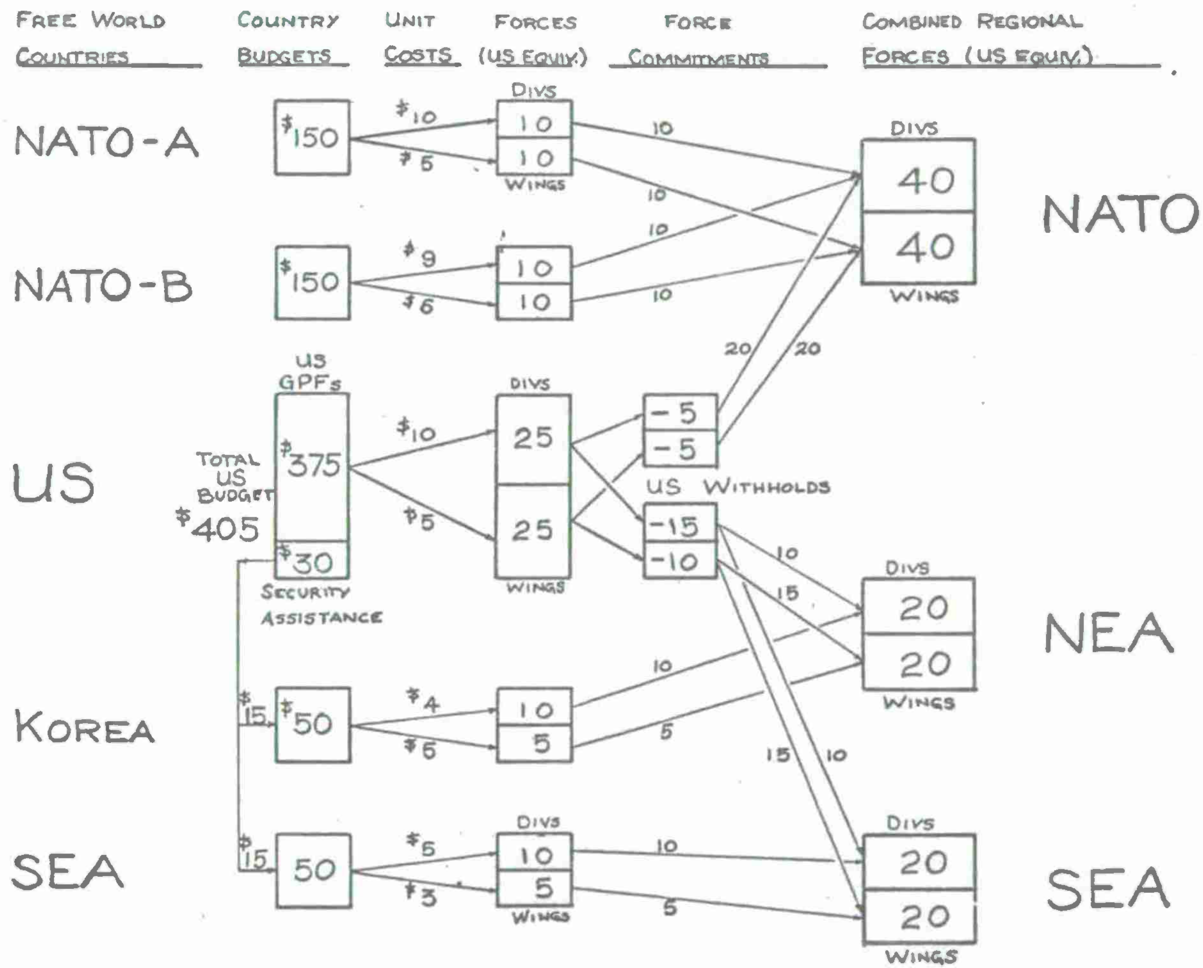

Fig. 2—Simplified Force Determination Model

five Free World countries, including the US, and these are selected because the planner has determined that he wishes to consider the three planning scenarios and corresponding combined forces indicated at the right. In this simplified model, the NATO countries are aggregated into two groups and each group is treated as if it were a single country. Similarly, the SEA countries have been grouped and treated as a single country. The alternate scenarios envision a WP attack on NATO center, or a communist attack in NEA or SEA in which the PRC participates. Across the top, we list the major data elements and problem variables. Having designated the countries to be represented, we establish the projected or assumed military budget for each country and enter from the resource analysis function, the estimated unit costs for each of the country force components such as divisions and wings. The variables in our model are the number of each type force component in the force structure of each country, the force commitment of each country to the respective combined forces, and the total number of each type component in each of the combined forces. In this simplified model, all forces are normalized and expressed in terms of US equivalents. The real model represents individual countries and their forces are expressed in natural country units. It is still necessary to normalize the combined forces, however.

In the center of Fig. 2, we develop first the US force planning problem. We show the total US budget for general purpose forces plus security assistance for the countries in the problem, and indicate the relative proportions devoted to each. Here is another major simplification. In this example, we treat only two distinct mission force types, Land and Tac Air, expressed in units of divisions and wings. The real model also represents sea control and sea projection forces as well as mobility forces where appropriate. Now US planning calls for the commitment of major forces to any one of the three scenario areas indicated. These scenarios are mutually exclusive in the time sense, but the US must be prepared for all of them. The objective is to structure US forces that will alternately combine effectively with different groups of allies, in different world areas and terrains, and in opposition to very different threats. In addition, the scenarios, may postulate concurrent US requirements in addition to those of the major theater. The US must withhold forces for such requirements as minor contingencies, assistance to allies, and the maintenance of forward deployments. These are represented in the model as shown, and the withholds for a NATO contingency may be different from those for an Asian contingency.

The diagram for other countries is similar to that for the US except that we represent no withholds, and no country has commitments to more than one combined force in this example. In addition, we indicate which countries are eligible for security assistance. This structure is planner input and the model is constructed so as to represent the desired assumptions.

This planning problem is formulated in a linear programming model whose variables represent the force structures of the Free World countries, their force commitments, and the combined force structures attainable in each planning scenario. The input required, in addition to the diagram we have constructed, is the budget data for each country, force component cost factors, and combined force normalizing factors. The forces in being for each country are also required, since we are dealing with mid-range planning and are strongly constrained by the inherited forces and the extent of change that is feasible within a planning horizon that is typically four to five years in the future. The model represents such planning constraints and others that the planner wishes to specify.

To illustrate the application of the model, we have put together a set of hypothetical data as shown in the figure. The numbers are purely for illustration and no effort has been made to make even their relative values correspond to reality. We have budget data, current security assistance, cost factors, force structures, and planned force commitments leading to the combined forces achievable with the Free World forces in being.

Figure 3 illustrates a solution to the model subject to the constraints shown. Shown in the left hand column are the forces in being for each country, the attainable combined forces in each scenario, and the elements of the current security assistance program. An improved solution is shown in the right hand column and was obtained in accordance with the goal and constraints shown at the right. Here, the goal or objective is simply to maximize the sum of the combined forces. The rules are that no country including the US, be required to increase its military budget and that no country be expected to make severe changes in its own internal force structure. This latter constraint is imposed by requiring that each country force have at least a specified number of divisions and wing in its force structure. In this problem, for example, we have required that the US force structure have no fewer than 20 divisions or 20 wings and that the NATO countries have no fewer than 8 divisions or 8 wings. These kinds of constraints, coupled with the budget limits, define the range of tradeoffs permitted within the force structure of each country.

With regard to the combined forces, we require that there be no change in the mix of combined forces as defined by the currently attainable forces. In this example, each combined force has an equal number of divisions and wings, and this one-to-one ratio of divisions and wings must be preserved in any new combined force determined by the model. If the NATO force has 41 divisions, it must also have 41 wings and similarly for the NEA and SEA combined forces. As a final ground rule, we have said that provision of security assistance is not mandatory. We will include security assistance in the US budget only if it militarily justified in the sense of furthering the objective of increasing the sum of the combined forces alternately attainable in the Free World.

The illustrative solution in the column headed "objective forces" shows significant improvement in the NATO combined force and minor improvement in the two Asian combined forces. We see that the combined force mix requirement was met in each case. Each force has equal numbers of divisions and wings. Now this is only part of answer. We need to

			FORCES IN BEING	"OBJECTIVE FORCES"	GOAL AND CONSTRAINTS
COUNTRY FORCES	US	DIVS	25	26.9	① MAX SUM OF COMBINED FORCES
		WINGS	25	27.1	
	NATO-A	DIVS	10	9.0	② NO CHANGES IN COUNTRY BUDGETS
		WINGS	10	12.1	
	NATO-B	DIVS	10	11.3	③ ONLY LIMITED CHANGE IN COUNTRY FORCE STRUCTURE.
		WINGS	10	8.0	
	KOREA	DIVS	10	8.4	e.g.
		WINGS	5	3.2	US DIVS ≥ 20
	SEA	DIVS	10	8.2	NATO-B WINGS ≥ 8
		WINGS	5	3.0	
COMBINED REGIONAL FORCES	NATO	DIVS	40	42.2	④ NO CHANGE IN COMBINED FORCE MIX, I.E.
		WINGS	40	42.2	
	NEA	DIVS	20	20.4	DIVS : WINGS = 1 : 1
		WINGS	20	20.4	
	SEA	DIVS	20	20.1	
		WINGS	20	20.1	
SECURITY ASSISTANCE	KOREA		$15	-0-	⑤ GIVE ASSISTANCE ONLY IF MILITARILY JUSTIFIED
	SEA		$15	-0-	

Fig. 3—Solution to Combined Force Improvement Problem

know the country objective force structures and the US security assistance program that would render these improved forces attainable. The US eliminates security assistance and increases both its land and air forces. NATO-A trades divisions for wings and NATO-B does the reverse. Korea and SEA both trade wings for divisions within the capabilities of their own budgets. This solution says that if each free world country adopted the plan shown here, the new combined forces would be attainable. Inherent in this result is the assumption that the US would increase its commitments to the Asian scenarios, and this was permitted under the rules of the problem. If the planner had entered a rule that said the land force commitments to Asia must be reduced, that would have been another problem; and the model would have found a different solution. The model is designed so that these rule changes are easy to make.

The country and combined force determination function within the METOFOR System is performed by a fully automated component. The Force Determination component is a modeling system comprised of a mathematical programming model generator, a commercial solution algorithm, and an English-language report generator. The model generator is a computer program that builds a specific, linear programming or goal programming model of the force determination problem as specified by the planner. The resulting model is developed in the appropriate form for solution by any of several commercially available algorithms which provide extensive capabilities for sensitivity analysis. Since the algorithm output is readable only by the analyst, the final element of the Force Determination component is a computer program that interprets the solution system output and produces English-language output reports that can be selected by the user from a wide variety of reporting options.

Returning to Fig. 2, the example just discussed illustrates the type of output obtained from the force determination function, and in particular, the set of attainable combined forces that become input to the force evaluation function. The following material describes the model that is employed to estimate theater outcomes in terms of results on the ground in the major theater of each planning scenario.

The name of this model is "VGATES" which is now just a name but at one time was an acronym for something like, "A Very Generalized Approach to Theater Effectiveness Study." As employed in METOFOR, the VGATES model is a simplified version of a simulation concept that was originally developed by Mr. Gerry Cooper, who is now with the Army Engineer Strategic Studies Group (ESSG). It is a simulation synthesizer that calibrates to and then extrapolates from one or more other detailed simulations of deployment and combat. A diagram of the typical force interactions that can be handled is shown in Fig. 4. All mission forces—land, tactical air, naval, and mobility forces—are represented and may interact as appropriate. The central arrows indicate those interactions involving attrition of one force by an element of the opposing force. The external arrows indicate supporting actions among the elements of blue or red. At present, as many as 15 distinct Blue force elements and 10 Red elements can be accommodated and the interaction of a particular force element with any other may be represented. As normally applied in

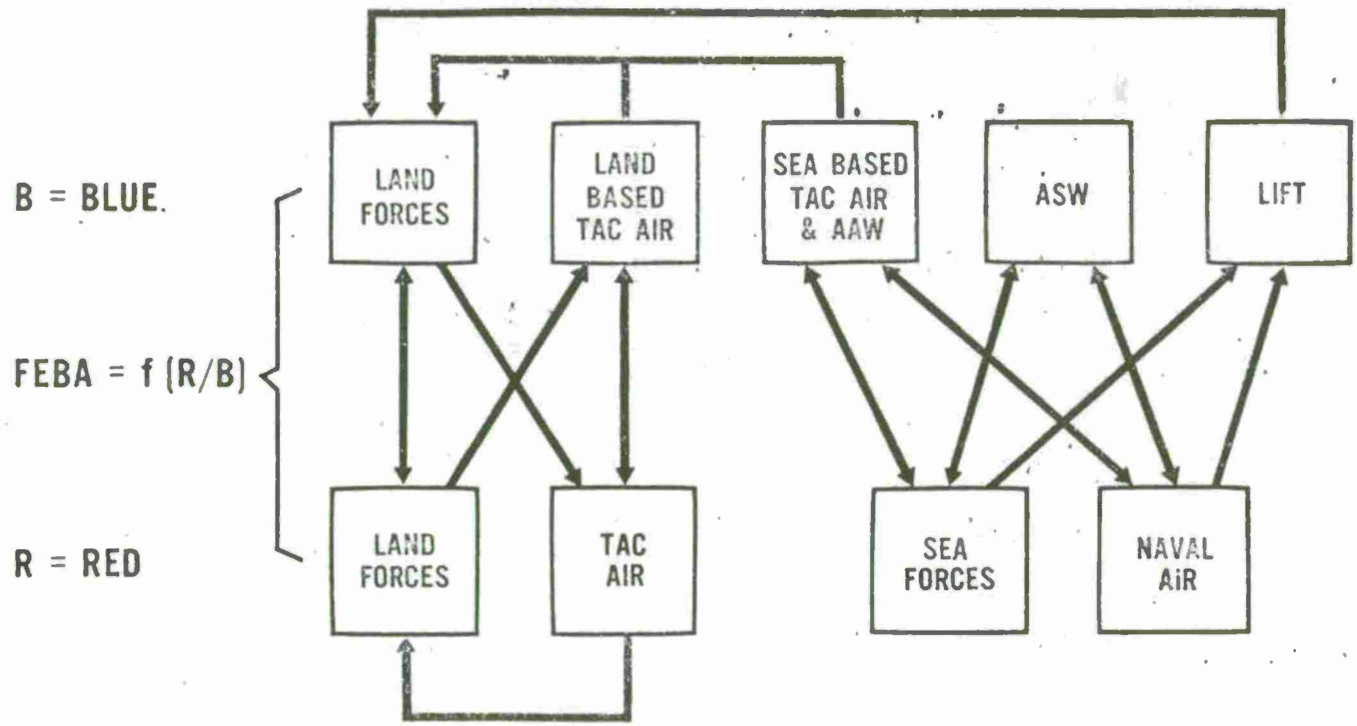

Fig. 4—Typical VGATES Force Interaction Diagram

the METOFOR system, the net output is a time history of the expected FEBA (Forward Edge of the Battle Area) location in the theater derived from the corresponding time history of the force ratio of the opposing land forces.

As indicated, the VGATES model is not an independent simulation but rather relies on the availability of more detailed simulations or war games to which it is calibrated. The force interaction calibration is accomplished by solving a set of attrition rates that will duplicate the casualty results of the base analysis when employing the base initial forces and augmentation schedule. This calibration may be performed in a piecewise fashion based on several sources. For example, the sea campaign and surface shipping attrition rates may be derived from a Navy study, air battle rates from and Air Force study and so on. FEBA movement calibration reproduces that observed in the calibration base after inputting the base time history of the opposing force ratios. Both these calibration processes have been automated. Once calibration is achieved, it is assumed that the model output remains valid over a range of force inputs and force combinations in the neighborhood of the calibration base.

The overall flow diagram of the model is shown in Fig. 5. The model is very simple and fights a 180-day war in less than 15 seconds of CPU time.

The METOFOR System was designed primarily for application in support of Army participation in the Joint planning and programming process as described in AR 1-1 and reflected in the Joint Strategic Objectives Plan (JSOP) and Joint Force Memorandum (JFM). Volume II of the JSOP develops US force requirements, recommends assistance programs consistent with achievement of Free World objective forces, and appraises the capabilities of the programmed and projected forces. The JFM provides JCS recommendations on constrained major force and support levels developed in accordance with fiscal and materiel guidance issued by the Secretary of Defense and includes JCS views on the capabilities of these forces to execute the military strategy.

The Army, as does each Service, provides objective force and constrained force inputs to this process, participates in the resolution of planning issues and develops unilateral Army views regarding the process for consideration by the Secretary of Defense. The METOFOR System models the Joint planning functions with respect to US/Free World conventional General Purpose Forces and provides a tool for Army evaluation of existing and proposed plans, analysis of issues, and the testing and refinement of Army views.

In addition to providing continuing analytical support to Army planners during the annual planning cycle, the METOFOR System has other areas of potential application. It may be applied in support of the conduct of Army selected analyses and in the appraisal of similar analyses prepared by the other services and the JCS. Of particular concern is the careful review of Joint studies that may impact on the level and composition of Army forces.

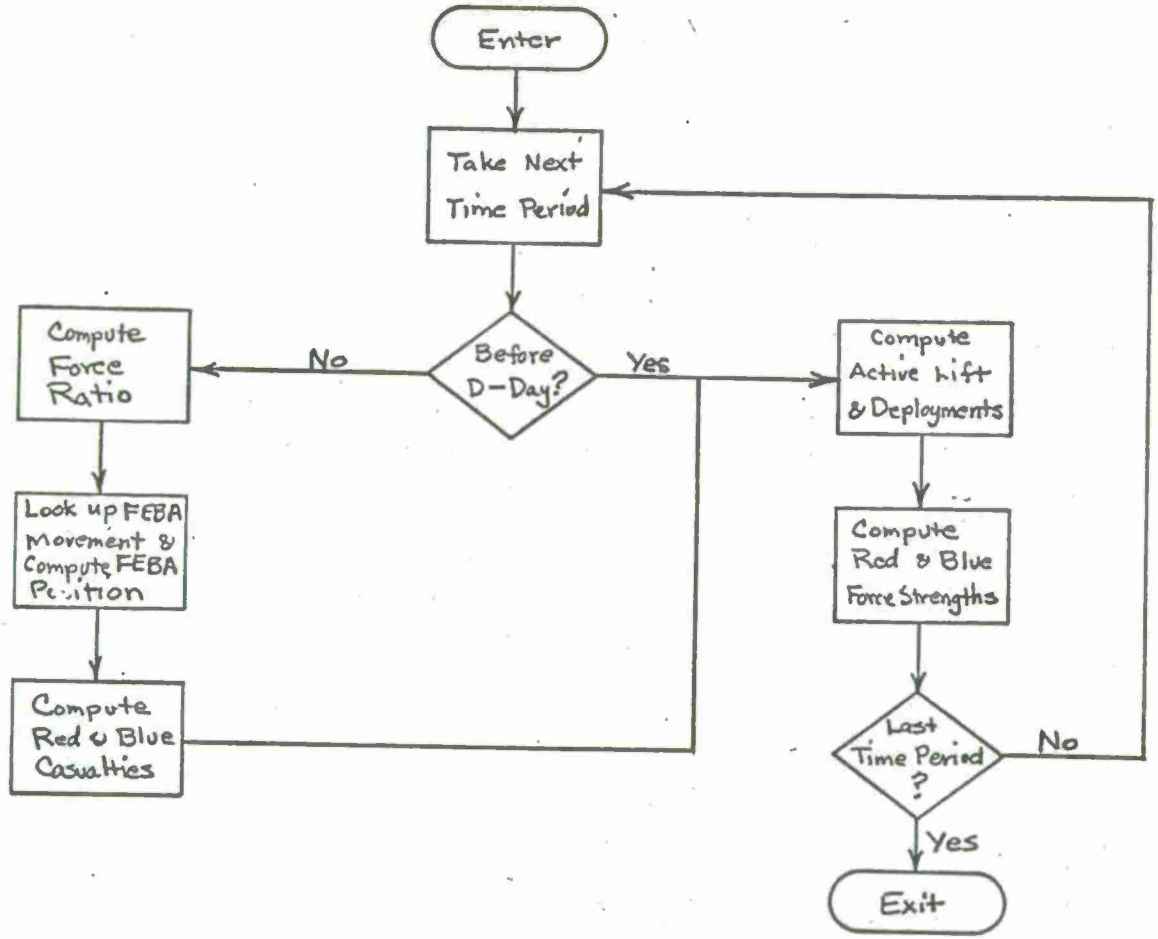

Fig. 5—VGATES Flow Diagram

The METOFOR System also appears to be adaptable to analysis of Mutual and Balanced Force Reduction (MBFR) issues, and in particular, offers a means of considering the effect of asymmetrical reductions because of its explicit treatment of all allied and threat mission forces in a common context. Overall, the system provides an analytical framework for the integration of more detailed analyses and plans of lesser scope in order to address US and allied force planning from the perspective of the Total Force concept.

RESOURCE ALLOCATION DIRECTIVES FOR RESEARCH AND DEVELOPMENT
II. Near Optimality in Capital Budgeting.

Major Walter L. Perry

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RESOURCE ALLOCATION DIRECTIVES FOR RESEARCH AND DEVELOPMENT
II. Near Optimality in Capital Budgeting.

This paper is the second in a series of 3 papers dealing with the allocation of scarce resources to many resource demand points. Particular emphasis in this paper is given to solving very large demand point problems using a pseudo gradient programming technique. Although the method does not guarantee an optimal solution, computer high speed storage requirements are such that conventional computers can be used to exercise the process in a reasonable amount of time.

The first paper presents a computer-assisted, user interactive fund allocation system for apportioning the Army R&D budget. Emphasis is placed on the operating system in dealing with reprogramming actions and its effect on the management process (1).

The last paper addresses the application of dynamic programming in relatively large allocation problems. High speed memory reduction techniques such as decomposition and incremental allocations are presented (2).

I. The Allocation Problem.

The general problem is to allocate a single scarce resource to many competing demand points. Specifically, the application that motivated this research is the Army Research and Development budget apportionment problem. Given a constrained budget, what is the best allocation of funds to the approximately 1,600 Army R&D tasks that maximizes some measure of military effectiveness?

A significant subproblem is that of recommending re-allocations based on reprogramming actions that take place between annual budget determinations. It is these reprogramming actions and their contingency planning counterparts ("what-if" exercises) that establish the need for the rapid system response discussed in I.3.

I.1 Problem Size.

For the discrete case in which a finite number of alternate funding levels, η, is allowed, the total number of candidate funding alternatives is η^{1600}. Clearly, even for the simple case where $\eta = 2$ (funded or unfunded), the total number of alternatives precludes any enumerating process. In practice, the R&D problem is such that the process can be logically decomposed so that any given allocation would be less than 200 tasks. Although this is better, it is still unmanageable.

Complicating the problem is the number of funding levels generally considered. The limiting case is the continuous benefit-cost relation for each candidate task with an infinite number of funding levels. Aside from the fact that such relations are not available for most R&D tasks, their use in an optimization process is no more manageable than discrete relations. Indeed they are typically non-linear "S-curves". Hence their use would require solving a constrained, non-linear optimization problem in 200 decision variables. In practice, the 4 funding levels defined in figure 1 are used in the R&D allocation problem.

One way to reduce the problem size is to raise the decision variable to the R&D project level. Since projects are composed of tasks, the number of decision variables is reduced to approximately 600. This translates to 100 projects per decomposed problem. However, because each project consists of subordinate tasks, a decision to fund any project is equivalent to funding its subordinate tasks. These tasks may, in turn, be technologically coupled to other projects in the R&D program. As a result, we loose independence in the decision variables.

Figure 1: R&D Funding Levels

Level	Description	Definition
0	Unfunded	No funds are allocated. The task will not achieve its milestone.
1	Sustained	Funding at this level will cause the task to slip its milestone by some fixed time increment.
2	Programmed	The level at which the task will achieve its scheduled milestone as planned.
3	Advanced	Funding at this level will cause the task to advance its milestone by some fixed time increment.

A detailed discussion of these levels is presented in (3).

I.2 Risk

Because of the uncertain nature of R&D tasks, the probability of achieving the benefit predicted impacts on the solution process. Although this argues for a stochastic cost-benefit relation, the problem of size and the rapidly changing nature of the Army's R&D program makes it impossible to assess these probabilities in a reasonable period of time. Consequently, a deterministic cost-benefit relation is assumed. The treatment of risk in the R&D fund allocation problem is described in (4).

I.3 System Characteristics and Constraints.

The decision point selected for the allocation process is the R&D task. This level assures technological independence among the decision variables. The R&D budget is taken as the single constrained resource to be allocated and a cost-benefit relation is available for each task at the four funding levels presented in figure 1.

The computerized solution process must insure a near real time interactive operating system used in the R&D budget allocation process. The iterative nature of this system in assessing subjective decision criteria is fully discussed in (1). In addition, the technique must be capable of handling a very large decision problem.

II. Problem Formulation.

In this section, the allocation problem is formulated first as a capital budgeting, integer program, and then as a sequential decision problem.

II.1 Integer Programming Formulation.

The capital budgeting problem can be stated mathematically as a zero-one integer program:

II.1.1 $\text{Max } B = \Sigma_{i=1}^{m} \Sigma_{j=0}^{n} x_{ij}\, b_{ij}$ subject to

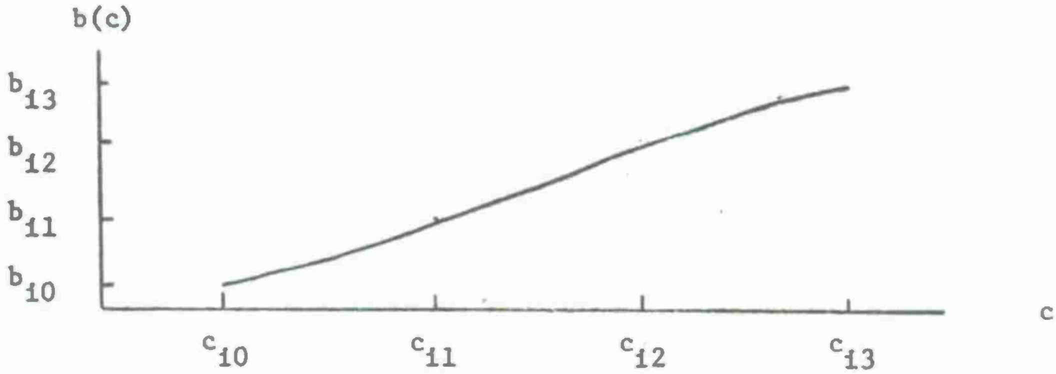
II.1.2 $\Sigma_{i=1}^{m} \Sigma_{j=0}^{n} x_{ij}\, c_{ij} \leqslant K$ and

II.1.3 $\Sigma_{j=0}^{n} x_{ij} = 1$ for every i, where b_{ij} is the measure of benefit derived from funding task i at level j; c_{ij} is the cost of funding task i at level j; K is the constrained budget and;

$$x_{ij} = \begin{cases} 1 \text{ if task } i \text{ is funded at level } j \\ 0 \text{ otherwise.} \end{cases}$$

Implicit in this formulation, is the assumption that a total additive benefit score, B. is meaningful. The b_{ij} functions (figure 2) for each task are taken to be strictly quantifiable performance measures such as nearness to completion or the fraction of total projected funds expended to date. A more detailed discussion of the b_{ij} function can be found in (1).

Figure 2: Typical Cost-Benefit Relation for Task i



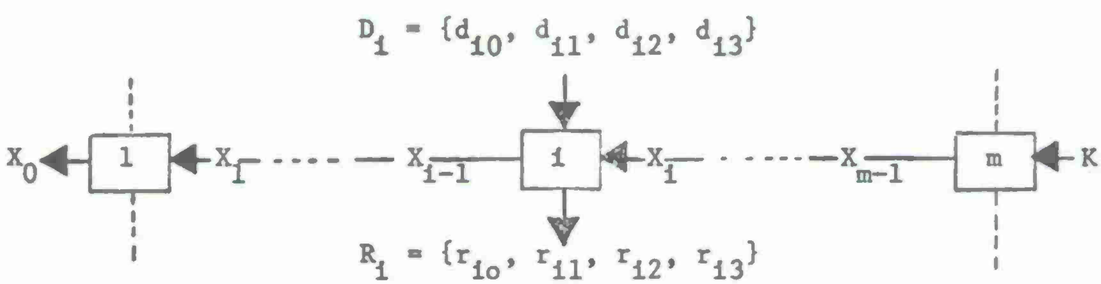
Note 1: Although $b_{ij} > b_{ik}$ for $j > k$, this need not be the case except when benefit is defined as meeting a scheduled milestone. Then the funding levels determine the b_{ij} ordering.

Note 2: In application, c_{i0} and b_{i0} are scaled to 0.

II.2 Multistage Formulation.

The problem can also be stated as a multistage decision problem and can be solved using dynamic programming. The combinatorial problems mentioned above can be clearly seen using this technique. A graphical representation of the backward solution process is depicted in figure 3.

Figure 3: Sequential Multistage Decision Formulation.



Each stage in the process is a task (i). D_i is the decision set at stage i where $d_{ij} = c_{ij}$ is a decision that task i be funded at level j. The return (payoff) at every stage is the benefit scored for funding task i at level j. The state vector, X_i, represents the set of possible budget residuals at stage i after funds have been allocated to task i + 1. Hence $x_{i-1,\,j} = x_{ij} - d_{ij}$ (j = 0, 1, 2, 3) and $X_m = \{K\}$. Since the benefits, b_{ij}, are stipulated to be additive, the objective then is:

II.2.1
$$G' = \underset{D_1, \ldots, D_m}{\text{Maximum}}\ G\ [R_1\ (X_1, D_1), \ldots, R_m\ (X_m, D_m)]$$
$$= \underset{D_1, \ldots, D_m}{\text{Maximum}}\ \Sigma_{i=1}^{m}\ R_i\ (X_i, D_i)$$

where $R_i\ (X_i, D_i)$ is the return function at stage i given the decision set D_i and the state vector X_i. Note that G is decomposable since it is monotonic and separable.*

The optimal benefit at any stage, k, can be expressed as a recursive relation:

II.2.2
$$f_k\ (X_k) = \underset{D_k}{\text{Max}}\ [R_k + f_{k-1}\ (X_{k-1})] \text{ where}$$
$$X_{k-1} = X_k - D_k \text{ and } f_o(\cdot) \equiv 0.$$

$f_k(X_k)$ is the cumulative payoff from optimal fund allocations to tasks 1 through k. Hence, $f_m(X_m) = G'$.

By way of illustration, consider the simple 3 task problem depicted in figure 4. Note that the state vector size at stage i is 4^{3-i}. Since all state vectors except X_0 are required for the backward solution unfolding process, the total computer memory requirements for this simple problem is

$$M = \Sigma_{i=1}^{3}\ 4^{m-i} = \frac{4^3-1}{3} = 21.$$

---

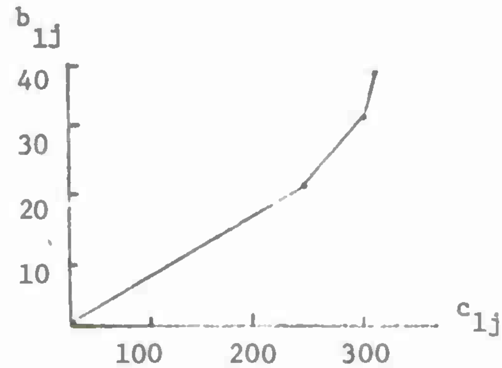
*Monotonicity: $\Sigma_{i=1}^{i'} R_i \geqslant \Sigma_{i=1}^{i'-1} R_i$ for all pairs (i, i') where $i' > i$ and $i, i' \in \{1, 2, \ldots, m\}$

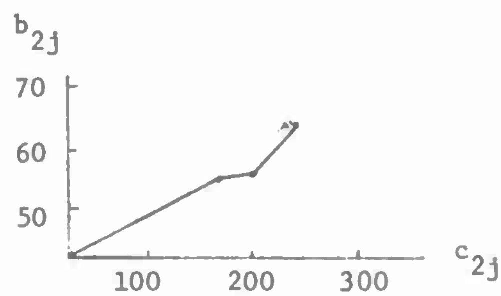
Separability: Let $G_1 = R_{i'}$, and $G_2 = \Sigma_{i=1}^{m} R_i$ and $i \neq i'$. Then $G = G_1 + G_2$ for all $i' \in \{1, 2, \ldots, m\}$

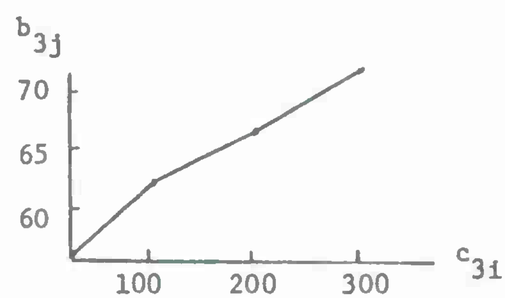
An economy is gained if we realize that only one state vector at a time need be available for computation. As a result, all others may be written to accessible storage files and called into high speed memory when needed. However, for the 200 task problem, the high speed memory requirements at stage 1 is 4^{199}.*

Figure 4: A three-task problem:

Task(i)	Level(j)	Cost(c_{ij})	Benefit(b_{ij})
1	0	0	0
	1	241	21.0
	2	301	31.1
	3	310	40.3
2	0	0	0
	1	187	54.0
	2	202	55.0
	3	252	63.2
3	0	0	0
	1	107	62.0
	2	210	66.1
	3	307	72.2







*In general, if p is the number of decision variables at each stage, the state vector size is p^{m-1} at stage i and total memory requirements for this simple problem is:

$$M = \Sigma_{i=1}^{m} p^{m-1} = \frac{p^{m}-1}{p-1}.$$

Given a budget, K = \$825, what is the optimal allocation that maximizes total benefit?

Solution:

Stage 1:

$$f_1\ (X_1) = \max_{D_1}\ [R_1\ (X_1,\ D_1) + f_0\ (X_0)] = \max_{D_1}\ R_1\ (X_1,\ D_1)$$

X_1 \ D_1	0	241	301	310	$f_1\ (X_1)$	d_1^*
	$R_1\ (X_1,\ D_1)$					
825	0	21.0	31.1	40.3	40.3	310
718						
638						
623						
615						
573						
531						
518						
516						
466						
428						
413						
363						
331						
316			31.1	40.3	40.3	310
266	0	21.0	-	-	21.0	241

d_1^* = optimal decision given X_1 $d_1^* \in D_1$.

Stage 2:

$$f_2 (X_2) = \underset{D_2}{\text{Max}} [R_2 (X_2, D_2) + f_1 (X_1)]$$

where $X_1 = X_2 - D_2$

X_2 \ D_2	0	187	202	252	$f_2 (X_2)$	d_2^*
	$R_2 (X_2, D_2) + f_1 (X_1)$					
825	0+40.3	54.0+40.3	55.0+40.3	63.2+40.3	103.5	252
718	0+40.3	54.0+40.3	55.0+40.3	63.2+40.3	103.5	252
615	0+40.3	54.0+40.3	55.0+40.3	63.2+40.3	103.5	252
518	0+40.3	54.0+40.3	55.0+40.3	63.2+21.0	95.3	202

Stage 3:

$$f_3 (X_3) = \underset{D_3}{\text{Max}} [R_3 (X_3, D_3) + f_2 (X_2)]$$

where $X_2 = X_3 - D_3$

X_3 \ D_3	0	107	210	307	$f_3 (X_3)$	d_3^*
	$R_3 (X_3, D_3) + f_2 (X_2)$					
825	0+103.5	62.0+103.5	66.1+103.5	72.2+95.3	169.6	210

Optimal solution:

Task	Recommended Funding Level		Cost	Benefit
1	3		310	40.3
2	3		252	63.2
3	2		210	66.1
		TOTALS	$772	169.6

Residual funds: $825-772 = $53

Even if the high speed memory requirements were not prohibitive, the interactive requirements of the operational management system limits the execution time that can be tolerated. To test the execution time and to establish a control set of solved problems, a simple 5-stage dynamic program was developed. A FORTRAN code listing is included in Appendix A. Results of the time-to-compute study are discussed in Section IV.

III. Pseudo Gradient Programming.

The coupled problems of high speed memory requirements and the need to reduce computation time in the R&D study overshadowed any insistance upon pure optimality of results. What was required more than the best solution was a quick solution that satisfied the budget constraint. The solution should be as near optimal as possible, but need not maximize B in II.1.1 or G' in II.2.1.

The main reason for this relaxation in requirements is the benefit functions required for the optimization process. In order to create benefit functions for 200 or more tasks, only easily quantifiable measures could be used. As a result, many subjective measures were not included in the solution process other than through user interaction with the computer program (See (1)).

III.1 A Pseudo Gradient Search Technique.

Simply put, the pseudo gradient solution algorithm consists of generating a basic feasible solution (BFS) and then iteratively improving the solution until a stopping criterion is satisfied.

The BFS is taken to be the solution that funds tasks in order of benefit/cost scores. For each task, the set of benefit/cost ratios are:

III.1.1 $$\Phi_i = \{\Psi_{ij} | \Psi_{ij} = b_{ij}/c_{ij} \text{ and } \Psi_{io} \equiv 0\}$$

where $i = 1, 2, \ldots, m$ and $j = 0, 1, 2, 3$. The set

$$\Phi = \{\Phi_1, \Phi_2, \ldots, \Phi_m\}$$

is ranked on the Ψ_{ij}'s and funding begins with the task with the largest Ψ_{ij} at the j level and proceeds until the budget, K is allocated.

The solution improvement process requires that the slopes of the lines connecting the adjacent cost benefit points to the point currently in solution for each task be considered. These slopes can be loosely thought of as first-order-correct approximations to the derivative of a continuous curve connecting the points of the cost-benefit curves at the current solution level. If $[b(c)]_i$ describes the continuous benefit function for task i, then

$$b'_{ij} = \left[\frac{db(c)}{dc}\right]_{ij}$$

is the derivative of $[b(c)]$ at the point (b_{ij}, c_{ij}).

The backward approximation to b'_{ij} is defined by the slope:

III.1.2 $$\Delta_i^{(jj')} \equiv \frac{b_{ij} - b_{ij'}}{c_{ij} - c_{ij'}} . \quad (c_{ij} \neq c_{ij'})$$

where $j = j' + 1$. III.1.2 is a backward approximation since the adjacent point used $(b_{ij'}, c_{ij'})$ is at a lower funding level. For each task, the set of all backward slopes at iteration s is:

III.1.3 $$\Delta_i^s(B) \equiv \{\Delta_i^{(jj')} | j \neq 0 \text{ and } j = j' + 1\}.$$

The backward pseudo gradient is defined as the set of all backward slopes from $\Delta_i^s(B)$ for each task in the current solution:

III.1.4 $$\Delta^s(B) \equiv \{\Delta_i^{(jj')} | \Delta_i^{(jj')} \varepsilon \Delta_i^s(B)\}.$$

The solution improvement procedure begins by selecting the largest* $\Delta_i^{(jj')}$ value in III.1.4. Since reducing the funding level for task i from j to j' surrenders the least benefit for each unit of cost gained, task i is reduced accordingly and the cost savings, $c_{ij} - c_{ij'}$, are then added to any residual from the last iteration. An attempt is now made to increase the total benefit by increasing the funding level of some other tasks.

We now wish to apply the new residual to increase the funding level of the task that will contribute the greatest amount of benefit for each unit of cost expended. The forward approximation to b'_{ij} is now useful.

III.1.5 $$\Delta_i^{(jj'')} \equiv \frac{b_{ij''} - b_{ij}}{c_{ij''} - c_{ij}} \quad (c_{ij''} \neq c_{ij})$$

where $j'' > j$. The parallel to III.1.3 for forward slopes is

III.1.6 $$\Delta_i^s(F) \equiv \{\Delta_i^{(jj'')} | j'' \neq 3 \text{ and } j'' > j\}.$$

and the forward pseudo gradient is defined as

III.1.7 $$\Delta^s(F) \equiv \{\Delta_i^{(jj'')} | \Delta_i^{(jj'')} \varepsilon \Delta_i^s(B)\}.$$

An important distinction is made between $\Delta^s(B)$ and $\Delta^s(F)$. For $\Delta^s(F)$, the forward slopes in the set are not confined to just those that are calculated using the adjacent forward point in the cost-benefit relation. That is, there is no restriction that $j'' = j + 1$. The reason for this is that the benefit received for each cost unit expended may be greater by jumping levels than simply examining the adjacent level.

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*The $\Delta_i^{(jj')}$ values are normally negative since most cost-benefit functions are monitonically increasing. However if $\Delta_i^{(jj')}$ is positive, this indicates that an increase in benefit is possible if the funding level is dropped.

The new residual is first applied to funding the task with the largest $\Delta_i^{(jj'')}$ in $\Delta^s(F)$ to the level j". The remaining residual is then applied to the task with the next highest $\Delta_i^{(jj'')}$ and so on until all the funds that can be applied are exhausted.

The following stopping rule is used in the algorithm: If the benefit forgone from dropping the funding level for task i from j to j' at iteration s, $(b_{ij} - b_{ij'})$ is at least equal to the benefit accrued from increasing the funding for other tasks, then the best funding policy has been achieved at iteration s. Finally, the iteration s funding policy is optimal if

III.1.8 $$(b_{ij} - b_{ij'})_s \geq \sum_{p \varepsilon P} (b_{pj''} - b_{pj})_{s+1}$$

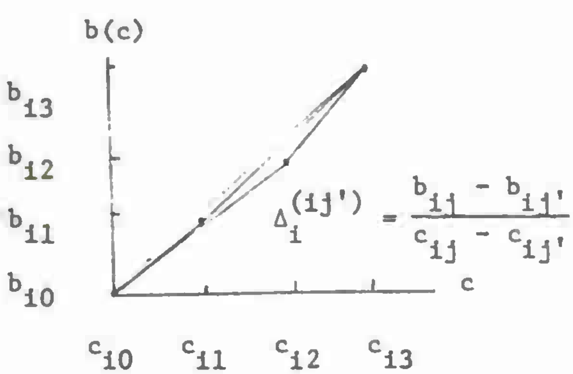
where P is the set of all tasks whose funding levels are to be increased at this iteration.

Although this stopping rule guarantees that each successive iteration produces an increase in the total benefit score, the solution improvement rule does not guarantee convergence to the global optimum. Convergence problems are discussed in III.5 below.

III.2 The algorithm.

The solution process is iterative and proceeds in two phases: (1) Selection of a BFS, and (2) Solution improvement procedure. To facilitate the manipulation of the backward and forward gradients for the solution improvement process, a slope matrix is used to display the $\Delta_i^{(jj')}$ values for each task (figure 5). Since $\Delta_i^{(jj')} = -\Delta_i^{(j'j)}$, the matrix is skew symmetric. Hence only the right triangular is needed to define all slopes.

Figure 5: The Slope Matrix



Cost Benefit Function

jj'	0	1	2	3
0	0	$\Delta^{(01)}$	$\Delta^{(02)}$	$\Delta^{(03)}$
1	-	-	$\Delta^{(12)}$	$\Delta^{(13)}$
2	-	-	-	$\Delta^{(23)}$

Note: $\Delta_i^{(01)} = \Psi_{i1}$, $\Delta_i^{(02)} = \Psi_{i2}$ and $\Delta_i^{(03)} = \Psi_{i3}$. Hence $\Delta_i^{(00)} \equiv 0$

Slope Matrix

Basic Feasible Solution

1. Calculate the set of benefit/cost ratios,

$$\Phi = \{\Phi_1, \Phi_2, \ldots, \Phi_m\}.$$

2. Rank the $\Psi_{ij} \varepsilon \Phi$ from high to low and set the iteration counter, s = 1.

3. Let K, be the residual budget after the first allocation ($K_0 = K$). Select the largest Ψ_{ij} and fund task i at level j if $c_{ij} \leqslant K_1$. Otherwise select the next largest Ψ_{ij} and repeat.

4. Eliminate all other funding levels for task i from consideration by removing $\Psi_{ij'}$ for all j' from Φ.

5. Set $K_1 = K_1 - c_{ij}$ and repeat to 4 until there are no tasks for which $c_{ij} \leqslant K_1$, at any but the 0 level. Calculate

$$B_1 = \Sigma_{(ij)_1} b_{ij} \text{ and } C_1 = \Sigma_{(ij)_1} c_{ij}$$

where $(ij)_s$ represent the funding level (j) for each task (i) in the solution at iteration s.

Solution Improvement Procedure

6. Set s = s+1. Select the largest $\Delta_i^{(jj')}$ from $\Delta^s(B)$. Task i is the candidate for reduction.

7. Decrease the funding for task i from c_{ij} to $c_{ij'}$, and set $K_s = K_{s-1} + c_{ij} - c_{ij'}$.

8. Select the largest $\Delta_q^{(jj")}$ from $\Delta^s(F)$, $q \neq i$. If $K_s \geqslant c_{qj"} - c_{qj}$ fund task q at level j" and delete $\Delta_q^{(jj")}$ for all j" from $\Delta^s(F)$.

9. If $K_s < c_{qj"} - c_{qj}$, find the next largest $\Delta_q^{(jj")}$ in $\Delta^s(F)$ and repeat from step 8 until all $\Delta_q^{(jj")}$'s have been considered. If there are no $\Delta_q^{(jj")}$'s that have qualifying cost differentials, reduce the funding level for the task with the next largest $\Delta_1^{(jj')}$ and set $K_s = K_s + c_{1j} - c_{1j'}$. Repeat from step 8.

10. Set $K_s = K_s - (c_{qj"} - c_{qj})$ and repeat from step 9 until no more tasks can be found to fund.

11. Apply the residual, K_s to the task that was originally reduced from level j to j'. Beginning with level 3, if $K_s \geq c_{i3} - c_{ij'}$ and $b_{i3} > b_{ij'}$, increase the funding level to 3 and set $K_s = K_s - (c_{i3} - c_{ij'})$. Continue for level 2 if j' < 2 and so on.

12. Calculate $B_s = \Sigma_{(i,j)_s} b_{ij}$. If $B_s \geq B_{s-1}$, terminate. Otherwise repeat from step 6.

III.3 Sample Problem

Consider the sample problem solved earlier (figure 4). The slope matrices for the 3 tasks and the Ψ_{ij} values are recorded in figure 6. The constrained budget is K_0 = \$825.

Figure 6: Slope Matrices for Sample Problem.

Task 1

jj'	0	1	2	3	
0	0	.087	.103	.130	←Ψ_{1j}
1	-	-	.168	.280	
2	-	-	-	1.022	

Task 2

jj'	0	1	2	3	
0	0	.289	.272	.251	←Ψ_{2j}
1	-	-	.733	.142	
2	-	-	-	.104	

Task 3

jj'	0	1	2	3	
0	0	.579	.315	.235	←Ψ_{3j}
1	-	-	.040	.061	
2	-	-	-	.063	

$\Phi_1 = \{0, .087, .103, .130\}$

$\Phi_2 = \{0, .289, .272, .251\}$

$\Phi_3 = \{0, .579, .315, .235\}$

Basic Feasible Solution.

Iteration 1:

Ranking the tasks on Ψ_{ij} produces the following BFS:

Tableau I:

$(i, j)_1$	c_{ij}	b_{ij}
(1, 3)	310	40.3
(2, 1)	187	54.0
(3, 1)	107	62.0
	C_1 = \$604	B_1 = 156.3

The unallocated residual from this solution is K_1 = \$825 - 604 = \$221.

Iteration 2:

The backward pseudo gradient is:

$$\Delta^2(B) = \{\Delta_1^{(32)}, \Delta_2^{(10)}, \Delta_3^{(10)}\} = \{-1.022, -.289, -.579\}$$

The largest $\Delta_i^{(jj')} = .289$. Hence task 2 is reduced from level 1 to unfunded. The increased residual then is:

$$K_2 = K_1 + c_{21} - c_{20} = 221 + 187 - 0 = \$408.$$

The forward pseudo gradient is:

$$\Delta^2(F) = \{\Delta_3^{(12)}, \Delta_3^{(13)}\} = \{.040, .061\}.$$

The largest $\Delta_i^{(jj'')} = .061$. Since $K_2 > c_{33} - c_{31}$ (408 > 307-107) task 3 is funded at level 3. The new residual is K_2 = \$408-200 = \$208. Now there are no more candidates for increased funding in $\Delta^2(F)$. However since $K_2 > c_{22} - c_{20}$ (208 > 202), task 2 is funded at level 2 with residual K_2 = \$6.

Tableau II:

$(i, j)_2$	c_{ij}	b_{ij}
(1, 3)	310	40.3
(2, 2)	202	55.0
(3, 3)	307	72.2
	C_2 = \$819	B_2 = 167.5

Since $B_2 > B_1$ another iteration is required:

Iteration 3:

The backward pseudo gradient at this iteration is:

$$\Delta^3(B) = \{\Delta_1^{(32)}, \Delta_2^{(21)}, \Delta_3^{(32)}\} = \{-1.022, -.733, -.063\}.$$

The largest $\Delta_i^{(jj')} = -.063$. The increased residual is

$$K_3 = K_2 + c_{33} - c_{32} = \$6 + 97 = \$103.$$

The forward pseudo gradient at this iteration is:

$$\Delta^3(F) = \Delta_2^{(23)} = .104$$

Since $K_3 > c_{23} - c_{22}$, task 2 is funded at level 3 and K_3 = \$103 - 50 = \$53. This completes this iteration since $\Delta^3(F)$ is exhausted and K_3 is insufficient to increase the funding level for task 3.

Tableau III:

$(i, j)_3$	c_{ij}	b_{ij}
(1, 3)	310	40.3
(2, 3)	252	63.2
(3, 2)	210	66.1
	C_3 = \$772	$B_3 = 169.6$

Again, $B_3 > B_2$ and another iteration is required.

Iteration 4:

$$\Delta^4(B) = \{\Delta_1^{(32)}, \Delta_2^{(32)}, \Delta_3^{(21)}\} = \{-1.022, -.164, -040\}.$$

The largest $\Delta_i^{(jj')} = -.040$. The reduction of task 3 to level 1 leaves only tasks 1 and 2 to receive the increase in funds. However, both are fully funded and hence $\Delta^4(F)$ is empty. As a result, task 3 receives the residual funds. The effect is no change to the solution and the process terminates. The "optimal" solution is displayed in Tableau III.

III.4 Convergence.

In most cases the pseudo gradient algorithm will produce the global optimum as in the sample problem. However it is not too difficult to construct one for which it does not. The simple problem presented below illustrates the suboptimal convergence problem that can occur using the pseudo gradient search technique for solution improvement.

Consider a simple 3 task problem with only two funding levels, unfunded and fully funded. Dropping the second subscript, suppose the costs, benefits and benefit-cost ratios are ranked as follows:

$$c_1 < c_2 < c_3$$
$$b_1 < b_2 < b_3$$
$$\Psi_2 < \Psi_3 < \Psi_1$$

where c_i = fully funded cost for task i; b_i = the associated benefit; and $\Psi_i = b_i/c_i$. If the budget is large enough to fund at most two tasks, then the optimal policy is to fund tasks 2 and 3.

Using the pseudo gradient technique, the BFS is to fund tasks 1 and 3. For this case

$$\Psi_i = - \Delta_i^{10} = \Delta_i^{01}.$$

$\Delta^2(B) = -\Psi_1, -\Psi_3$ and the largest $\Psi_i = \Psi_3$. At iteration 2 then tasks 1 and 2 are fully funded. However, since $b_1 + b_2 < b_3 + b_2$, the initial solution is the best we can obtain. In general, if Ψ_1 is greater than either of Ψ_2 and Ψ_3, the resulting allocation is sub-optimal.*

In general, if the stopping rule is suspended, the benefit score, B_s, will either oscillate about the terminal solution or it will remain constant. For those cases in which the terminal solution is not optimal, a perturbation rule needs to be developed that will displace the search neighborhood.

IV. Test Results.

The pseudo gradient programming technique was compared to dynamic programming for 100 five-task problems. The input data is included in Appendix B. FORTRAN listings for the programs used to conduct the test are included in Appendix A.

IV.1 Methodology and General Results.

A total of 125 tasks were divided into 25 sets of 5 each. Each task was given a benefit score for 4 different funding levels. In all cases the unfunded level earned a zero benefit score. For each 5-task problem, 4 constrained budgets were proposed. Figure 7 records two typical problems along with solutions from DYNA (dynamic programming) and GRAD (pseudo gradient programming).

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*There are 6 possible orderings on Φ. The pseudo gradient programming technique will allocate optimally for all but the 2 cases described.

Of the 100 cases tested, GRAD produced the optimal funding allocation 69 times. However, considering all 100 cases, the GRAD solution was 97.7% optimal on the average and if only the 31 non-optimal cases are considered, the figure only drops to 92.6%. The percent optimal score for GRAD solutions is defined as the ratio of the total benefit at the terminal GRAD solution to the total benefit at the optimal DYNA solution. Standard deviations and confidence intervals are recorded in figures 8 and 9 along with frequency histograms. The complete test results are included in Appendix B.

Figure 7: Typical Test Cases at Two Budget Levels.

Task (i)	b_{i1}	c_{i1}	b_{i2}	c_{i2}	b_{i3}	c_{i3}
1	14.36	25	20.71	50	27.34	92
2	12.60	26	14.71	46	17.36	53
3	7.29	14	14.23	22	18.29	27
4	34.99	32	50.64	34	57.29	46
5	91.24	164	93.55	201	98.84	210

Note: $b_{i0} = c_{i0} = 0$ for all i.

Test Budget Level: K = $200.

GRAD Solution

Iteration 1:

Task (i)	Level (j)	c_{ij}	b_{ij}
1	1	25	14.36
2	1	26	12.60
3	3	27	18.29
4	2	34	50.64
5	0	0	0
		B_1 =	95.89

Iteration 2:

Task (i)	Level (j)	c_{ij}	b_{ij}
1	3	92	27.34
2	1	26	12.60
3	3	27	18.29
4	3	46	57.29
5	0	0	0
		B_2 =	115.52

DYNA Solution

Task (i)	Level (j)	c_{ij}	b_{ij}
1	0	0	0
2	0	0	0
3	0	0	0
4	3	34	50.64
5	2	164	91.24
		B_{opt} =	141.88

GRAD = 86.1% optimal.

Test Budget Level: K = $75

GRAD Solution

Iteration 1:

Task (i)	Level (j)	c_{ij}	b_{ij}
1	0	0	0
2	0	0	0
3	3	27	18.29
4	2	34	50.64
5	0	0	0
		B_1 =	68.93

Iteration 2:

Task (i)	Level (j)	c_{ij}	b_{ij}
1	0	0	0
2	0	0	0
3	3	27	18.29
4	3	46	57.29
5	0	0	0
		B_2 =	75.58

DYNA Solution

Task (i)	Level (j)	c_{ij}	b_{ij}
1	0	0	0
2	0	0	0
3	3	27	18.29
4	3	46	57.29
5	0	0	0
		B_{opt} =	75.58

Figure 8: Statistical Analysis; Full Test.

1. Y_1 = Percent optimal for GRAD Solutions (full test).

   $Y_1 = 97.699$, $S^2_{Y_1} = 25.154$, $S_{Y_1} = 5.015$

2. Confidence Intervals.

$$Pr\{96.849 \leq \mu_1 \leq 98.549\} = .90$$

$$Pr\{96.716 \leq \mu_1 \leq 98.682\} = .95$$

$$Pr\{96.408 \leq \mu_1 \leq 98.991\} = .99$$

3. Frequency Distribution

$$f(Y_1) = Pr\{A \leq Y_1 \leq B\}$$

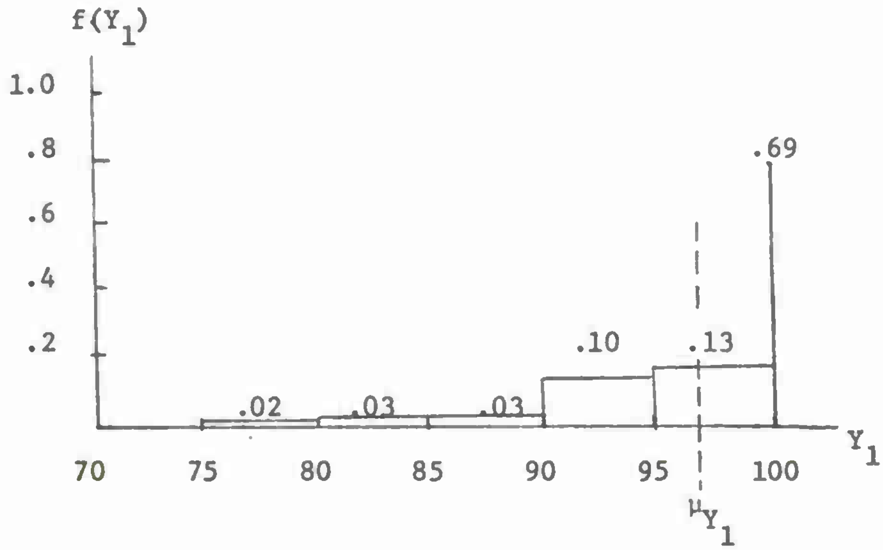


Figure 9: Statistical Analysis; Non-optimal Results.

1. Y_2 = Percent optimal for GRAD Solution (non-optimal results only).

$$Y_2 = 92.577, \quad S^2_{Y_2} = 43.726, \quad S_{Y_2} = 6.613$$

2. Confidence Intervals.

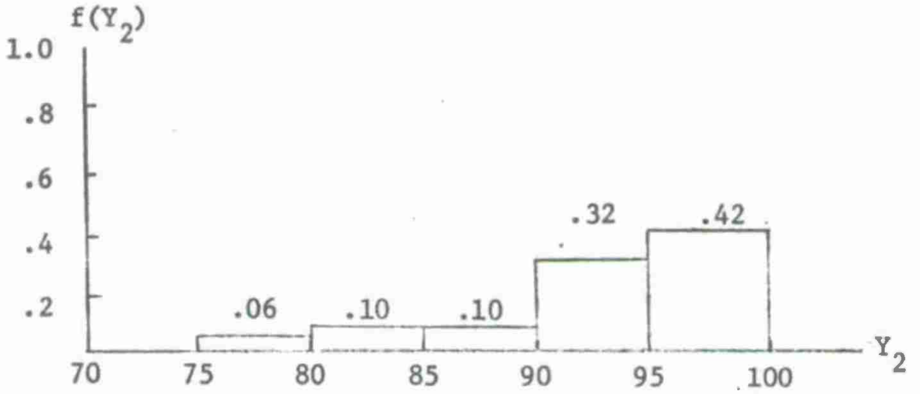
$$Pr\{90.564 \leq \mu_2 \leq 94.591\} = .90$$

$$Pr\{90.250 \leq \mu_2 \leq 94.905\} = .95$$

$$Pr\{89.519 \leq \mu_2 \leq 95.636\} = .99$$

3. Frequency Distribution

$$f(Y_2) = Pr \{A \leqslant Y_2 \leqslant B\}$$



IV.2 Benefit per Unit Cost Analysis.

Although the program objective is to maximize total benefit, a measure of GRAD's effectiveness in allocating funds is the benefit per unit cost associated with the GRAD solution versus the DYNA (optimal) solution. All things being equal, we prefer that solution for which the unit cost for benefit achieved is the smaller. This, of course presupposes that an alternative use for the funds is available. That is, the R&D program is taken to be part of a larger allocation process.

If we let T_C and T_B represent the total cost of funding all tasks at the highest level and the total benefit to be gained from funding at this level respectively, then $T_{B/C} = T_B/T_C$ is the benefit per unit cost that can be attained from full funding. We now let $G_{B/C}$ represent the benefit per unit cost achieved from the GRAD solution and $D_{B/C}$, the benefit per unit cost achieved with the DYNA solution. In order to compare $G_{B/C}$ and $D_{B/C}$ across the 31 sub-optimal test cases, it was necessary to normalize both measures. Normalized $G_{B/C}$ and $D_{B/C}$ are defined as:

$$G_{B/C} = G_{B/C}/T_{B/C} \text{ and } D_{B/C} = D_{B/C}/T_{B/C}.$$

Finally, we define

$$\Delta(B/C) \equiv (D_{B/C} - G_{B/C}) \times 100,$$

the percent increase in benefit per unit cost provided by the optimal solution over the pseudo gradient programming solution. A summary of all these data for the sub-optimal cases is included in Appendix B.

Figure 10 records the statistical results for $\Delta(B/C)$. Note that the average for all cases is -4.7%. Hence, on the average and for sub-optimal solutions, the pseudo gradient programming method generates a solution that provides 4.7% more benefit per unit cost than does the dynamic programming solution. This result is not too surprising considering the fact that the BFS is arrived at using a benefit-cost ranking scheme.

Care must be taken in weighing these results too heavily since insisting on a high $G_{B/C}$ score is equivalent to stating a dual objective function for the allocation process: maximize benefit and minimize cost. The futility of coupling these two objectives is apparent when we consider that they represent conflicting goals: cost is minimized at $0 where benefit is also minimized.

Figure 10: Benefit per Unit Cost Results.

1. Δ (B/C) = -.0471, S_Δ = .2830

2. Confidence Intervals.

$$\Pr\{-.1333 \leq \mu_\Delta \leq .0390\} = .90$$

$$\Pr\{-.1468 \leq \mu_\Delta \leq .0525\} = .95$$

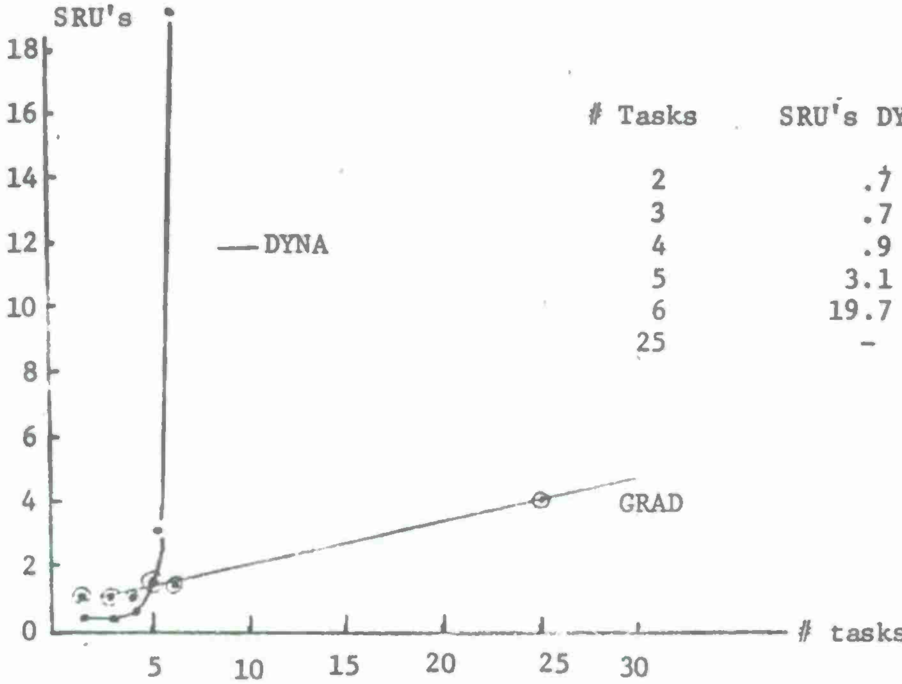
$$\Pr\{-.1780 \leq \mu_\Delta \leq .0838\} = .99$$

IV.3 Execution Time.

Earlier, it was pointed out that a process that allows for near real time solutions was necessary to support the interactive management procedures for Research and Development budget planning (1). As a result, a comparison test on computation time was conducted. Program execution time for the GRAD and DYNA programs were recorded for 2, 3, 4, 5 and 6 stage problems. In addition, execution time for a 25 stage problem was recorded for GRAD. It was not possible to run that large a problem using DYNA because of high speed storage limitations. The time units recorded are System Resource Units (SRU's). This measure is used by Computer Sciences Corp. on their INFONET time-sharing system. The computer used is a UNIVAC 1108.

Figure 11 records the results of this test in graph form. Note the dramatic increase in execution time for DYNA as the number of tasks exceeds 5. The exponential rate of increase becomes effectively vertical for very few tasks. The GRAD execution time on the other hand is fairly linear with problem size. The rate of increase is also small.

Figure 11: Time to compute comparison.



# Tasks	SRU's DYNA	SRU's GRAD
2	.7	1.0
3	.7	1.1
4	.9	1.1
5	3.1	1.4
6	19.7	1.3
25	-	4.0

V. Conclusions.

In those cases where optimality is not critical and computation time is, the pseudo gradient programming process is an extremely efficient technique to use in capital budgeting. Its main features are:

(1) Large problems may be handled on conventional computers (200 or more tasks at 4 or more alternative funding levels).

(2) Processing time is dramatically shorter than conventional optimization technique. (15 times shorter than dynamic programming for a 6 task problem, for example).

(3) The expected degradation in optimality is only 2.3%.

(4) The solution provides on the average 4.7% more benefit per unit cost expended.

The process makes up in speed and manageability what it lacks in absolute accuracy. For the interactive system described in (1), the technique is quite adequate. However, if the global optimal is required, certain efficiencies can be made to allow the dynamic programming method described in this paper to handle larger problems. This is the subject of the 3rd paper in this series (2).

A LIFE CYCLE COST MODEL FOR PROCUREMENT

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There has been general agreement concerning the advantages (as yet mostly untapped) of design-to-life-cycle-cost acquisition of equipments and systems. [1] Accordingly, the US Army Communications Systems Agency is trying a new approach to acquisition based on a life cycle cost model. The new approach makes use of the concept of "failure cost." Initial investment, operating, and failure costs together include the total life cycle costs of any system. The Government will allocate a fixed sum to the combination of investment and failure costs in the RFP. This will give the supplier latitude to trade-off investment costs to be bid by him against his proposed values for certain variables which determine failure costs (reliability, maintainability, repair parts).

The new model considers only costs; and, thus, is one element of the overall benefit analysis process:

$$\text{Net Benefit} = \left[\text{Gross Benefit}=f(\text{performance})\right] - \text{DLCC}$$

Where DLCC is design life cycle cost (including losses exterior to the system concerned). While determination of gross benefit is generally the more difficult task, this model for life cycle cost should shed some additional light on the general benefit analysis problem. This is particularly true since certain mission oriented and loss-of-service costs appear in the cost model.

In the past, system users have frequently experienced difficulty in specifying their statistical or stochastic requirements (e.g., reliability, maintainability, repair parts costs, etc.). Specifying deterministic requirements has been easy by comparison. This model reduces all requirements to more easily understood and manipulated dollar values.

Design life cycle cost (DLCC) consists of three costs: initial investment, operating cost, and failure cost. The latter cost is the principal new element in this model. The model expresses failure cost in terms of the others:

$$\frac{C_O}{MTBF_O} = L_O = \frac{(LS+R)\,MTTR_O + P_O + FFL}{MTBF_O} \leq \frac{DLCC - IC - OC(PV)}{LH(PV)} \qquad (1)$$

Where: C_O is the cost of a standard failure.

L_O is loss per life cycle hour due to failures.

LS is loss-of-service cost per outage hour.

R is the cost of the repair system per hour.

$MTTR_O$ is the mean time to repair.

P_O is the repair parts cost of a standard failure (including management costs).

FFL is a fixed failure loss. For continuously used systems, it is a function of LS, R, and repair system response time. For periodically used systems, it is the expected mission abort loss.

$MTBF_O$ is mean time between failures.

DLCC is design life cycle cost.

IC is initial investment cost (hardware, software, initial provisioning, R&D, and all other one time costs) less salvage value.

OC is life cycle operating cost (including replacement training and preventive maintenance).

PV is present value factor.

LH is the life of the system in hours.

In an acquisition situation, the supplier proposes values for each of the parameters labeled with subscript "o" plus the investment cost (IC). The user must specify all other parameters in his RFP. Basically this means the user must decide how much he is willing to spend over the life cycle (DLCC) and how much of that he wants to allocate to initial investment and failure cost together. The supplier is then free to propose any combination of IC, $MTBF_O$, P_O, and $MTTR_O$ which fits his equipment, maximizes his profit, and remains within the user financial constraints expressed in (1). It is evident that, in a competitive situation, the supplier proposing the greatest inequality within the constraints of (1) will win the contract.

The authors note that the operating cost can be affected by the supplier's design effort. It is clear that the supplier could propose number and skill levels of operating personnel, consumption rates, and replacement training costs based on the type and configuration of the system or equipment concerned. The user would have to supply information on personnel, consumables, and training where these things are user constrained. The authors have not yet explored this area in detail. For the purposes of this paper, they have tacitly assumed that OC will be constant and specified by the user. This is often the case in relatively stable, off-the-shelf, non-R&D situations.

It is not necessarily easy to provide explicit values for the user parameters--particularly LS and FFL, which are costs partly external to the system. Often "parametric costing" will be necessary until the user gains experience. There is some evidence that the model is relatively insensitive to errors in estimating these parameters, but this remains to be tested.

Both user and supplier have something to gain from use of this model. The user can see better, in dollar terms, how the supplier intends to "deliver" reliability, maintainability, and repair parts over the life cycle. Heretofor only initial investment was really visible. Further, he can better evaluate competing proposals because most factors of interest to him are out on the table. The user is relieved of the need to specify difficult parameters (P_O, $MTBF_O$, and $MTTR_O$)--he need only look at the overall failure performance parameter, L_O. The user gets the benefits of competition in these stochastic areas rather than only in initial investment. The supplier can propose costly, but high-performance equipment, and still be competitive over the life cycle. He can trade off $MTBF_O$, $MTTR_O$, P_O, and IC to fit his own situation and product line.

The use of a failure loss rate (L_O) as an overall measure of "goodness" for the statistical parameters proves convenient when the user tests his new system. The supplier, having specified L_O in the first place, can be made to demonstrate that the actual system will indeed generate failure costs at a rate no greater than L_O. This approach pleases the supplier because he no longer has to demonstrate $MTBF_O$, $MTTR_O$, and P_O separately. Random aberrations, which might cause one or two of these three parameters to fail, tend to cancel out when all are tested together in a "coherent" manner. In general, risks are lower.

Since each hour of testing is expensive, the authors favor tests which use test time most effectively, i.e., fixed length tests with inclined reject lines.[2] It is necessary to convert the usual reliability tests to loss-per-hour (L_O) tests. We do this by weighting each failure for time-to-repair and parts costs in the proportions dictated by equation (1). Thus:

$$F = \frac{(LS+R)(TTR-MTTR_O) + (P-P_O) + C_O}{C_O} \qquad (2)$$

Where: F is the number of standard failures per failure (the weight of an actual failure relative to a standard failure weight of 1 where $TTR=MTTR_O$ and $P=P_O$).

TTR is the actual measured time to repair.

P is the actual parts cost for the failure being weighted.

($TTR-MTTR_O$) and ($P-P_O$) are the deviations of the measured failure from the averages. When the deviations are zero, F = 1.

The effect of the distributions of TTR and P on the operating characteristics of the above tests is being investigated.

When the user's repair system contains more than one tier of maintenance it is necessary to amend expression (1) as follows:

$$L_o = \frac{\sum \left[(LS+R)\,MTTR_o\right]_i + P_o + FFL}{MTBF_o} \leqq \frac{DLCC-IC-OC(PV)}{LH(PV)} \qquad (3)$$

Where i is the level of repair. In tiers of maintenance behind the flight line or operating station, LS and FFL are negligible and R and $MTTR_o$ are greater. Multi-tier repair systems imply some investment in maintenance float. The authors prefer to consider this float as part of initial investment (generally a multiple of $\frac{P_o}{MTBF_o}$); indeed, it differs little from built-in redundancies such as multiple main frames in computer systems or hot standby radios. Also, in this scheme, parts costs per failure (P_o) pertain only to bad parts thrown away--whether these be modules or piece parts.

Expression (1) tacitly assumes that all "failures" result in an actual loss of service. Whether this is true or not depends on one's definition of failure. The authors define failure to mean any situation requiring repair, whether service is lost or not. This matter can be very important during testing of systems with redundancies; if "failure" means service outage, the system may suffer few "failures" while continuing to drain away maintenance resources.

If losses of service (LS and FFL) play a role in some failures and not in others, there are two MTBF's with which we must deal. By defining MTBF for total system failure ($MTBF_{os}$) and rearranging terms in (1), we can take into account both types of failure:

$$L_o = \frac{\sum \left[R(MTTR_o)\quad\right]_i + P_o + FFL}{MTBF_o} + \frac{LS(MTTR_{o1}) + \Delta FFL}{MTBF_{os}}$$

$$= \frac{\sum \left[R(MTTR_o)\quad\right]_i + P_o + FFL + \left[LS(MTTR_{o1}) + \Delta FFL\right](MTBF_o/MTBF_{os})}{MTBF_o} \qquad (4)$$

Where: Δ FFL is an additional increment of fixed failure loss associated with loss of service.

$MTBF_o$ is mean time between all failures.

$MTBF_{os}$ is the mean time between failures which result in loss of service.

$MTTR_{o1}$ is mean time to repair at the first tier of maintenance (where LS > 0).

The corresponding failure weighting schemes analogous to (2) are:

For failure with no loss of service

$$F = \frac{C_o + \sum \left[R(TTR - MTTR_o) \right]_i + (P - P_o) - \left[(LS)(MTTR_{o1}) + \Delta FFL \right] (MTBF_o / MTBF_{os})}{C_o} \qquad (5)$$

For failure with loss of service

$$F = \frac{C_o + \sum \left[R(TTR - MTTR_o) \right]_i + (P - P_o) + LS \left[TTR_1 - MTTR_{o1} \ (MTBF_o / MTBF_{os}) \right] + \Delta FFL \left[1 - (MTBF_o / MTBF_{os}) \right]}{C_o} \qquad (6)$$

In some systems, a partial failure will allow continued service in a degraded state. For such cases losses of service (LS and FFL) can take on more than one value. When that happens, the user must supply values for LS and FFL in each state. Then the supplier proposes an average value for LS and FFL based on the proportion of time he thinks the system will stay in each state. This will give the designer an incentive to preserve a partial operating capability.

The approach described in this paper is one of many possible,[3] but has the special advantage of being simple enough to mesh easily with Government and commercial procurement practice. It redistributes the task of specifying the various stochastic parameters to give the supplier more latitude than heretofor, without penalizing the user. At the same time, it gives the user an opportunity to look at the failure costs of his purchase over its whole life cycle.

This approach could lead to better Government-contractor relationships and more effective use of defense funds.

REFERENCES

1. DOD Directive 5000.1, "Acquisition of Major Defense Systems," 13 Jul 71

2. USAF proposed MIL-STD-781C, "Reliability Tests: Exponential Distribution," 21 Aug 73, ASD/ENYS HQ Aeronautical Systems Division, AFSC, Wright-Patterson AFB, Ohio

3. Review of the Application of Life Cycle Costing to the ARC-XXX/ARC-164 Program, August 1974, Avionics Program Office, Aeronautical Systems Division, Wright-Patterson AFB, Ohio

USE OF QUATERNARY S-CURVES TO PREDICT PRODUCTION COSTS

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INTRODUCTION

Todays austere budget climate within DoD and Government-wide has generated an unparalleled need for better techniques for predicting and evaluating the cost of the Army's weapon systems. This message is loud and clear as attested to by the recent renewed emphasis on the DoD design-to-cost concept and the Congress' intent in the structure of the Congressional Budget Committees that are being created by the Budget Reform and Impoundment Act which becomes effective in 1976.

This paper discusses techniques for (i) predicting production costs or for evaluating design-to-cost claims from R&D costs, (ii) predicting or evaluating R&D estimates based on a predetermined design-to-cost and (iii) predicting the R&D costs for achieving various performance levels. These techniques are based on an array of quaternary S-curves. Actual case examples will be given.

QUATERNARY S-CURVES

Cochran[1] recognized that during the early phases of production when many configuration and performance changes were taking place that plots of actual production costs were not approximated by the well known log-linear learning curve with an acceptable degree of accuracy. Over a fifteen-year period Cochran developed the S-curve technique empirically for predicting production costs for a given production run early in a particular production process. Subsequently, he developed a mathematical procedure for approximating an array of these curves. Unfortunately, the concept could not be applied without making certain assumptions that were often untenable unless some actual production had occurred.

In 1968 this author developed a procedure for expanding this technique to enable the prediction of the production cost, given a degree of change, prior to production commencing. In 1969 the technique was expanded from an array of mono S-curves to the array of quaternary S-curves that is addressed here. These findings were published in 1969 and are available from the Defense Documentation Center[2].

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1 Journal of Industrial Engineering, July-August 1960.

2 On Predicting Production Costs and Probable Learning Rates from R&D Investments by S-Curve/Learning Curve Relationships, October 1969, AD Number 750098.

This is a log-log graphical portrayal of one of the array of the family of quaternary S-curves (Figure 1). For the moment please disregard the X's on the chart. These will be referred to later to facilitate the review of two of the actual case examples that I will present.

As you can see, there are four curves shown. Each of these curves has a direct relationship to the other curves. They represent the four possible hardware events beginning with prototyping that occur in the materiel acquisition process. However, before proceeding, to avoid confusion let me make it clear that it is not necessary for all of these events to occur in a given situation in order for one to utilize this technique.

Proceeding from the top, the first of these curves, $R\&DS_n$, represents the R&D prototypes. The second curve, $PR\&DS_n$, represents R&D production units. This is an event that is not frequently encountered. An example of this event is that a contractor has developed R&D prototypes, usually a small item. The actual fabrication of the prototypes was accomplished by the designers and skilled technicians. The customer directs that the design be "frozen" and that a certain quantity of the same configuration as the prototypes be produced by the same personnel. The third curve, PPS_n, represents the pre-production models that are fabricated, usually in a job-shop atmosphere, before proceeding into full scale production. The fourth curve, PS_n, represents quantity or full scale production.

These curves, as all of the curves in the array, are cubic and are expressed in the form

$$a + bx + cx^2 + dx^3$$

The coefficient values are based on the slopes of the inherent R&D and production curves utilized in the computation of the structure of each set of quaternary curves in the array (see 2).

The DY shown on the graph represents the ratio of engineering costs to fabrication costs. The importance of this particular function can't be over emphasized. A full understanding of DY is necessary to fully grasp the concept that is being presented and to enable one to accurately apply the technique. In fact, the development of DY is what has made this technique so versatile in application and enables the user to avoid the pitfalls inherent in making several assumptions that are required by many other techniques.

As stated a moment ago, DY equals the engineering costs divided by the fabrication costs. For example, if a contractor's bid or actual cost for the first R&D prototype is \$350K, comprised of \$250K for engineering and \$100K for fabrication, then DY = 250/100 = 2.5. As will be seen in the examples, this tells us two very significant things. First, the relative complexity of the contractor's approach with respect to what degree his design is off-the-shelf componentry versus design from "scratch" can be determined. Secondly, the appropriate quaternary S-curve that the contractor's approach can be predicted to follow can be identified.

The derivation of DY for any given S-curve is

$$DY = \frac{1}{\text{R\&D Slope}/100 - (\text{Pdn Slope}/100 - \text{R\&D Slope}/100)}$$

Using the previous example of DY = 2.5 and an established production slope of 96% it can be determined that the R&D slope = 67%. This is the manner in which the S-curve tables are identified, i.e., for this particular set of quaternary curves one would look in the tables for R&D = 67% and P = 96%.

The final item on the graph is the values along the abscissa. These values represent the increments of experience gained for a given configuration of a system or item. As will be explained later, these increments do not necessarily represent the number of units of hardware that have been produced. It should be noted that the last value on the abscissa is 100. This point is defined as the theoretical point where, for a given configuration, perfection in design and production methods has been achieved.

As mentioned several times before, there is an array of the S-curves. This array parallels that of the well known log-linear learning curve and is identified in the same manner, i.e., by the slopes of the R&D and production curve that are utilized in the structure of a given curve. To date, the array of R&D slopes 67% - 99% and the production slopes 67% - 99%, for an array of some 1100 S-curves, has been computed and is presently in publication for submission to the Defense Documentation Center.

Perhaps what has been stated will become clearer by going through some case examples.

EXAMPLES

Case 1.

An RFQ has been issued soliciting bids for developing one (1) R&D prototype of Widget "A". The RFQ continues to state that a subsequent RFQ will be issued for the fabrication of three (3) full scale development test units and that two subsequent procurements will follow, one initial production buy of 100 units and a two-year multiyear procurement of 100 units each year. The RFQ incorporates a targeted design-to-cost of $5K per unit based on the cumulative average cost of the 300 production units derived on a 96% production curve.

Contractor YZ prepares a response stating his bid as $350,000 for the R&D prototype based on engineering costs of $250K and fabrication costs of

$100K. The contractor also states that his design will meet the target design-to-cost and all of the performance requirements in the RFQ.

Will it? Utilizing the S-curve technique based on an R&D slope of 67% and production slope of 96% with DY = 250/100 = 1.5:

A. The cost of the three (3) full scale development units would be the cost of $R\&DS_2$ taken from the S-curve plus the cost of PPS_3 times the cumulative total factor for two units from the log-linear curve with a 96% slope.

$$\text{Cost for } R\&DS_2 = R\&DS_1 \text{ (unit factor } R\&DS_2) = \$350K\ (.44229) = \$154{,}802$$

The difference in the cost between $R\&DS_2$ and PPS_2 is for the conversion of R&D drawings to production drawings.

The cost for units 2 and 3 would be

PPS_3 (cumulative total factor for 2 units from 96% log-linear curve)

or $R\&DS_1$ (unit factor PPS_3) (1.96) = 350K (.07328)(1.96) = $50,270

B. The cost for the initial production contract for 100 units would be

$PPS_4+PPS_5+PS_5$ (cumulative total factor for 98 units)

(350K)(.05392)+(350K)(.04357)+(350K)(.01927)(79.31460190) =

$569,099

C. The cost for the two-year multiyear procurement for 200 units would be

1st year - 100 units

$PPS_5+PPS_6+PS_6$ (cumulative total factor for 98 units)

(350K)(.04357)+(350K)(.03709)+(350K)(.01641)(79.31460190) =

$483,823

2nd year - 100 units

PS_7 (cumulative total factor for 100 units) (350K)(.01443)

(80.83995724) = $408,323

D. Then the cumulative average cost for the 300 production units would be

$$(569{,}099 + 483{,}823 + 408{,}323)/300 = \$4{,}871$$

Thus, provided the technical evaluation of the contractor's proposal indicates his design meets the desired performance characteristics, the contractor's bid and approach compares very favorably with the Government's targeted design-to-cost of $5K per unit.

Case 2.

The same situation exists as in Case 1 with the exception that the technical evaluation has determined that the contractor's design meets 90% of the desired performance characteristics. What will be the cost to develop this basic design to conform 100% with the desired performance characteristics.

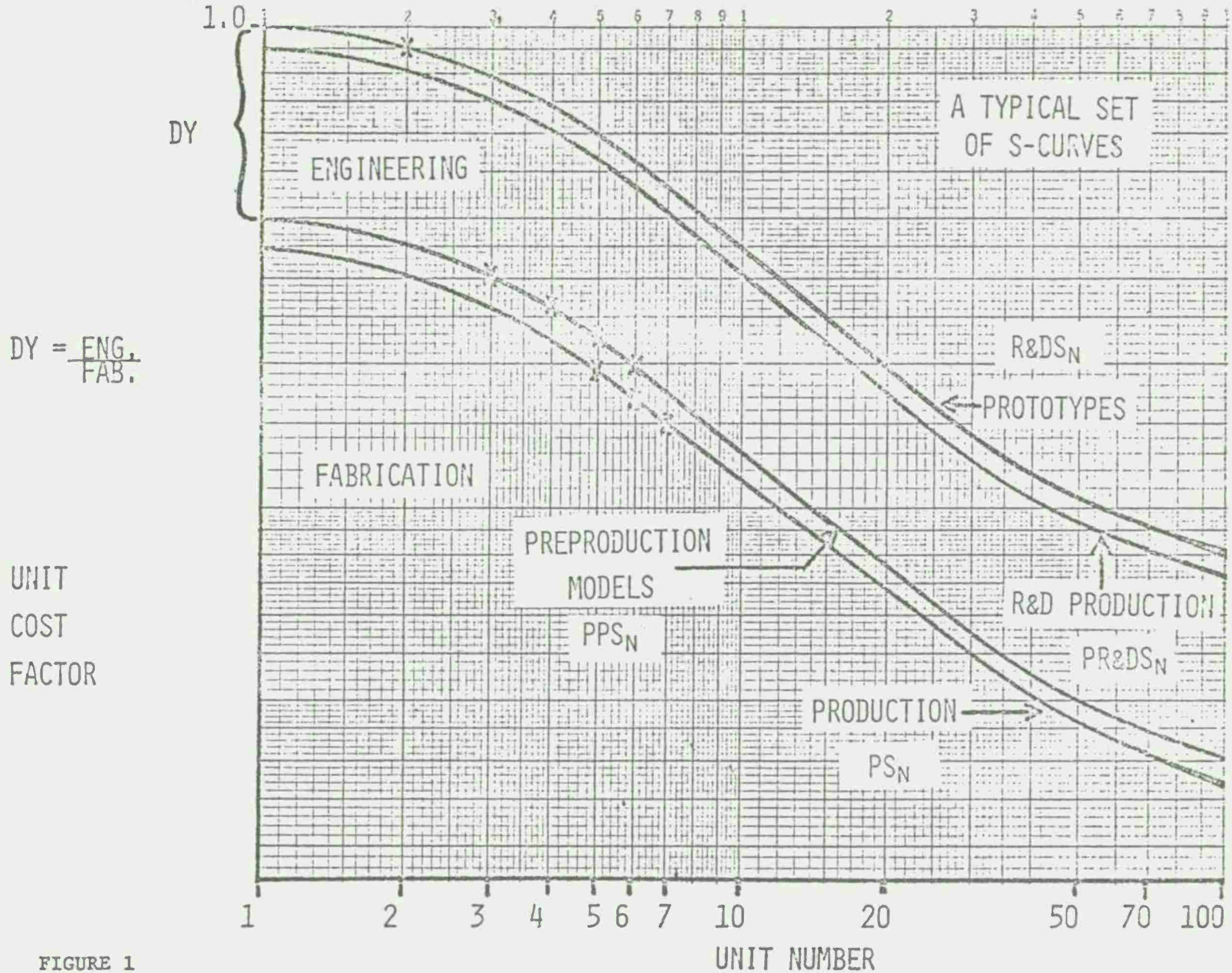
This can be approximated (Figure 2) by relating the rate of change of cost to the percent of change in performance. The merit for this lies in the definition of unit 100 on the S-curve. As can be seen on the graph, the intercept for a 90% technical rating is 8.98 (the same value as $R\&DS_{10}$ from the S-curve table X100), hence, it can be readily determined that to accomplish 100% conformance the cost for the first prototype would be

$$R\&DS_1 = 350K/.0898 = \$3{,}897{,}550$$

It then becomes obvious that this design cannot meet the original design-to-cost and conform 100% to the desired performance characteristics. To continue with this design it would be necessary to make trade-offs between cost and performance.

SUMMARY

The quaternary S-curve has proven to be a very valuable tool for predicting and assessing costs. The technique minimizes the number of assumptions that are usually necessary in cost analysis. The technique has been successfully used in cost analysis on such items as the AVL bridge, FAMECE, and the mobile assault bridge.



1.0
DY
ENGINEERING
A TYPICAL SET OF S-CURVES
DY = ENG./FAB.
R&DS$_N$
PROTOTYPES
FABRICATION
PREPRODUCTION MODELS
PPS$_N$
R&D PRODUCTION
PR&DS$_N$
PRODUCTION
PS$_N$
UNIT COST FACTOR
1
2
3
4
5
6
7
10
20
50
70
100
UNIT NUMBER

FIGURE 1

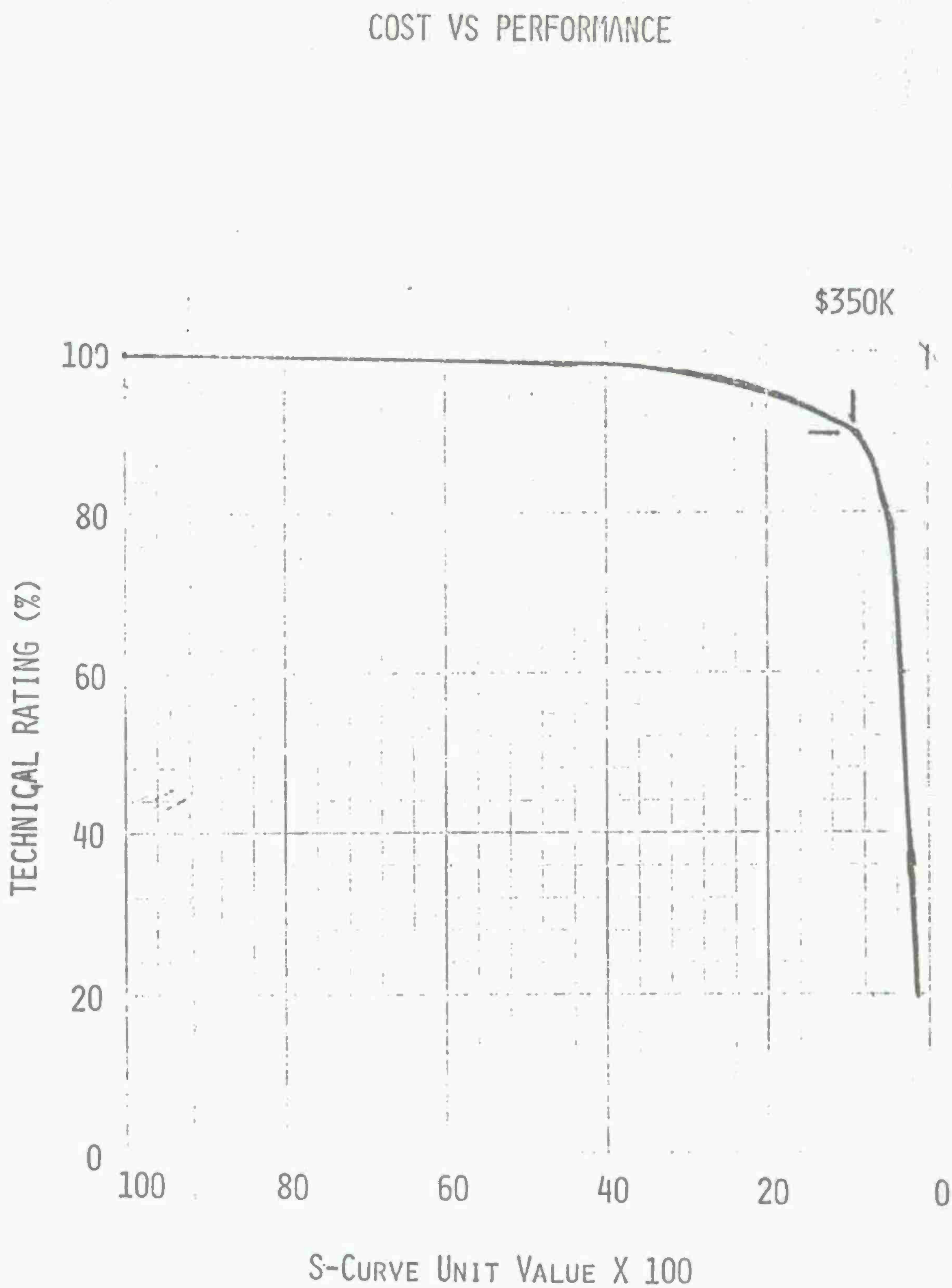

COST VS PERFORMANCE
$350K
TECHNICAL RATING (%)
100
80
60
40
20
0
100
80
60
40
20
0
S-CURVE UNIT VALUE X 100

FIGURE 2

DEADLINE COST MODEL STUDY

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INTRODUCTION

In the current environment of limited fiscal resources and competition for available funds, it is important that all economic factors relevant to the proposed program/project be considered using the best estimates available. This is particularly true in the area of logistics support, where the nonavailability of repair parts can result in deadlined equipment and idled crews. Unless the penalty costs of idled equipment and crews are included in our supply models, the decisions regarding the size of inventories and/or the addition or deletion of items to the supply system may be economically sub-optimum.

In December 1973, the Commanding General (CG), ARMCOM, directed his Systems Analysis Office to develop a generalized model which would quantify the costs, direct and indirect, which are incurred by the Army when an item of equipment is deadlined. "Deadline" used in the context of this study is taken to mean, "the removal of an item of equipment and its crew from operation or immediate operational readiness because of actual or potential mechanical, electrical, and safety device failure."[1] In his memo, the CG made reference to a practice used by the construction industry which equates the cost of a deadline to the cost of having to rent a similar piece of equipment. While this approach apparently works well in the construction industry where project completion schedules and/or penalty clauses are of sufficient impact to force the contractor to rent equipment, is it applicable to the military situation? A shortcoming of the construction industry approach is that it does not include such costs as operator/crew downtime or the cost of the repair and maintenance actions necessary to keep the equipment in service.

The results of this study should be considered for incorporation into the present logistics models which currently consider only the direct inventory costs identified to the PEMA and/or O&MA appropriations.

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[1] AR 310-25 defines deadlined equipment as follows: "Any major end item of authorized equipment charged to a using unit or agency which has been removed from operation or immediate operational readiness because of actual or potential mechanical, electrical, or safety device failure. It does not include equipment scheduled for routine preventive maintenance or inspection."

SCOPE OF STUDY

The initial phase of the study consisted of a literature search of data obtained from the Defense Documentation Center and the Defense Logistics Studies Information Exchange. Upon finding the available literature void of similar or related studies, several initial approaches to the model were investigated, of which the unit-level model was selected for further development. This model addresses those costs specifically identified to the deadline/failure event. The reader is cautioned that this approach is not all inclusive because indirect costs such as mission abort are not included. Initial testing of the model was conducted on the Howitzer, M109A1; Vulcan Air Defense System (VADS), M163 and M167; and the Armored Recon Airborne Assault Vehicle (ARAAV), M551.

UNIT LEVEL MODEL

$$C_{Dl} = F_1 \left[C_{R1} + (C_C)(D_{T1})\right] + F_2 \left[C_{R2} + C_C\,(D_{T2})\right] + F_3 \left[\left(\frac{(F_L)(A_C)}{S}\right)(D_{T3}) + T_C + C_{R3} + C_C(T_T)\right]$$

where

C_{DL} = Average cost of a deadline

A_C = Acquisition cost/standard price

C_C = Average crew cost

F_1 = Portion of the repairs completed at the mission site $0 \leq F_1 \leq 1$ (Basic assumption is that mission site repairs do not require issuance of a float.)

F_2 = Portion of the repairs completed at the support level not requiring the issuance of a float, $0 \leq F_2 \leq 1$

F_3 = Portion of the repairs completed at the support level requiring the issuance of a float, $0 \leq F_3 \leq 1$

$$F_1 + F_2 + F_3 = 1$$

C_{R1} = Average repair cost for mission site repair

C_{R2} = Average repair cost for support level repairs not requiring a float

C_{R3} = Average repair cost for support level repairs requiring a float

D_{T1} = Average deadline time for the mission site repairs

D_{T2} = Average deadline time for support level repairs not requiring a float (includes transportation time to and from support organization)

D_{T3} = Average deadline time for support level repairs which require the issuance of a float

T_C = Transportation cost to bring a float to the mission site

T_T = Transportation time required to bring a float to the mission site

S = Unit service life

F_L = Float level (number of items in the float)

Data Impact on the Unit-Level Model Development was as follows:

The maintenance data collection system utilized by the Army prevented deriving or estimating values for some of the parameters (F_1, F_2, F_3, D_{T1}, D_{T2}, and D_{T3}) required in the above model. In addition, a recent publication[2] cited serious gaps existing in these maintenance records.

DEVELOPMENT OF A GENERALIZED FORCE-LEVEL DEADLINE COST MODEL

Upon reviewing existing data, it was discerned that force-level life cycle data are readily available or readily estimated.

In quantifying the cost of deadline, it is necessary to make a basic assumption that in the allocation of the defense budget to provide a given level of combat capability, the benefit lost from not having an item of equipment and its crew operationally available is at least equal to the cost of acquiring, operating, and maintaining that unit in the force structure. If this transformation of dollar resources into troop and hardware inventories has been properly effected, the marginal benefit derived from a given military operating unit should be at least equal to the marginal cost of that unit[3]. In this context the term "unit" denotes an item of equipment and its crew. The nonavailability of a deadlined item, therefore, reduces the overall value of our combat capability by an amount at least equal to the dollar resources consumed by that unit, prorated over the length of the downtime.

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[2] Technical Memorandum No. 164, Vehicle Average Useful Life Study for Truck Cargo; 2-1/2 ton, 6 X 6, M35A2, Raymond Bell, Robert Mioduski, Edward Belbot, Robert Rosati, and Larry Crow, October 1973 - US Army Materiel Systems Analysis Agency, Aberdeen Proving Ground, Maryland.

[3] Richard H. Leftwich, The Price System and Resource Allocation, revised ed. (Holt, Rinehart and Winston, New York, NY, 1963), p 318-319.

It is reasoned that the fiscal resources consumed in the acquisition of the item amortized over its life, plus repair, maintenance, and crew costs, make available a certain number of productive service days per period for a given unit. It is recognized that this is not the exact value lost when a specific unit is unavailable for service; but, rather, it is approximately the deadline cost incurred for the aggregate of end items of a given class utilized by the Army.

It is proposed in this study that the total unit cost per service day (i.e., the average cost of a given unit per day) incurred by the Army be a proxy for the deadline cost.

Therefore,

$$C = \frac{(1 + FF)(AC/SL + RMC) + CC}{365} + IC$$

C = Deadline cost per service day

FF = Float Factor

AC = Acquisition Cost/standard price

SL = Service Life in years

RMC = annual Repair and Maintenance Cost

CC = annual Crew Cost

IC = Impact Cost - i.e., the cost of other personnel and equipment dependent upon the deadlined unit for continued operation

TRIAL RUN AND SENSITIVITY ANALYSIS

To test the model, data (Appendix A) was collected for the ARAAV, M551; VADS, M163 and M167; and Howitzer, M109A1; and entered into the model, Table 1.

TABLE 1 - FORCE MODEL INPUTS

	M551	M163	M167	M109A1
Float Factor	0.033	0.09	0.09	0.027
Acquisition Cost	$259,930	$276,377	$220,416	$145,812
Service Life	20 Yr	20 Yr	20 Yr	20 Yr
Crew Cost	$48,200/Yr	$47,580/Yr	$47,580/Yr	$96,675/Yr
Maintenance Cost	$30,736/Yr	$47,859/Yr	$36,443/Yr	$29,697/Yr

The results obtained from the force level model are shown in Table 2.

TABLE 2 - FORCE MODEL RESULTS

	M551	M163	M167	M109A1
Deadline Cost per Service Day	$256	$315	$272	$369
Percentage of Acquisition Cost	.098%	.11%	.12%	.25%

It is of interest to note the impact of the higher crew cost for the M109A1 upon the Deadline Cost per Service Day. Also, the difference in the Percentage of Acquisition Cost for the M551 and M109A1 would clearly indicate that these factors are item peculiar and not common to a commodity class of items.

Sensitivity analyses were conducted to determine model responsiveness to changes in data input and to identify those data elements which have the most significant effect on the independent variable, deadline cost per service day. First, an analysis of the major independent variables was performed in which each of these variables was increased by one percent while holding all the other independent variables constant and observing the percentage change in the dependent variable, Table 3.

TABLE 3 - SENSITIVITY ANALYSIS

(MAJOR INDEPENDENT VARIABLES)

Independent Variable (1% Change)	M551	M163	M167	M109A1
	% CHANGE IN DEADLINE COST PER SERVICE DAY			
Float Factor	.016	.048	.043	.007
Acquisition Cost	.148	.131	.121	.056
Crew Cost	.340	.454	.400	.718
Maintenance Cost	.516	.414	.479	.227

As can be seen, crew cost and maintenance cost have the most significant effect on the deadline cost per service day. Adding the independent effects of the two variables yields a value in excess of 86 percent for the items of equipment subjected to this analysis.

To examine the sensitivity of the model at the account level, a similar analysis was conducted on each of the cost accounts which make up the annual crew and maintenance cost variables. For a one percent increase in each of the account variables, the percentage change in deadline cost per service day shown in Table 4, were observed.

TABLE 4 - SENSITIVITY ANALYSIS OF ACCOUNTS

ACCOUNT VARIABLE (1% Change)	M551	M163	M167	M109A1
	% CHANGE IN DEADLINE COST PER SERVICE DAY			
Crew Cost				
Crew, Pay and Allowance - MPA	0.356	0.271	0.320	0.477
Crew, Replacement Training	0.035	0.037	0.042	0.046
Crew, Overhead	0.124	0.101	0.117	0.194
Maintenance Cost				
Maintenance, Pay and Allowance - MPA	0.051	0.109	0.101	0.049
Maintenance, Replacement Trng	0.01	0.025	0.024	0.012
Maintenance, Crew Overhead	0.022	0.046	0.043	0.021
Consumption, Parts	0.166	0.202	0.182	0.115
Consumption, Pet Oils and Lub - OMA	INSIGN	INSIGN	INSIGN	INSIGN
Transportation - OMA	0.005	0.006	0.004	0.003
Depot Maintenance	0.077	0.065	0.047	0.027

It can be seen from this analysis that crew pay and allowance is the dominant factor, contributing nearly three times more to the deadline cost per service day than any other account. This variable, however, is easily computed based upon crew composite and pay grades and should have a very low estimating error. It should also be noted that for three of the four items studied, repair parts are the next most significant variable. Cost estimates prepared by the ARMCOM Cost Analysis Division, based upon repair parts demand history, provide reasonable estimates for this data element.

Since the independent variable, service life, has a non-linear relationship with the dependent variable, deadline cost per service day, sensitivity calculation were made to observe the relationship between these two variables (Figures 1 through 4). As can be seen, service life does not effect the deadline cost per service day more than 10 percent providing the service life of the item does not fall below 12 years, using a base case life of 20 years. The percentage increases a little more than double when moving from a service life of 12 to 8 years. However, as service life is reduced to less than 8 years, the deadline cost per service day increases rapidly.

For the items studied, the variable impact cost (IC) was not included because the effected organizations could not be identified. It was, however, of interest to get some idea of the relative magnitude of the cost of deadline when impact costs are included. A test case was developed to determine the impact cost resulting from the deadline of a 225 ton/hour rockcrusher and the four Horizontal Construction Platoons of an Engineer Battalion, which depend upon it for material. It was found that when the rockcrusher was deadlined, 18 on-equipment crew personnel were idled, as compared to

85 personnel and their equipment (i.e., trucks, scrapers, etc.), who depend upon the output of the rockcrusher to accomplish their primary mission. Cost data for equipment acquisition, personnel, and maintenance were estimated and inputted into the force level model. The results obtained are shown below:

$$C = \frac{(1 + FF)(AC/SL + RMC) + CC}{365} + IC$$

$$= \frac{(1 + 0)(\$472,242/5 + \$35,000/YR) + \$165,988/YR}{365\ DAYS/YR} + \$2,526/DAY$$

$$= \$809/DAY + \$2,526/DAY = \$3,335/DAY$$

As can be seen, the impact cost per deadline day is $2,526 or three times as large as the cost directly identified to the unit of equipment and its crew.

COST ESTIMATING RELATIONSHIP (CER)

The recommended method for computing the deadline cost per service day for a specific unit of equipment is by the force level model. It is recognized, however, that there are situations in which an easily computed, approximate order of magnitude estimate will suffice. Based upon the results obtained from the force level model for the limited sample of four weapons systems studied the following CER was developed.

$$C = .0006\ (\text{Acquisition Cost}) + \$32\ (\text{No. of personnel in Crew})$$

Comparison of the deadline costs per service day obtained from the CER to the values obtained from the force level model disclosed that the CER results were accurate within -7% to +11%.

CONCLUSIONS

For the hardware items used as test elements in this study, it would appear that the force-level model has a fairly high degree of stability. Except for the crew pay and allowance account, estimation errors of $\pm$ 20 percent or less in the independent variables will not have a significant effect on the dependent variable. However, the crew pay and allowance account is readily computed based upon crew composition and grades for the item under study and the Military Pay and Allowance Tables and should have a very low estimating error. The remaining data required by this model are readily available for the items used in this study and for additional hardware items[4]. It is, therefore, concluded that the force-level model may be applied, and it yields a reasonable estimate of the value lost to the US Army when an item of equipment is not available because of being deadlined.

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[4] Technical Report No. 73-6 (unpublished), Comparative Cost Analysis WECOM Managed Items, I PEMA Hardware Unit Cost, II Annual Unit Operating Cost, HQ US Army Weapons Command, Cost Analysis Division, Rock Island, IL, April 1973.

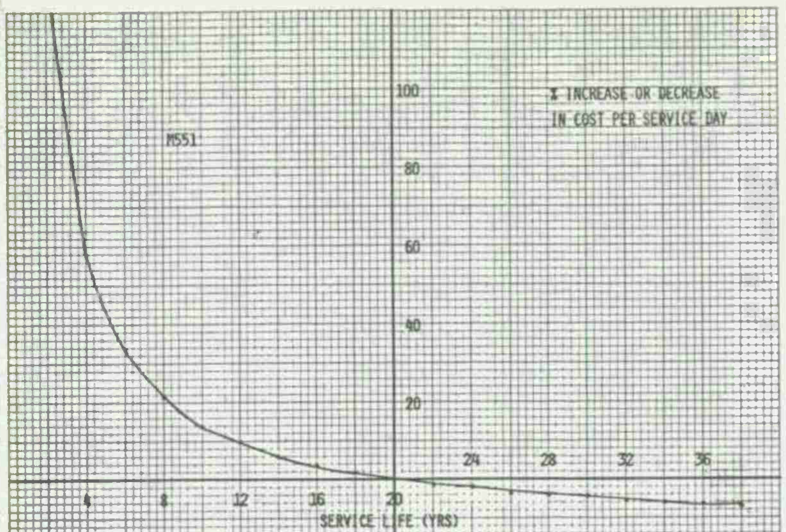

FIGURE 1. SERVICE LIFE SENSITIVITY FOR ARAAV M551.

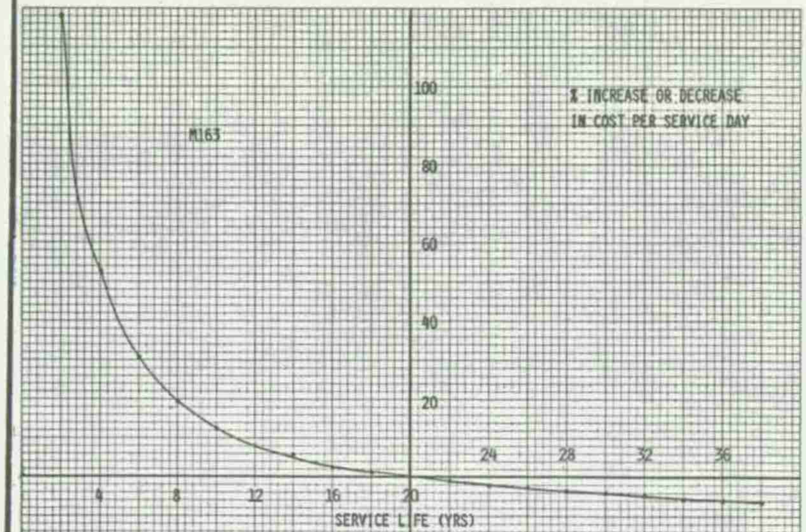

FIGURE 2. SERVICE LIFE SENSITIVITY FOR VULCAN AIR DEFENSE SYSTEM M163.

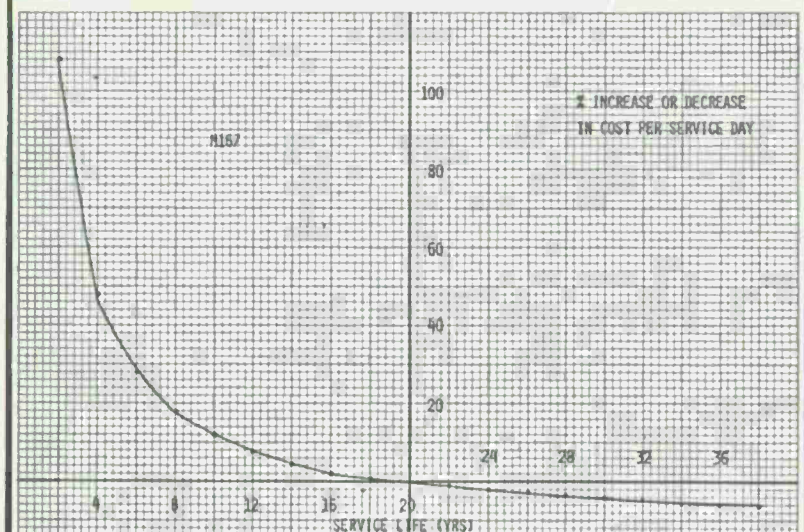

FIGURE 3. SERVICE LIFE SENSITIVITY FOR VULCAN AIR DEFENSE SYSTEM M167.

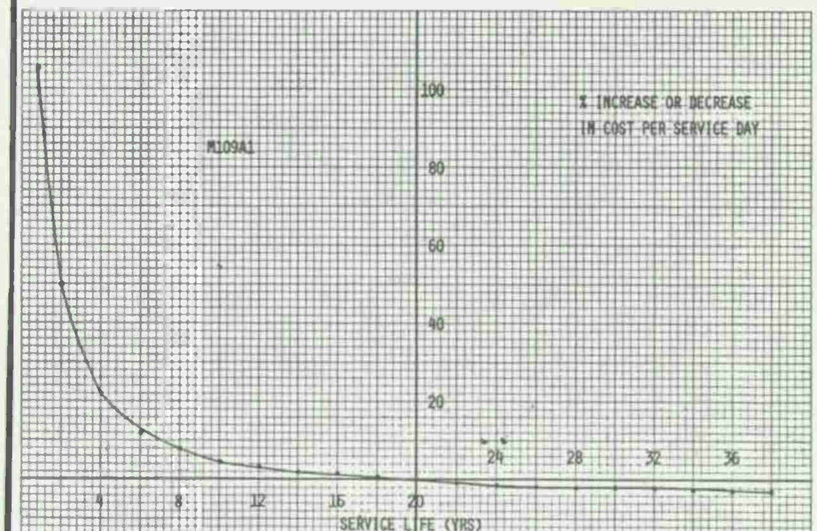

FIGURE 4. SERVICE LIFE SENSITIVITY FOR ARAAV HOWITZER M109.

APPENDIX A

DATA ELEMENTS USED TO EXERCISE THE MODEL

1. Float Factor

M551	0.033
M163	0.09
M167	0.09
M109	0.027

2. Acquisition Cost

M551	$259,930
M163	$276,377
M167	$220,416
M109	$145,812

3. Estimated Service Life

M551	20 years
M163	20 years
M167	20 years
M109	20 years

4. Crew, Pay & Allowance - MPA

Based upon crew composition and average grade level

M551	$33,280/year
M163	$31,770/year
M167	$31,770/year
M109	$64,280/year

5. Crew, Replacement Training

Based upon the percentage of annual turnover of item 4 above

M551	$3,300/year
M163	$4,190/year
M167	$4,190/year
M109	$6,250/year

6. Crew, Indirect

Developed from data obtained from Comptroller of the Army, Cost Analysis, that the indirect cost per year for an individual soldier is $2,905. This factor is multiplied by the number of personnel in the crew.

M551	$11,620/year
M163	$11,620/year
M167	$11,620/year
M109	$26,145/year

→ TOTAL Crew Costs (4 + 5 + 6)

M551	$48,200/year
M163	$47,580/year
M167	$47,580/year
M109	$96,675/year

7. Maintenance, Pay and Allowance - MPA

Based upon equivalent number of man-years to perform maintenance actions.

M551	$4,630/year
M163	$11,500/year
M167	$9,190/year
M109	$6,430/year

8. Maintenance, Replacement Training

Based upon a percent annual turnover of item 7 above.

M551	$1,740/year
M163	$2,590/year
M167	$2,160/year
M109	$1,500/year

9. Maintenance, Crew Indirect

Based upon a computed percent value to allocate the indirect cost per individual soldier (Item 6) to the number of equivalent man-years shown in item 7 above.

M551	$1,956/year
M163	$4,859/year
M167	$3,883/year
M109	$2,717/year

10. Consumption, Parts

M551	$14,990/year
M163	$21,320/year
M167	$16,590/year
M109	$15,020/year

11. Consumption, Petroleum Oils and Lubricants - OMA

M551	$60/year
M163	$100/year
M167	-
M109	$70/year

12. Transportation - OMA

M551	$420/year
M163	$670/year
M167	$360/year
M109	$410/year

13. Depot Maintenance

Overhaul costs prorated on an annual basis.

M551	$6,940/year
M163	$6,820/year
M167	$4,260/year
M109	$3,500/year

→ TOTAL Repair and Maintenance Cost (7 + 8 + 9 + 10 + 11 + 12 + 13)

M551	$30,736/year
M163	$47,859/year
M167	$36,443/year
M109	$29,697/year

REMOTELY MONITORED BATTLEFIELD SENSOR SYSTEM (REMBASS) DEFINITION EFFORT

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System Description

The Remotely Monitored Battlefield Sensor System (REMBASS) is a ground based supplemental surveillance system capable of remote operations anywhere in the world. REMBASS is designed to provide the commander in the field with an all weather, day-night surveillance and target acquisition capability which will be used to complement and supplement other manned and unmanned surveillance systems. It is comprised of small remote sensors, unattended data relays, and readout equipment which are capable of operation by the Army in the field.

REMBASS is employed in the three basic roles of surveillance, target acquisition and alerting. These roles may take place in offensive, defensive and retrograde operations in high, mid, and low-intensity warfare, REMBASS sensors are to be employed by all echelons of the Army from patrol through division and employment within the maneuver battalion in fluid offensive and defensive operations is emphasized. In addition to tactical applications, the REMBASS alerting function is to be used for rear area and base security.

The REMBASS is designed to be deployed both behind and forward of the Forward Edge of the Battle Area (FEBA) and will be capable of transmitting information over a distance of up to 60 km through the use of tandem radio repeaters. REMBASS sensors/relays are designed to be emplaced by hand, aircraft, and artillery.

REMBASS must accomplish the following:

a. Determining target classification,
b. Determining the number of targets present,
c. Determining the target direction,
d. Determining target speed, and
e. Determining the location of targets and sensors on standard UTM coordinates.

The REMBASS will be composed of equipment that will fulfill the requirements generated by the using organization. The equipments will be organized into generic subsystems to describe the major functions of REMBASS. The six subsystems required for REMBASS are illustrated in Figure 1.

The function of the sensor subsystem is to report the presence of a target and to determine the class of targets that is being detected. Sensors are devices which use phenomena of a target to determine if a target is within the zone of influence of the sensor. Sensors will report this information to the sensor reporting unit where information can be assembled to fulfill the system surveillance, target acquisition, and alerting functions. Sensors will use acoustic and seismic technologies to classify targets, and the information conveyed by a particular sensor will be identified with respect to that sensor. Sensors will have a detection range of 100 meters against men and 500 meters against vehicles. These ranges are dependent on environmental conditions.

The function of the Data Transmission Subsystem (DTS) is to provide a means of data transfer between remotely deployed sensors and a Sensor Reporting Unit (SRU). This data consists of digital messages originating at the sensors as a result of target activations. These messages occur as short burst transmissions and contain control information, sensor identification, and various amounts and kinds of target data, dependent upon the type of sensor which originates the message. These messages may be received directly by a SRU receiver or they may be relayed through one or more repeaters if line of sight (LOS) between sensors and SRU cannot be achieved - The DTS may also provide a command link between the SRU and the Store and Forward Repeater.

The DTS operates in the VHF band and several communication channels are available within the system bandwidth for independent, simultaneous, non-interfering operation between multiple sensor fields.

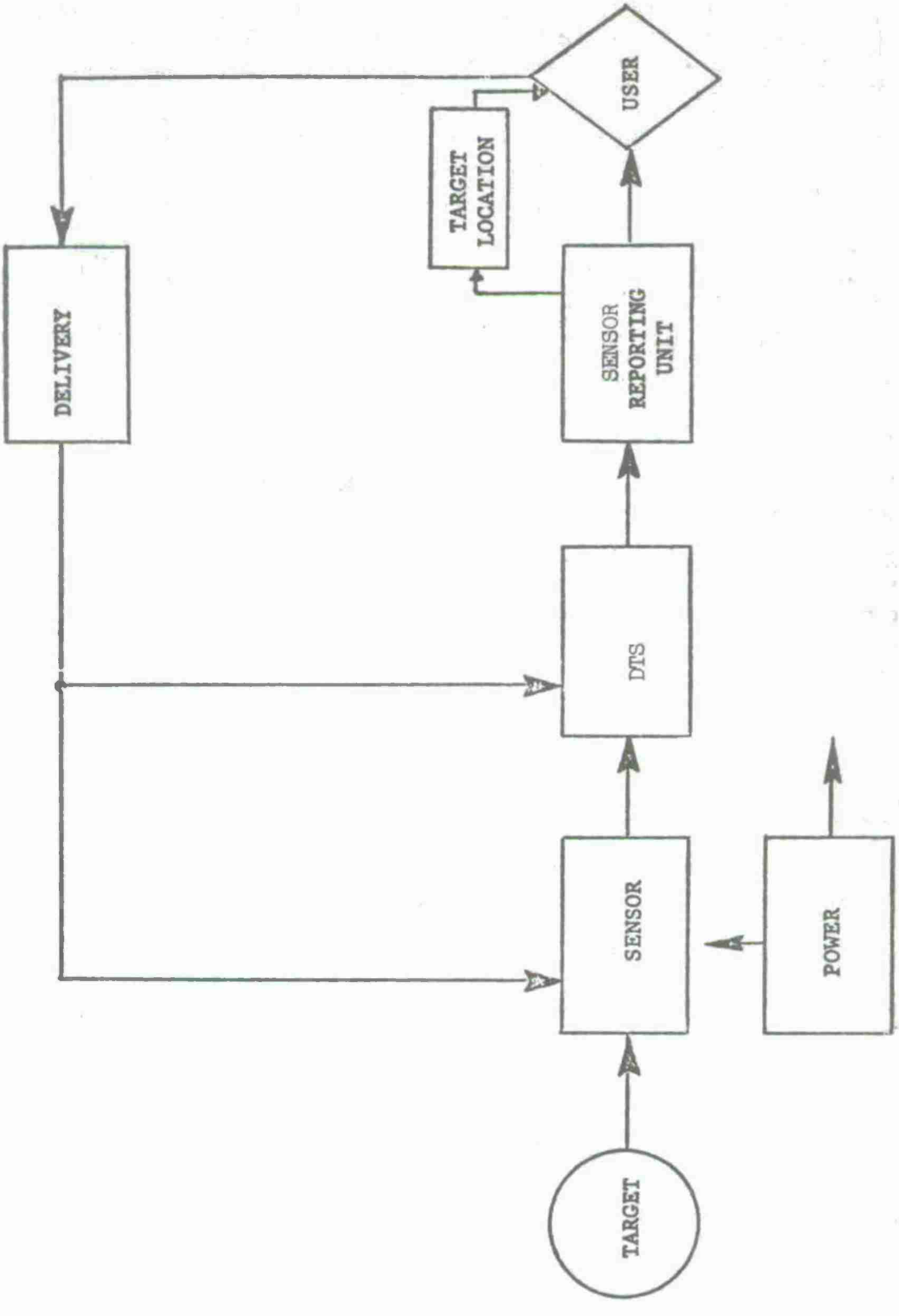
The function of the Sensor Reporting Unit (SRU) Subsystem is to display incoming sensor data so that an operator can perceive and determine target activity in his area of interest. The SRU Subsystem provides the data processing, hard-copy recording, visual display and command capability for the REMBASS. Data presented to operator provides the basis for pattern analysis and assessment of target movements.

The SRU subsystem may be used at battalion, brigade, and division levels.

The function of the delivery subsystem is to deliver REMBASS equipment by one of the following three means:

A. hand emplacement,
B. aircraft emplacement, and
C. artillery emplacement.

The Target Position Location (TPL) Subsystem estimates location and velocity of a target in the area being monitored. The velocity measurement is useful in predicting target position a short time ahead so that effective counteraction may be initiated. There will ordinarily be an array of two or more sensors emplaced to cover the target area.



DELIVERY
USER
TARGET LOCATION
SENSOR REPORTING UNIT
DTS
SENSOR
POWER
TARGET

Figure 1

Data from sensor arrays assists in locating and predicting target motion. Array data is processed at the SRU, either manually or by computer. The TPL Subsystem also includes computer algorithms, where necessary, to process array data and to generate the required target location estimates.

The function of the Power Sources Subsystem is to provide appropriate self-contained power sources for use in REMBASS unattended or portable equipment. These power sources must supply adequate voltage and current to power the REMBASS equipment for the full operational life and under all the specified environments. The principal REMBASS power source is the lithium organic electrolyte primary battery. This will be available in a standard Army format for hand emplaced equipment, and in a common REMBASS shock resistant format for air or ballistic emplaced equipment. Both formats will be compatible with REMBASS electronics and with standard Army battery test equipment.

PROBLEM

The basic problem was to define the REMBASS. Although the problem can be stated simply, it is a very complicated one to solve.

REMBASS is not really a fixed system. It is rather an inventory of equipments from which the commander can select those items he requires for a certain mission. The system definition is complex and involves input from several different agencies. The definition process cannot be accomplished by the developer in a vacuum. The close cooperation of the user is necessary.

To solve the problem, the Project Manager (PM) REMBASS established an iterative process between the AMC and TRADOC communities. TRADOC first submitted a basic set of requirements. The PM then established six subsystem teams to review these requirements.

Each subsystem team was composed of representatives from the MITRE Corporation, the Office of the PM, the ECOM Systems Analysis Office and various Government laboratories which were directly involved in development work in the subsystem area.

The PM directed the teams to formulate a series of questions which had to be answered in order to define the subsystem. Alternative solutions were also generated. The questions and alternative solutions were reviewed and approved by the PM.

Each problem was analyzed separately and the method used is described in the following section.

METHODOLOGY

After each problem was formulated, a list of viable solutions was generated. The subsystem teams attempted to make the list a complete one, where no viable alternative was initially eliminated from further analysis.

Since there were a large number of analyses to perform and a limited time in which to complete them, a standardized method was developed for collecting data, analyzing the data and documenting the results.

Each subsystem team examined each problem individually and developed a list of evaluation criteria. These criteria were to represent all pertinent factors which must be considered in solving the problem.

At this point the alternatives and evaluation criteria were established. The data collection phase could now begin. This was a two step process. The first was to generate quantitative data (i.e. range in meters, cost in dollars, etc.). Once this had been completed, these quantitative values were converted to relative values on a common scale and are called scores.

While the subsystem teams were engaged in the data collection, another group was generating weighting factors. This second group was made up of management oriented personnel who are familiar with basic priorities within the Army. The group included the PM and his deputy, and AMC, TRADOC and DA personnel. The generation of weighting factors in essentially determining the relative importance of the criteria.

A completed matrix of alternatives, scores and criteria weights is shown in Figure 2.

The scores and weights were then combined to determine the preference ranking of the alternatives. Four weighting techniques were utilized to combine the scores and weights. They are described below:

1. Additive weighting combines the weights and scores in a linear fashion. Subcriteria weights and scores are multiplied and summed within each major criteria. The sums are multiplied by the appropriate major criteria weights and summed again.

This can be expressed as follows:

$$ER = \sum_{j=1}^{n} \omega_j \left(\sum_{k=1}^{r_j} S_{jk} \alpha_{ijk} \right)$$

Where:

ER = Evaluation Rating

α_{ijk} = Relative Evaluation Score for Alternative i for Subcriterion k of Major Criterion j

S_{jk} = Weighting Factor for Subcriterion k of Major Criterion j

W_j = Weighting Factor for Major Criterion j

n = Number of Major Criteria j

rj = Number of Subcriteria of Major Criterion j

2. RMS Weighting - The resultant evaluation rating is the square root of the sum of the products of the evaluation score squared times its appropriate weighting factor. This can be expressed as follows:

$$ER = \sqrt{\sum_{j=1}^{n} \omega_j \left(\sum_{\kappa=1}^{r_j} S_{j\kappa} a^2_{ij\kappa} \right)}$$

This method places greater emphasis on high scores.

3. Multiplicative Weighting - The resultant evaluation rating is the product of all evaluation scores raised to the power of their appropriate weight. This can be expressed as follows:

$$ER = \prod_{j=1}^{n} \left(\prod_{\kappa=1}^{r_j} a_{ij\kappa}^{S_{j\kappa}} \right)^{\omega_j}$$

This method places greater emphasis on low scores.

4. Logarithmic Weighting - The resultant evaluation rating is the logarithm of the sum of the products of 2 raised to the evaluation score power times its appropriate weight. This can be expressed as follows:

$$ER = \log_2 \left[\sum_{j=1}^{n} \omega_j \left(\sum_{\kappa=1}^{r_j} 2^{a_{ij\kappa}} S_{j\kappa} \right) \right]$$

This method places extreme emphasis on high scores.

The application of these four techniques to the data of Figure 2 results in the Evaluation Ratings of Figure 3.

The resultant ratings are based on nominal values of scores and weights. Both are subject to dispute as they represent opinions of persons involved. Because of the subjectivity of the values, it was decided to perturb them and examine the effects on the results.

It was decided not to vary the scores. They were the output of technical "experts" and were based on quantitative data which could be supported. The weights, on the other hand, are strictly a matter of opinion, and should be varied.

The group supplying weights was asked to supply a range on the nominal values. This is essentially an attempt to Preclude "what if" questions at the end of the analysis. By using the minimum and maximum values for major criteria weights (and scaling the remaining weights up or down accordingly) and repeating the calculations, one can develop confidence in the rankings. An example of these results is shown in Figure 4. (Because the impact of the subcriteria weights on the evaluation rating is much less than the major criteria weights, a sensitivity study including subcriteria weights was not considered necessary.)

It is very likely that the results will change when the weights are varied and when one weighting technique is compared to another. To resolve this, the final ranking of alternatives was based on a rank frequency chart as shown in Figure 5. This chart is a summary of rank position for all calculations made. It was decided to use rank as the final basis rather than scores, as scores shift in the different weighting techniques and averaging could erase the differences.

The results were reviewed and used to generate conclusions and recommendations. A presentation was then made to the PM.

APPLICATION OF RESULTS

The results of these analyses were utilized in the next iteration with the user. The PM asked the user more specific questions about his requirements, specifically the types of functions he desired in REMBASS. When the user stated a requirement for a certain function, the PM could present the analysis addressing that area and explain how the function would be implemented in the system.

Upon completion of this iteration, the results were taken by the PM and given to a Systems Group. This was made up of persons who were familiar with the results of the separate subsystems analyses. They were to examine all results and resolve any problems created by combining the separate pieces into a system. This effort is currently being accomplished with a scheduled completion date of 2nd Quarter FY-75.

Figure 2

	A	B	C	D	E
I. COST (.2000)					
1. R&D (.2000)	4.0	6.0	10.0	7.0	10.0
2. Acquisition (.3875)	10.0	2.0	2.5	6.5	1.0
3. Life Cycle Support (.4125)	6.0	6.0	7.7	5.0	2.3
II. PERFORMANCE (.2750)					
1. Stability (.2900)	10.0	7.0	.0	10.0	7.0
2. Power (.3150)	6.0	7.5	10.0	8.0	10.0
3. Reliability (.3950)	6.0	8.0	8.0	8.0	10.0
III. VERSATILITY (.1875)	9.0	4.0	4.0	10.0	2.0
IV. SCHEDULE (.1000)	7.0	7.0	5.0	7.0	5.0
V. TECHNICAL RISK (.0875)	7.0	8.0	6.5	8.0	8.0
VI. PHYSICAL (.0875)	7.5	9.0	10.0	8.0	9.0
VII. HUMAN FACTORS (.0625)	10.0	8.0	6.0	7.5	8.0

ALTERNATIVE KEY

A. DIGITAL FREQUENCY SYNTHESIZER
B. SINGLE FREQUENCY OSCILLATOR MODULE
C. CRYSTAL SUBSTITUTION
D. COMBINATION OF ALTERNATIVES A, B, & C
E. FIXED FREQUENCY/FACTORY SET

Figure 3

Evaluation Ratings and Ranks Listing Nominal Weights and Different Weighting Techniques

ALTER-	ADDITIVE		RMS		MULTIPLICATIVE		LOGARITHMIC	
NATIVE	RATING	RANK	RATING	RANK	RATING	RANK	RATING	RANK
A	7.68	2	7.87	2	7.48	2	8.57	2
B	6.40	3	6.71	5	5.97	3	7.33	5
C	6.03	5	6.72	4	3.62	5	8.14	4
D	8.09	1	8.22	1	7.94	1	8.75	1
C	6.04	4	6.92	3	4.76	4	8.40	3

ALTERNATIVE KEY

A. DIGITAL FREQUENCY SYNTHESIZER
B. SINGLE FREQUENCY OSCILLATOR MODULE
C. CRYSTAL SUBSTITUTION
D. COMBINATION OF ALTERNATIVES A, B, & C
E. FIXED FREQUENCY/FACTORY SET

FIGURE 4

OVERALL SCORES AND RANKS LISTING WEIGHTS CHANGING COST FACTOR

ALTERNATIVE	ADDITIVE RATING	ADDITIVE RANK	RMS RATING	RMS RANK	MULTIPLICATIVE RATING	MULTIPLICATIVE RANK	LOGARITHMIC RATING	LOGARITHMIC RANK
MIN COST								
A	7.73	2	7.90	2	7.55	2	8.55	2
B	6.59	3	6.86	4	6.22	3	7.43	5
C	6.02	5	6.71	5	3.50	5	8.14	4
D	8.28	1	8.40	1	8.16	1	8.86	1
E	6.29	4	7.09	3	5.11	4	8.46	3
MAX COST								
A	7.58	2	7.81	2	7.34	2	8.60	1
B	6.04	4	6.40	5	5.52	3	7.11	5
C	6.05	3	6.75	3	3.88	5	8.15	4
D	7.69	1	7.86	1	7.51	1	8.50	2
E	5.53	5	6.57	4	4.13	4	8.30	3

WEIGHTS USED IN THESE RUNS

MIN COST: COST - .1250, PERF - .3008; VERS - .2051, SCHD - .1094, RISK - .0957, PHYS - .0957, H F - .0684

MAX COST: COST - .3500, PERF - .2234, VERS - .1523, SCHD - .0812, RISK - .0711, PHYS - .0711, H F - .0508

ALTERNATIVE KEY

A. DIGITAL FREQUENCY SYNTHESIZER
B. SINGLE FREQUENCY OSCILLATOR MODULE
C. CRYSTAL SUBSTITUTION
D. COMBINATION OF ALTERNATIVES A, B, & C
E. FIXED FREQUENCY/FACTORY SET

Figure 5

CUMULATIVE RANK FREQUENCY TABLE
ALL METHODS

ALT	1st	2nd	3rd	4th	5th
A	1	58	1	0	0
B	0	0	28	7	25
C	0	0	2	29	29
D	59	1	0	0	0
E	0	1	29	24	6

ALTERNATIVE KEY

A. DIGITAL FREQUENCY SYNTHESIZER
B. SINGLE FREQUENCY OSCILLATOR MODULE
C. CRYSTAL SUBSTITUTION
D. COMBINATION OF ALTERNATIVES A, B, & C
E. FIXED FREQUENCY/FACTORY SET

CAMOUFLAGE R&D - A CHALLENGE TO OPERATIONS RESEARCH

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Army Mobility Equipment Research and Development Center

I am Bob Adams. For the past six months I have been helping the Camouflage Lead Laboratory at the US Army Mobility Equipment Research and Development Center (MERDC) evaluate camouflage testing. I am here today to report on some of the more interesting challenges to operations research (OR) which are apparent in Camouflage R&D. This paper is largely the product of briefings prepared by my coauthors, Mr. Frank Paca, Chief of the Camouflage Effectiveness Assessment Office and Mr. Allan Sylvester of the Countersurveillance and Topographic Division. I have also borrowed liberally from thinking of our own Systems Analysis Office personnel and from contractual assistance, largely Battelle people.

As you probably know, the Army Materiel Command (AMC) has recently begun working to camouflage the Army under HQ Department of the Army guidance. Right here, in developing guidance, OR enters into the camouflage picture. But as you also probably know, this kind of guidance generally develops from an upward flow of requests for guidance. In this paper we are going to discuss the analyses necessary to determine what detailed guidance is required at the R&D level, that hopefully, OR is going to assist in providing.

Operational research techniques have been used to some degree in test and evaluation of items in the Camouflage R&D process, mostly in test design. Integration of OR into systems analyses has been less frequent and only more recently attempted in the camouflage community. Experimental designs were developed formally for field trials of the effect of various degrees of camouflage on fighter pilots' ability to detect and attack vulnerable segments of air defense sites. Similarly, statistical design techniques have been used to set up tests of pattern painting's effect on detection and identification of various Army vehicles - tanks, APC's, tracked command posts, etc. The first in-house major systems analysis of countersurveillance and counter target acquisition was attempted last year. The draft study was evaluated by a committee made up largely of operations research oriented personnel, including a past president of the Operations Research Society of America, and led to development of a Master Plan for Camouflage R&D now being staffed in the US Army.

One of the tasks made obvious by the Master Plan development was a requirement for review of testing methodology with an eye toward development of quantitative objective data. There are very likely methodologies available which might integrate test data into generally usable quantitative measures of effectiveness (MOE's) of camouflage. This we are starting on. And this is why we are putting forth a call for help today - how can OR and the OR community assist Camouflage R&D in determining where we want to go, and how far? What camouflage methods available today are cost effective for an Army company and are they more or less cost effective for a division?

How effective must new camouflage methods be to make R&D and the procurement cycle costs worthwhile in consideration of the detection threat probable at that time in the future when the new camouflage reaches the troops?

We are going to enlarge on these questions in the rest of this paper and try to put them in context. In the next section I want to give you some examples of development: some just beginning, some in the test and evaluation phase of R&D, and some ready for near-term application. The following phase of the discussion covers OR aspects of the R&D cycle for camouflage projects, including requirements for evaluation of concepts and hardware as camouflage development proceeds; criteria for decision as to continuation of camouflage R&D projects versus cutoff; and the relationships of development and assessment agencies.

The final phase of this paper consists of a review of the basic steps of systems analysis as taught here at ALMC, and the normally recognized problems in OR analysis of "effectiveness", reviewed in terms of "what is good camouflage". These should exemplify the challenge of camouflage to operations research. In conclusion we will indicate our hopes to obtain the OR assistance that you as individuals and your offices might provide in response to the challenge.

I believe that I should indicate what aspects of camouflage will not be discussed in this paper due to time and classification limitations. We recognize that the scope of the problem presented is much larger and has many aspects which we will not touch on today. Discussion of the threat to our forces which might be countered by camouflage will be limited, the sensor spectrum which our camouflage must counter, and detailed examples of camouflage R&D will not be fully developed. And although we will be talking "countersurveillance" and "counter target acquisition", MERDC's charter is limited to passive systems and only passive measures will be considered. Destruction of enemy sensors or observation platforms are part of firepower solutions to the problem, not passive, and are not discussed. Electronic countermeasures which are not part of the Camouflage Lead Lab's responsibility will also not be considered.

So what are examples of the camouflage projects in R&D which lead to this challenge to OR? I will mention eight or ten in a moment, but just grouping these projects for discussion raises an OR or systems analysis (SA) problem. Measures of effectiveness (MOE's) and their assessment will be the principal area of camouflage requiring operations research, so I would like to take time to describe our current views as to groupings of MOE's. Other studies have indicated that there are at least seven or eight levels of assessment from the item or bench level up to the US national goal levels. Only four levels are of significant interest to the Army camouflage program. The four levels are design, system, tactical, and force. The first two are of prime interest to the AMC development community. The design and system levels make technical assessments of the items characteristics and technical performance. The tactical and force level assessments study the utility of camouflage and ask "what did it do towards winning the battle? Chart 1 indicates the objectives or basic purpose of each assessment level.

I would like to note one other major general OR subject pertinent to many of our comments about the current state-of-the-art of camouflage analysis. The assumptions involved in camouflage evaluations have not been made explicit. We are only beginning to realize that there are positive and negative assumptions implicit in our evaluations, and these assumptions may be of overriding importance. Will the commander's use of camouflaged vehicles be as effective if he cannot see them as when his forces are visible for all to see? It is implicitly assumed to be in most camouflage evaluations.

Back to Chart 1. Projects in the early stages of development are generally subject to evaluation almost strictly from the point of view of design criteria. Does this piece of equipment suppress the dust cloud normally raised by tank movements? To what degree does that type of camouflage net attenuate radar viewing or near infrared photography? Similar questions are being asked about various anti-sensor devices, hiding of vehicular movement behind smoke screens, and even about computer model simulations of heat generating features of electric generators, tanks, and fuel storages.

Concept validation is also done at the design level. How, and under what conditions, camouflage equipment is to be used, may well be the key to the effectiveness and value of the equipment. I will be back to problems with higher level mission objectives a little later, but for examples of current camouflage R&D, I will stick to very low level system descriptors - movement camouflage, dispersion and decoys, smoke, etc. However, I will separate projects in early stages of development from those which we think might offer a near-term capability for camouflage and from projects in test and evaluation, because I will have different things to say about each of these groupings of projects.

Camouflage which has proven successful in design evaluation must be considered for its effectiveness at the system level. What different camouflage equipment must accompany a unit moving through varied types of terrain, and what are the vehicle requirements to move it? Similar questions apply to camouflage of uniforms and equipment for the individual. What equipment is required to repaint a mechanized unit to provide a CBR protective coating? How often must pattern painting be modified - telling us how much paint and thinner and how many spray guns must move with a battalion? What is the weight of poles needed to support camouflage net, how should they be packaged and where should the poles, net, spreaders, and tie-down materials be carried? These are system questions, and like technical design level questions, they are generally engineering, not OR problems, although they imply tactical level OR problems.

ASSESSMENT OBJECTIVES

	ASSESSMENT LEVELS			
OBJECTIVES	DESIGN	SYSTEM	TACTICAL	FORCE
CONCEPT OR DESIGN VALIDATION	X			
TECHNICAL PERFORMANCE OF ITEMS/SYSTEMS		X		
EXPECTED PERFORMANCE DURING OPERATIONS		X	X	
TACTICAL CONSEQUENCE OF TECHNICAL PERFORMANCE			X	
EFFECTIVENESS COMPARED TO EQUAL COST ALTERNATIVE			X	X
AGGREGATED CONTRIBUTION TO FORCE EFFECTIVENESS				X

Chart 2 lists some assessment methods used to measure effectiveness of various kinds at the four key assessment levels. Facilities, equipment, installations, and methodology needed for test and evaluation can become a problem at the design and system levels of assessment. Test design almost always becomes an OR problem when considered for tactical and force application levels.

Experimental evaluations of effectiveness can lead to unexpected results. Camouflage of a Division Headquarters by paint and nets, evaluated at MASSTER, rather than providing indications of the value of paint and nets, indicated the need for camouflage discipline - personnel, beer cans and trash in the open, vehicle tracks leading to netted thickets, jeeps left uncamouflaged. Evaluation of various paint patterns for a moving tacked command vehicle, carried out at Fort Hood, indicated that the degree of color contrast with the background was more important than the pattern used. Evaluation of patterns on pattern boards at Fort Knox indicated that positioning of the boards relative to tree or contour lines was more important than the patterns.

Time expended on systems analyses and OR for test and evaluation of camouflage has only begun to be significant in the last few years. Mathematical model development has so far been confined to specialized purposes such as sensor studies, with overall value of camouflage a second order parameter, often input. Under our direction, Battelle has recently completed a study of MOE's for camouflage, but results are primarily requirements for MOE's themselves. A two manyear systems analysis effort in-house has produced a good analysis of the variables involved in camouflage evaluation, but most of the work to determine sensitivity and to fit available test inputs into the system remains to be done.

That is about all I have time to tell you about what has been done. From these efforts to date we have learned largely about what we need to know. So now I would like to discuss the requirement for evaluation of concepts and hardware as camouflage developments proceed. First, there is the need for data to justify continuation of any camouflage project underway. At what point in a series of design test failures should the basic project be stopped (assuming that other approaches are still possible)? More often our question is: to what degree must desired capabilities be assured in order to justify continued funding of the project. The OR problem is: how effective is effective enough?

Perhaps a few specific examples are in order. We are designing radar scattering nets and paints. We are confident that by the time such materials can be with the troops, the threat will be greater. Should we continue with projects that will thwart surveillance by today's radars but which will probably not be effective against the higher resolution airborne radars of tomorrow?

Another example: preliminary testing indicates that pattern painting can significantly disrupt aiming capabilities under certain combinations of background, pattern and colors used, type of observing sensor, and distance from aiming point. What OR techniques, test designs and replications can confirm that pattern painting should be extensive?

ASSESSMENT METHODS

METHODS	DESIGN	SYSTEM	TACTICAL	FORCE
	ASSESSMENT LEVELS			
LABORATORY EXPERIMENT	X			
ENGINEERING TEST		X		
ONE ON ONE MODELS		X	X	
FIELD EXPERIMENTATION		X	X	
HIGH RESOLUTION MODELS			X	
FIELD EXERCISES (1)			X	X
GAMES AND SIMULATIONS				X
COMPUTER ASSISTED WAR GAMES				X
COMBAT LESSONS LEARNED		X	X	(?)

(1) INCLUDES LARGE OPERATIONAL TESTS

Two other examples of the problem of how effective is effective enough: First, considering the countless combinations of possible battle conditions, what scenario aspects so significantly influence the effectiveness of a type of camouflage as to establish "must" criteria for a type of camouflage? Must we use the criteria of the worst situation in terrain, flora, roads, urbanization, footing, season, precipitation, ceiling, visibility, wind direction and velocity, space control ratio, firepower ratio, tactical skill ratio, and other scenario factors to evaluate effectiveness of a camouflage program?

And the last example I'll mention relates to the influence of the logistic tail on the effectiveness (and cost) of projected camouflage. Can equipment to be hidden carry its own cover or must extra vehicles be added to support the camouflage? If vehicles carry their own camouflage, what decrease in efficiency or effectiveness results and how can this be measured?

When a camouflage project satisfies whatever continuation versus cutoff criteria are used, at least two other significant questions occur in the RDT&E cycle for which OR should be conducted. These will be discussed briefly.

One very important OR factor concerns the measures of effectiveness (MOE's) referred to several times previously. Design and system level MOE's have been shown to be of a different type than tactical level MOE's. What are the performance goals for a camouflage system in tactical situations? How do they vary with scenarios? And assuming we can say what the camouflage system must accomplish, how do we measure whether or not performance goals are obtained?

Measurement of performance at the higher levels of assessment is very difficult. Subjective measures have generally been obtained by maneuvers or simulated tactical situations. The MASSTER facility at Fort Hood has been used to evaluate tactical operations at the company and battalion levels, in this subjective manner. The Combat Development Evaluation Center (CDEC), at Fort Ord has been used to measure results from platoon or company level tactical situations. CDEC's facilities provide some quantitative measures, and we hope to use them more in the future.

But the real-life use of tanks and helicopters and other real-life vehicles, with troops and necessary instrumentation is very expensive. It also has two other serious drawbacks. It is so difficult to set up tactical tests that many types of testing are usually piggy-backed on a maneuver set up for some other basic purpose. Because weather, time, or some other limitation causes cutbacks in original plans, some degradation of the camouflage testing programs attempted at the tactical level has invariably resulted.

The second serious drawback to the tactical level performance measurements result from the independence of development and assessment agencies. Chart 3, Organizations Vs Levels, indicates the agencies directly involved in the camouflage assessment process. Within AMC, various agencies are

ORGANIZATIONS VS LEVELS

ORGANIZATION	DESIGN	SYSTEM	TACTICAL	FORCE
AMC				
RDTE LABS	X	X		
STANO, BRL	X	X		
TECOM	X	X		
AMSAA		X	X	X
TRADOC				
CACDA			X	X
CDEC		X	X	
FORSCOM				
MASSTER			X	X
HQS - DA				
OTEA			X	X
CAA			X	X

responsible for testing, with TECOM responsible for testing most of the MERDC camouflage developments. It is sometimes difficult to specify objective measurements needed. There is often lack of assurance that testing is performed as desired because something is lost in the translation between agencies.

The development and measurement of force level MOE's is the most difficult phase of camouflage R&D. What difference will use of individual and combined types of camouflage make on the outcome of a major engagement of forces? Here doctrine with regard to combat methods, along with doctrine as to use of camouflage, may be the most important factors determining the effectiveness of camouflage. The responsibility for developing doctrine lies with TRADOC, and to date, that command has only begun development of the requirements for doctrinal criteria believed essential to critically examine camouflage.

The key problem, put another way, is to estimate military worth of camouflage per unit cost. This evaluation is a combination of results from measuring performance for unit cost with military worth of a camouflage item's performance:

$$\frac{\text{Performance}}{\text{Cost}} \times \frac{\text{Military Worth}}{\text{Performance}} = \frac{\text{Military Worth}}{\text{Cost}}$$

If we spend a million dollars on one type of camouflage for a brigade, what difference does it make in combat power or tactical results? Would other camouflage, or buying more tanks, trucks, or APC's do more to increase our combat power?

By now I have mentioned some of the OR problems arising in camouflage R&D. In the last section of this paper I would like to look at the challenge to OR from the point of view of systems analysis rather than from that of the camouflage program itself. For this approach I am going to use the "six basic steps of systems analysis" and their list of major effectiveness problems in operations research, as taught right here at ALMC. For each I will give an example from the camouflage R&D program.

Step one in a systems analysis is selection of the objective. What objectives should the camouflage test and evaluation program have? How important is the requirement for assessments at the tactical and force levels with regard to the program of camouflage developments.

Step two is to list feasible alternatives. Camouflage has many purposes and there are often several possible methods for accomplishing each purpose. Alternative methods of test and evaluation are usually technical choices, but alternatives in models and paper OR value assessment techniques are the logical alternatives. Can practical, acceptable models be developed for evaluating camouflage?

Step three is to estimate costs of alternatives. What are the costs of holding and deploying camouflage material, in CONUS, overseas areas, and forward combat positions? What units of measurement for loss of unit movement time when using camouflage nets are comparable to other incremental costs of nets?

Step four is to develop an effectiveness scale. Our previous discussions of MOE's illustrate this most important point. I will only add that math models will almost certainly be emphasized in developing effectiveness scales to evaluate camouflage projects.

Step five is to estimate the effectiveness of competing alternatives. Against how many backgrounds, at what ranges, with what type of observers, must what kind of measurements be made to be able to say that camouflage pattern A is more effective than pattern B in causing firing misses against tanks? What are the factors which must be variables in math models estimating effectiveness?

Step six is to establish and apply cost effectiveness criteria. Under what conditions does smoke provide more effective camouflage than netting? What are the key factors in infantry, mechanized combat, and transportation units determining the effectiveness of various types of camouflage?

Finally, in this section of examples of the challenge to OR offered by camouflage, I would like to talk about effectiveness problems. Again, I will use an ALMC list of "effectiveness problems in operations research" (from ALM-64-3497-H).

The first problem is that of multi-attributes. Camouflage may cause an item to be difficult to identify but simple to detect. Under what conditions do these two attributes add to or subtract from the effectiveness of countersurveillance? And how do we make these measures objective rather than subjective?

The second problem with effectiveness relates to measurability. Many attributes of camouflage are non-quantifiable. Even more are measurable only in units which are difficult to relate to each other. What units do we use to measure "flexibility" or "command interest" in camouflage items? And these must be related to units of measure, which have never been really satisfactory, for "morale" of troops, and "leadership".

The problem of commensurability of effectiveness measures also was illustrated by the last examples. Another involves comparing the value of decoys in drawing fire with pattern painting in causing misses.

The importance of attributes is the next problem area. Is deceiving the enemy as to the size of the force opposing them more important than denying him indications of your intentions, say as to attack? If the probability of detection of a forward refueling area is 95 percent against infrared photographic reconnaissance and 5 percent against visual, is the camouflage method used better than if there is a 50-50 chance of detection by either method?

The problem of sensitivity is of vital significance to camouflage effectiveness because of the very large number of variables involved. Attenuation of infrared night vision sensors is much more important at night than are methods to prevent visual observation. What factors should math model sensitivity studies concentrate on initially? What is the difference in sensitivity of dust suppressors on tracked vehicles as a function of terrain types and areas of the world?

Lastly, the problem of uncertainty is intimately connected with measurement of camouflage effectiveness. Is protection against aerial observation worthwhile if the probability of visibility is only 10 percent? What is the likelihood of contingency warfare in an area requiring snow nets as compared with one requiring woodland screen or a desert blend?

In conclusion, let me reiterate that my purpose today has been to give enough examples of OR problems in camouflage to give you a feel for the challenge to OR it represents. We are thinking about approaches to many of these problems and are working actively on some. As we find obstacles, we intend to get out in this OR community for advice and assistance.

But don't wait for us. If ideas in this area hit you, my address and phone number are listed with the meeting agenda. And I would be pleased to discuss or just listen to your suggestions. We are open to suggestions from uniformed people with hands-on experience, from those of you on military staffs and analysis agencies, and from the contractor community - in short, from anyone with an idea which will fit our problems. Application of practical OR to practical camouflage is not easy; rather it is highly complex and difficult. Most military people feel (from somewhere about the belt-line) that "camouflage is good". That's not enough, however, to sell expensive programs for R&D and procurement. Abilities to measure and quantify are important to our programs to provide the best in camouflage protection to the troops in the field, because if we can't sell the programs, the troops will never get the goods.

That, gentlemen, is the real challenge to OR in the camouflage business. Questions??

A COMBAT RATES LOGISTICS ANALYSIS

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BACKGROUND

The purpose of this working-session paper is to examine some problem areas in a good systems analysis study. The study that we will examine is the Combat Rates P76-80 Study performed by the United States Army Concepts Analysis Agency (CAA) in Bethesda, Maryland. The study was directed by the Department of Army staff and is a reoccurring study effort on an approximately annual basis. Therefore, the resolution of these problem areas may contribute in a real sense to future studies. In fact, the Concepts Analysis Agency is currently running two studies, the AMMIP-II and P78-82 studies, that could possibly be effected by recommendations concerning these problem areas. All of the problem areas to be discussed have been brought to the attention of the Study Advisory Group for these two studies and to the Concepts Analysis Agency study teams that are performing these studies. The direction for the performance of the P76-80 studies from the Army to the Concepts Analysis Agency envisioned a much narrower use of the study output than actually occurred, and it was this broader use that created problems in the study effort. However, these problems are of a general nature and may impact in other than the Combat Rates area.

Before discussing the problem areas, however, it seems appropriate to present some background on Combat Rates Studies. Combat Rates are the quantity of ammunition required per tube per day and are used in the determination of ammunition requirements (Shown in Figure 1). Concept Analysis Agency's rates, in Figure 1, were designed to be used for planning theater war reserves only.

The purposes of these studies are shown in Figure 2. In addition to these purposes, there is a driving need for Combat Rates Studies to provide a mechanism for the introduction of new items into the ammunition system. Facilitation and inventory acquisition depend heavily on having available a meaningful way to establish reliable and realistic combat rates. The guidance that CAA received restricted their effort principally to the determination of Combat Rates for the initial period of conflict; however, they did run a second period for each theater that was called sustaining rates. Again, CAA looked on their task as the determination of theater stockage levels and did not plan or intend that the rates be utilized for CONUS inventory or production base planning. The Army staff had used these studies for theater war reserve planning for the "budget year plus five" time frame and had negotiated the rates even for this time frame with regard to availability of rounds and weapons. However, in the case of the P76-80 Study, the Army staff planned to use the rates (since they were called sustaining rates) for Ammunition Acquisition Objectives and Production Base Planning. The Combat Rates Studies that

WHAT ARE COMBAT RATES

COMBAT RATES = NUMBER OF ROUNDS OF AMMUNITION FIRED PER TUBE PER DAY BY THEATER BY FORCE.

REQUIREMENTS = WEAPONS DENSITY X COMBAT RATES X NUMBER OF DAYS.

USE - PLANNING THEATER WAR RESERVES

- PLANNING AUTHORIZED ACQUISITION OBJECTIVE

- PLANNING PRODUCTION BASE

Figure 1

PURPOSE OF THE COMBAT RATES STUDY (P76-80)

- TO PROVIDE THE DEPARTMENT OF THE ARMY WITH THEATER COMBAT RATES FOR US FORCES AND REPUBLIC OF KOREA FORCES FOR PLANNING AND PROGRAMMING PURPOSES.
- TO PROVIDE EXPECTED EXPENDITURES OF AMMUNITION TO BE USED IN THE CALCULATION OF FIREPOWER POTENTIALS WHICH, IN TURN, ARE AN IMPORTANT INPUT TO CERTAIN WAR GAMES.
- TO PROVIDE RATES OF LOSS FOR MAJOR END ITEMS OF EQUIPMENT SO THAT ESTIMATES CAN BE MADE OF EQUIPMENT REPLACEMENTS NEEDED DURING THE EARLIER DAYS OF COMBAT IN THE EUROPEAN AND PACIFIC THEATERS.

Figure 2

had previously been run had not provided any sustaining rates, and, therefore, these studies had not been used in these roles previously. It was the availability of these sustaining rates that permitted the broader application of combat rates to the Ammunition Acquisition Objectives and Production Base Planning areas.

In addition to the background, it is interesting to examine the impact of these rates in the Ammunition Acquisition Objectives and Production Base Planning areas. Figure 3 shows a comparison of the current and study rates for small arms and howitzer ammunition. In addition, the last column shows the impact of adoption of the new rates in ratio form. These ratios are based on the Pacific Theater sustaining rates because, by DOD guidance, mobilization and production base planning is based on sustaining rates in the Pacific Theater. Furthermore, the largest part of the Ammunition Acquisition Objective (better than 50% in the current budget) is also based on the Pacific Theater rates.

In addition to the rates, it is interesting to observe the impact on Level II, III, and IV requirements as a result of the adoption of these rates. The Level II, III, and IV requirements are in essence a limitation on the capacity of plants that can be built, maintained, retained, or modernized for production of munitions in the event of mobilization. For comparison purposes, Figure 4 shows the impact on Level II for the 155 Howitzer rounds. This is a fairly typical case which represents the severity of the impact that could result if these rates were completely adopted.

PROBLEM AREAS

The P76-80 Combat Rates Study raised some problem areas for this type study effort that required resolution before proceeding to the next combat rates study. These problems are discussed in detail below.

DEFINITION OF SUSTAINING PERIOD: The definition of the sustaining period to be used as a basis for sustaining rates is probably the most pressing and difficult problem area. The P76-80 Combat Rates Study used the activity depicted in the FOREWON Study in the D+76 to D+165 day period as a basis for sustaining rates in Korea. The activity, as depicted in the FOREWON Study during this period, is very passive as a result of the cyclic nature of conflict. CAA used the rate of movement of FEBA as the criteria for activity and in the FOREWON Study during this period, the FEBA was very stable. Therefore, the battle activity was classified as a light defense which consisted of patrolling and probing. As a result of this low activity, the combat rates for the determined sustaining period were extremely low as were shown in the preceding figures. In the logistic community, the sustaining rates are utilized for materiel acquisition, modernization expansion, and retention planning for the production base. Therefore, had we used these rates, the production base which is supposed to supply ammunition for an indefinite period after the initial conflict would have been sized to supply only that ammunition required in these very passive periods. However, materiel support planning guidance clearly expects the production base to be able to provide the ammunition

SMALL ARMS WEAPON SYSTEMS & HOWITZER AMMUNITION ITEMS
(US FORCES - PACIFIC)

	SUPPLY BULLETIN 38-26		COMBAT RATES STUDY 76-80		
	INTENSE	SUSTAINING	INTENSE	SUSTAINING	SUSTAINING RATIO
Rifle, 5.56mm, M16	3.9	2.1	2.8	1.2	.57
SAWS, 6mm	-	-	118	55	New Reqmt
Bushmaster (ARSV) 20-30	No Reqmt	No Reqmt	No Reqmt	No Reqmt	No Reqmt
M1, HE/M1E2, HF For 105 How	67	36	12	6	0.2
XM710 For 105 How	9	5	47	34	7
M107, HE For 155 How	96	52	3.2	2.2	.04
M449 For 155 How	27	14	19	12	0.9
M483 For 155 How	.2	.1	10	1.6	16
M549 For 155 How	.9	.5	1.7	2.3	5
M106, HE For 8" How	41	22	2.9	1.5	0.07
M404, AP, For 8" How	7	4	3.3	0.9	0.2
M509, DP, For 8" How	5	2.5	15	7	3
XM650E2, RAP, For 8" How	-	-	0.5	0.1	New Reqmt

Figure 3

155MM HOWITZER - SUSTAINING REQUIREMENTS LEVEL 2

AMMUNITION ITEM	OLD	NEW
M107 & E1	950,000	220,000
M449, A1	182,000	289,100
M483	41,000	44,000
M549	5,300	16,000
XM731/692 ADAM-A&B	0	5,600
XM718/XM ADATM-A	0	1,200

Figure 4

necessary to re-establish the original boundaries after the losses sustained in the initial period of conflict. The definition used by CAA for the sustaining period was not of sufficient duration and did not cover a wide enough range of ammunition usage to permit the production base managers adequate capacity or inventory to achieve the objectives of the logistic support planning guidance. I am happy to report that the Chairman of the SAG for the P78-82 Study has recognized the need for a definition of the sustaining rates period. It has been decided that a period long enough to be representative of the sustaining period defined in the logistics guidance will be used in the new study. Threat, forces, sequencing of postures, and the rate of introduction of replacement troops and equipment will be taken into consideration in the new study. It should be recognized that the definition of this threat with its accompanying sequence of postures is a difficult task and strains the gaming methodology that is currently used in studies such as the FOREWON Study. The Army staff's agreement to tackle this problem should make the combat rates to be developed in the P78-82 Study a more meaningful and useful study effort.

FIXED LEVEL OF EFFECTIVENESS: A method is required that enables trade-offs between items of ammunition during and/or after a ombat ates tudy. This method must permit these trade-offs to be performed at levels of effectiveness that makes the trade-off results comparable. Frequently, it has been and probably will be necessary to change the list of available items during, before, and after completion of a Combat Rates Studies. The essence of Combat Rates Studies is the development of rates and subsequently requirements for new items that are expected to emerge from the RDT&E programs in the next several years. Under these conditions, the performance of Combat Rates Studies is always going to require the use of item lists that have a high degree of change. Also, the transition from production of the replaced items to production of the new item must be planned. This causes a need for transition rates. Therefore, it is essential that appropriate and comparable trade-off methodology be available.

Some of the reasons that the supply of new or standard items may be restricted and cause list changes are given below.

(1) (Insufficient) or (no) funds have been made available for either item acquisition of or production capability for new items making it necessary to substitute available items.

(2) The development and/or production programs have been terminated because items failed to meet desired criteria.

(3) The development programs have been delayed because of technical or funding difficulties.

(4) The Combat Rates Team or the development team or the user team have over-estimated the effectiveness of the new item or system in comparison to its final developed capability.

(5) The new or standard rounds have developed difficulties that require limitation being put upon their use.

(6) A new or standard round of ammunition has limited use because an incompatibility exists between it and the weapon that fires it.

(7) Higher authority, such as congress, decrees restricted use of an item of ammunition or a weapon system.

With these many and these kinds of problems, it seems very unlikely that future combat rates studies will be made that do not require adjustments of the results, including trade-offs between items.

In the past, the approach taken has been to rerun the submodels, inserting the substitute item for the item that the substitute item displaces. This has resulted in the determination of "equivalent" rates that are not derived from equivalent levels of effectiveness. As an example, the new item could result in a winning war game and the substitute item could result in a losing war game. It is recognized that it may not be possible to achieve the degree of effectiveness with a substitute item that was achieved with the original item. (Ways around this problem are suggested in the solution section below.) It is mandatory that the decision makers, using the trade-offs derived, be fully aware of the conditions under which the equivalent rates have been developed.

PROPOSED SOLUTIONS: Several alternative approaches to the resolution of this problem area are offered. Some advantages and disadvantages of each method are discussed. No attempt has been made to be exhaustive in either resolutions or in the discussion area. It is suggested that these approaches, as well as those suggested by other sources, be considered in the resolution of this critical problem.

PROPOSED SOLUTION 1: Determine the degree of force attrition accomplished with the basic item availability list. Force the models to achieve this level of force attrition, using the substitute items. If necessary, release model constraints and increase force structure to achieve these goals.

ADVANTAGE: This would provide the decision maker with a full account of the necessary changes and impact of the decision to use substitute items.

DISADVANTAGE: It probably is not realistic to assume that the decision maker has this range of choices available. However, it may serve to make him aware of the problems that are created by his decision to use substitute items.

PROPOSED SOLUTION 2: Determine the level of effectiveness that is achievable by the substitute items and rerun the basic case for the initial items, using this new level of effectiveness. Make the trade-off or equivalency determination at this level of effectiveness.

ADVANTAGE: This would provide the decision maker with a trade-off at a comparable level of effectiveness that does not require force structure changes or violate the model constraints.

DISADVANTAGE: The use of this lower level of effectiveness may result in planning to buy a quantity of ammunition that is not large enough to "win the war" or, putting it another way; it may result in a losing strategy instead of a winning strategy.

PROPOSED SOLUTION 3: Sort out the target where equivalent levels of effectiveness can be achieved and make comparison of equivalent rates only on these targets only. In addition, report those categories of targets that cannot be defeated and the quantity of ammunition in the base case required to defeat these targets. (As an example, HE rounds required to defeat soft targets compared to ICM rounds, since equivalent effectiveness could be achieved plus ICM rounds to defeat hard targets for which only unreasonable amounts of HE could achieve the required defeat criteria).

ADVANTAGE: The use of this technique would permit a strong argument to be waged for an interim production capability and inventory of ICM rounds at least equivalent to that required to defeat the hard targets. In essence, this may provide a minimum capability in ICM rounds that is essential to the national defense of this country.

DISADVANTAGE: This methodology provides a continuous chain of interim solutions rather than one expensive and difficult long term solution when annual Combat Rates Studies are run.

PROPOSED SOLUTION 4: Determine the force attrition achieved by the base case items and force the methodology to achieve the same level of force attrition with the items in the substitute list of items. Release model and force structure constraints if it is absolutely necessary to achieve the level of effectiveness in the base case. (This solution is similar to Proposal 1, except that, all items in the available list are being traded for each restricted item.

ADVANTAGE: (Same as Proposal 1)

DISADVANTAGE: (Same as Proposal 1, plus the following) This makes trade-off between items extremely difficult, since, for each restricted use item, every other item in the system is allowed to change.

CONFIDENCE LIMITS: The P76-80 Study derived one number for each item. Since these rates were developed, using both deterministic and subjective analyses, it is suggested that some estimate of the range in confidence levels of these estimates of combat rates be made. These confidence levels should reflect the uncertainty in the combat rates as a result of potential variability in length and activity of the conflict during the sustaining period, the uncertainty in the scenario and theater of future conflict, the uncertainty in the input data used in the study and the uncertainty in the models and their heuristic rules. It is suggested that scenarios, theaters of conflict, length of sustaining periods, intensity of conflict and data input be thoroughly studied using extensive sensitivity testing. It is essential that future combat rate studies carry out their sensitivity testing in order to provide flexibility in planning and a higher confidence level in our ability to defend the country against any aggressor anywhere in the world. These suggestions have been brought to the attention of the chirman designate for the P78-82 SAG, and they will be addressed in the course of that study.

AMMUNITION COST INPUTS: The P76-80 Combat Rates Study was based on level-off costs for new items. These level-off costs included only the variable costs required to produce the item. Investment costs were not included. (Investment costs normally include RDT&E funding, plus funds to establish the production base necessary to produce the item.) In addition, level-off costs do not include the variable costs required to learn to make the item plus the facility maintenance and layaway costs. The use of these level-off costs may not have provided the realistic basis upon which new item selection should be made.

The original guidance for Combat Rates Studies was to determine the supply rates for ammunition to be used during the initial 90 days of conflict. During this time period, the theater was not expected to be resupplied; and, therefore, these rates were principally used for theater war reserve determinations. It did not appear reasonable to spread these fixed costs across this relatively small amount of ammunition. The level-off costs were the best approximation available for an appropriate cost. However, after the initial studies were complete, the rates were frequently used to derive new supply bulletin rates, and these rates have a large impact in selection of items throughout the life cycle of ammunition. ACSFOR and CDC recognized this problem and established several study efforts to address this and related problems (examples, AMMIX by RAC and the original AMMIP studies by CDC). These studies did not develop appropriate methodology for handling mixtures of fixed and variable costs or non-linear cost quantity relationships. It is recognized that inserting non-linear or fixed and variable costs in the present methodology is an extremely difficult problem and would probably unduly complicate these models.

Since the present methodology does not address the total life cycle costs, and these costs are not highlighted in the study, the present methodology does not provide the necessary justification for these fixed investment expenditures when they are requested on the basis of decisions made, using the study results. In the past, this has resulted in the establishment of large requirements on items for which the Army has no production capability and low requirements (insufficient to support the existing base) on items for which we have existing production capability.

The new Army staff structure, which places production as the last phase of the research, development, and acquisition cycle, emphasizes the necessity to incorporate all appropriate costs.

PROPOSED SOLUTION 1: Develop new methodologies that are capable of handling fixed and variable non-linear cost input.

ADVANTAGE: Provides combat rates that are truly based on life cycle or original operating costs.

DISADVANTAGE: Attempts to achieve this goal in the past have resulted in models that were overly complex, difficult to operate, and required assumptions that were even less saleable than the current methodology (See AMMIX Study).

PROPOSED SOLUTION 2: Develop new methodology that chooses ammunition expenditure unrestrained by costs. Determine Combat Rates based on this methodology. Then, spread total life cycle costs across this quantity of ammunition, determining an average cost per round for each specific item. Use this average cost for ammunition in the current models and determine if Combat Rates have changed significantly. If the Combat Rates have changed, redetermine average ammunition costs and rerun current models again. Repeat until Combat Rates are determined to be stabilized.

ADVANTAGE: Models and methodologies required to perform these runs are probably available or can be developed with a minimum effort.

DISADVANTAGE: Requires one or more reruns of the current methodology in order to develop appropriate rates.

PROPOSED SOLUTION 3: (Same as Proposed Solution 2 above, except process is started with level-off cost rather than unrestrained by cost.)

ADVANTAGE: (Same as Proposed Solution 2, but with shorter running time.)

DISADVANTAGE: (Same as Proposed Solution 2, plus the following:)

It may miss some opportunities to use new systems that would be available with Proposed Solution 2.

PROPOSED SOLUTION 4: (Same as Proposed Solution 2, but process is started with an estimated life cycle cost based on recognized RDT&E and facility costs and estimated for a quantity based on the current production of the item to be replaced.)

ADVANTAGE: (Same as Proposed Solution 3.)

DISADVANTAGE: (Same as Proposed Solution 3.)

STUDY RESULTS

In order to evaluate the results of the Combat Rates Studies, it is critical that the study output include a measure of the success of the Blue forces in overcoming the Red threat. The user of the study output (for the logistics' side of the house, DCRDA) in the acquisition of ammunition should know whether that quantity of acquired ammunition permitted the achievement of the Blue objectives. Therefore, the methodology developed for use in the study should include a statement of results of the war game at its termination.

The Concepts Analysis Agency has developed means of portraying the results of the game since the publication of the P76-80 Study. These results show the residual Red and Blue forces in equipment and personnel. This is a significant improvement in capability.

INPUT

. AVAILABILITY GOAL
. SYSTEM LIFETIME
. ORDER/SHIP TIME
. PIECE PART PROCUREMENT LEAD TIME
. SITE PIECE PART STOCK
. DEPOT PIECE PART STOCK
. RELIABILITY BLOCK DIAGRAM
. LABOR COST
. LRU DATA

  . PRICE
  . DENSITY
  . FAILURE RATE
  . REMOVE/REPLACE TIME
  . REPAIR TIME
  . WASHOUT RATE
  . DEPOT STOCK
  . PROCURE LEAD TIME
  . REPAIR SKILL
  . TEST EQUIP REQUIRED

PROCESSING

1. DETERMINE IF AVAILABILITY GOAL CAN BE ACHIEVED.

2. IF NOT, OUTPUT REPORTS.

3. IF SO, DETERMINE LEAST COST SET OF LRU's TO STOCK ON-SITE TO MEET REQUIRED AVAILABILITY.

4. COMPUTE COSTS AND OUTPUT REPORTS.

OUTPUT

1. LISTING OF ALL INPUT DATA.

2. OPTIMAL SITE STOCK LEVEL FOR EACH LRU.

3. MONTHLY LIFE CYCLE COST OF

  . LRU SITE STOCK
  . TEST EQUIP
  . TRANSPORTATION
  . OFF-LINE REPAIR
  . OFF-SITE INVENTORY, PIPELINE, AND WASHOUT

4. TOTAL COST BY SITE AND ALL SITES.

ACCLOGTROM
GENERAL DESCRIPTION

Figure 2

example, the decision maker should know that the quantity of ammunition calculated, using the P76-80 rates and current logistic guidance with designated force structures, will provide adequate ammunition to achieve our national objective of maintaining current boundaries in 10% of the world situations; that we may face aggressors 90% of the time, and in 30% of the world situations, 10% of the time. At the present time, the decision maker does not have any estimate of the confidence limits and probably assumes that the estimate of the risks are safe sided and will provide "adequate" ammunition for 90% of the world situation, 90% of the time. By performing sensitivity analysis on inputs, using the current theaters and by looking at theaters and other potential conflict situations, an estimate of confidence could be placed on the combat rates output, and the decision maker would have this valuable information.

Fourth, the P76-80 Combat Rates methodology did not tell the decision maker the probable results achieved by the quantity of ammunition. In this study, the Blue forces did not attempt to regain any lost territory; therefore, it must be assumed that the Blue forces would ultimately lose the war, and the quantity of ammunition acquired would be "adequate" to bring about this defeat of our forces. Systems analysts must be acutely aware of the impact that these study outputs will have on future decisions and must take into account these facets of the study effort. The P78-82 SAG is going to address this problem area.

The P76-80 Combat Rates Study is the type of effort that we in the logistics community need to assure that we can get these new, highly effective systems into our national armory. But, we must make sure that the systems analysts that run the study and the SAG that provides the guidance, do their job, so that the product of their efforts is useable by the logistic planner.

TITLE: Qualitative Risk Assessment Planning

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Early in the life cycle of a new weapons system, it is desirable to have information relating the relative risk associated with developing each of the feasible alternatives. This information can be used to help in the decision process by giving the decision makers all of the available data for each alternative. The problem with performing a risk analysis, or risk assessment, early in the life cycle is that the data at that time is generally incomplete, unavailable, or highly subjective in nature. This paper will address the technique used by members of the Systems and Cost Analysis Department of the Army Logistics Management Center to assess the technical risk associated with each of the sixteen alternatives for the proposed Scout Helicopter. The risk assessment included only technical risk, as cost and schedule risk were addressed by elements from AVSCOM's Systems Analysis office.

SCOUT HELICOPTER SYSTEM DESCRIPTION

The Scout Helicopter (SH) is to be a lightweight helicopter for use in cavalry, attack helicopter and field artillery units, which will be highly survivable. It will be used for reconnaissance, security and target acquisition functions around the clock and in all intensities of warfare.

The SH will have a minimum crew of two, with complete dual flight controls, and have a flight performance compatible with the Advanced Attack Helicopter (AAH) and the Utility Tactical Transport Aircraft System (UTTAS), as well as nap-of-the-earth (NOE) day/night flight capability. Communications with all Army ground units, other Army aerial vehicles and USAF aircraft will be possible. The crew and critical components will be provided with ballistic protection.

Sixteen design alternatives to be evaluated for technical risk were provided by the Aircraft System Division of the Scout Helicopter Special Task Force (SHSTF). The engines powering the alternatives for the Scout Helicopter were combinations of current and advanced technology designs with both single and twin configurations considered. Possible target acquisition equipment included the Airborne Laser Locator Designator (ALLD) and Forward Looking Infrared (FLIR), while mission equipment was studied at two levels, light and heavy. The permissible combinations are designated in Table 1.

TABLE 1

(1) ALLD - Target Acquisition by Airborne Laser Locator Designator.
(2) FLIR - Target Acquisition by Forward Looking Infrared.
(3) LIGHT - Only Mission Essential Equipment (no Target Acquisition Recorder, no Projected Map Display, no Armament, no Air Conditioning, AN/APR 39 Radar Warning System instead of AN/APR 39/41, no Laser Detector, and other equipment reductions).
(4) Current Single - This aircraft corresponds to the Bell Helicopter Model 214 A.

(5) BO-105
(6) WG-13

RISK ALTERNATIVES

Engine Technology	No. of Engines	Mission Equipment Package	Target Acquisition	Risk Assessment Nomenclature
Advanced	Twin	Heavy	ALLD(1)	ATE-T-H-A
-	-	-	FLIR(2)	ATE-T-H-F
-	-	Light(3)	ALLD	ATE-T-L-A
-	-	-	FLIR	ATE-T-L-F
-	Single	Heavy	ALLD	ATE-S-H-A
-	-	-	FLIR	ATE-S-H-F
Current	Twin	Heavy	ALLD	CUR-T-H-A
-	-	-	FLIR	CUR-T-H-F
-	-	Light	ALLD	CUR-T-L-A
-	-	-	FLIR	CUR-T-L-F
-	Single(4)	Heavy	ALLD	CUR-S-H-A
-	-	-	FLIR	CUR-S-H-F
German	Twin(5)	Light	ALLD	GER-T-L-A
-	-	-	FLIR	GER-T-L-F
English	Twin(6)	Light	ALLD	ENG-T-L-A
-	-	-	FLIR	ENG-T-L-F

METHODOLOGY

The general approach for assessing the risk of the proposed design alternatives consisted of obtaining risk assessments for each major component and then combining these results to assess the risk of each alternative. This approach for assessing risk is largely subjective in nature. To provide a common scale for assessing technical risk of items of equipment, a risk assessment plan was developed.

The data collection and evaluation was conducted as follows:

a. A questionnaire was developed which asked pertinent questions regarding schedule, cost, and technical requirements, capabilities, and risks associated with the major equipment packages to be used in SH designs. Cost and schedule risks were not directly considered in this report. The implications of schedule risks do enter indirectly into the technical risk assessments.

b. These questionnaires were distributed to and completed by those members of the SHSTF whose area of responsibility covered a specific item of equipment. Each evaluator was provided a copy of technical risk guidelines to insure uniform ratings.

c. The results of these questionnaires were supplemented by interviews with other members of the SHSTF on such matters as Reliability, Availability, and Maintainability (RAM), logistics, fuel consumptions, vulnerability, etc.

d. The results of this data collection were used by the risk assessment team members to make pertinent observations and conclusions regarding technical risk associated with the given alternatives.

The questionnaires included definitions of the various risk levels that were to be utilized during the study effort, to insure that the responses concerning risk would be as consistent as possible between the various responders. These risk level definitions are shown in Table 2.

TABLE 2

RISK LEVEL DEFINITIONS

Risk Level	Definition
None	On-the-shelf, fully developed, in production, and meets mil-specs.
Low	Small likelihood of not meeting requirements, at most 15%. Fully developed, producible item meeting mil-specs but not in production.
Moderate	At most 30% chance of not meeting requirements. Pre-Military Qualification Test (MQT) item requiring little further development effort.
High	At most 40% chance of not meeting requirements. Early prototype or breadboard requiring further development effort and debugging.
Very High	At most 50% chance of not meeting requirements. Conceptual, laboratory designs, item requires extensive R&D. Item may be pushing state-of-the-art.
Unacceptably High Risk	Greater than 50% chance of not meeting requirement. Conceptualized on paper. Item is theoretical in nature and exceeds current state-of-the-art.

The risk assessment based on the questionnaire responses, considered only those attribute risks that varied between the attributes, as consideration of factors with uniform risk would not affect the relative ranking of the 16 alternatives. The results from the questionnaires as they applied to the technical risk of system elements are shown in Table 3.

TABLE 3

RISK SUMMARY OF ATTRIBUTES HAVING DIFFERENT RISKS

	ALLD ATE-T-H	FLIR ATE-T-H	ALLD CUR-T-H	FLIR CUR-T-H	ALLD CUR-T-L	FLIR CUR-T-L	ALLD ATE-S-H	FLIR ATE-S-H
ENGINE								
ATE-T	High	High						
ATE-S							Moderate	Moderate
CUR-T			None	None	None	None		
CUR-S								
AIRFRAME								
COMPS	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
METAL								
NAVIGATION								
ASN-99/ID-1655	Moderate	Moderate	Moderate	Moderate			Moderate	Moderate
INSTRUMENT MK III	Moderate	Moderate	Moderate	Moderate			Moderate	Moderate
TAR ACQ								
ALLD	High		High		High		High	
FLIR		Moderate		Moderate		Moderate		Moderate
TAR ACQ REC	Low	Low	Low	Low			Low	Low
COMMO-AT-470	High	High	High	High	High	High	High	High
PFLIR	High	High	High	High	High	High	High	High
ASE								
AN/APR 39					Moderate	Moderate		
AN/APR 39/41	Moderate	Moderate	Moderate	Moderate			Moderate	Moderate
LASER DET	High	High	High	High			High	High
FLARE DIS	Moderate	Moderate	Moderate	Moderate			Moderate	Moderate
CHAFF DIS	Moderate	Moderate	Moderate	Moderate			Moderate	Moderate
ARM SAWS	Moderate	Moderate	Moderate	Moderate			Moderate	Moderate

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TABLE 3 (cont)

RISK SUMMARY OF ATTRIBUTES HAVING DIFFERNET RISKS

	ALLD ATE-T-L	FLIR ATE-T-L	ALLD CUR-S-H	FLIR CUR-S-H	ALLD GER-T-L	FLIR GER-T-L	ALLD ENG-T-L	FLIR ENG-T-L
ENGINE								
ATE-T	High	High						
ATE-S								
CUR-T					Low/Mod	Low/Mod	Low	Low
CUR-S			None	None				
AIRFRAME								
COMPS	Moderate	Moderate						
METAL			None	None	Low	Low	Low	Low
NAVIGATION								
ASN-99/ID-1655			Moderate	Moderate				
INSTRUMENT MK III			Moderate	Moderate				
TAR ACQ								
ALLD	High		High		High		High	
FLIR		Moderate		Moderate		Moderate		Moderate
TAR ACQ REC			Low	Low				
COMMO-AT-470	High	High	High	High	High	High	High	High
PFLIR	High	High	High	High	High	High	High	High
ASE								
AN/APR 39	Moderate	Moderate			Moderate	Moderate	Moderate	Moderate
AN/APR 39/41			Moderate	Moderate				
LASER DET			High	High				
FLARE DIS			Moderate	Moderate				
CHAFF DIS			Moderate	Moderate				
ARM SAWS			Moderate	Moderate				

RANKING

To determine the relative ranking of the 16 alternatives it was necessary to develop a method for converting the subjective estimates of risk from the questionnaires, into an overall numerical figure of merit. This figure of merit would allow the 16 alternatives to be ranked sequentially.

Each alternative is composed of five system components; capability, performance, survivability, avionics and armament. Each of these components is in turn characterized by system elements. Capability is composed of Target Acquisition, Target Acquisition Recorder and PFLIR. Performance is composed on the Engine and Airframe. Survivability is composed of the elements of ASE. Avionics consists of Communications and Navigation equipment and Armament consists of SAWS. In some alternatives not all system components are present. In these cases the component has no risk; e.g., the lightweight packages have no armament.

RAM is also listed in the DRP as a major area for consideration in design trade-offs. RAM was not quantified in this ranking procedure because risk of achieving the ROC reliability goal is considered high for all candidates and risk of achieving the ROC availability and maintainability goals is considered low for all candidates. Thus, weighting RAM would have no effect in quantitatively rank ordering the design alternatives.

Each system element has been classified according to risk as being no risk, low risk, moderate risk or high risk. The risk levels are defined in Table 2. No system elements were assessed a very high or unacceptably high risk. In the analysis, the midpoints of the ranges are used for ranking. For example, according to Table 2, moderate risk denotes between 15% and 30% chance of failure, or an average of 22.5% chance of failure. A sensitivity analysis shows that the relative ranking is insensitive to this choice of the midpoint over any other choice. In the analysis, the average risk level for no risk is 0, low risk is 7.5%, moderate risk is 22.5%, and high risk is 35%. The technique used is as follows:

Element Risk Level	F Average Risk	$\overline{F}$ 1 - Average Risk
None	0	1.000
Low	.075	.925
Mod	.225	.775
High	.350	.650

1. For each element within a component, list the average risk, F. Then, for each of the elements determine $\overline{F}$ (i.e., 1-F). For each component, multiply the $\overline{F}$'s for each element together and subtract this product from 1.000. The results will be risk of total component success.

From the DRP document it was determined that in rating the alternatives, capability is more important than performance which is more important than survivability which is more important than avionics which is more important than armament. Weighting factors for each component were chosen which are consistent with these DRP statements.

WEIGHTING FACTORS USED

SET	CAPABILITY	PERFORMANCE	SURVIVABILITY	AVIONICS	ARMAMENT
(1)	.22	.21	.20	.9	.18
(2)	.4	.4	.07	.07	.06
(3)	.5	.3	.07	.07	.06

2. Multiply the risk of total component success by the weighting factor for that component and sum these for each alternative. This result is a measure of risk of the alternative.

3. Rank the alternatives in order of ascending risk by using the measure of risk found in step 2.

EXAMPLE

ALTERNATIVE: Current Engine - Twin - Heavy Package - FLIR

(Refer to Table 6 for risks.)
(Weighting factors in Set 1, previous page, are used.)

Capability

Item	FLIR	Acquisition Recorder	PFLIR
Risk	Moderate	Low	High
$\bar{F}$	.775	.925	.65

Performance

Item	Engine	Airframe
Risk	None	Moderate
$\bar{F}$	1.0	.775

Survivability

Item	AN/APR 39/41	Laser Detector	Flare Dispenser	Chaff Dispenser
Risk	Moderate	High	Moderate	Moderate
$\bar{F}$	.775	.65	.775	.775

Avionics

Item	AT-470	ASN-99/ ID-1655	MK III Warning System
Risk	High	Moderate	Moderate
$\bar{F}$	.65	.775	.775

Armament

Item	SAWS
Risk	Moderate
$\bar{F}$	.775

	A Product of $\bar{F}$'s	B Weighting Factor	C 1-Product of $\bar{F}$'s	B X C Risk Contribution
Capability	.466	.22	.534	.118
Performance	.775	.21	.225	.047
Survivability	.303	.20	.697	.139
Avionics	.390	.19	.610	.116
Armament	.775	.18	.225	.040
Sum of Risk Contributions				.460

Measure of Risk for Given Alternative .460

RANKING WEIGHTS SET 1

ALTERNATIVE	MEASURE OF RISK
ENG-T-L-F	.251
CUR-T-L-F	.268
ENG-T-L-A	.268
GER-T-L-F	.280
CUR-T-L-A	.286
GER-T-L-A	.296
ATE-T-L-F	.325
ATE-T-L-A	.343
CUR-S-H-F	.413
CUR-S-H-A	.430
CUR-T-H-F	.460
CUR-T-H-A	.477
ATE-S-H-F	.478
ATE-S-H-A	.514
ATE-T-H-F	.517
ATE-T-H-A	.534

* Weight Sets 2 and 3 produced minimal changes in ranking of alternatives.

CONCLUSION

The technique presented here proved useful in evaluating the relative risk of the various system alternatives for the Scout Helicopter. It is felt that the technique is applicable to this specific situation within the constraints of the problem as presented to the risk assessment team. However, other problems might have certain characteristics which would reduce the effectiveness of this ranking procedure. This ranking technique should not be taken as a generalized method for risk ordering, although understanding this basic process will allow similar techniques to be developed which would apply to other specific problems.

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SAMPLE SIZE FOR DURABILITY TESTS

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INTRODUCTION

The number of units to be used for durability testing has a profound effect on cost and schedule for many materiel acquisition programs. All too often program decisions are made before adequate consideration is given to the size of the sample for durability testing. The result of such neglect is commonly to prevent the design of an adequate durability test. When durability test sample size is given substantial consideration, the tradeoff of sample size against acquisition program cost and schedule is often done poorly. Much of the blame for this situation can be traced to inadequate communications from statisticians, test planners and product assurance personnel to decision makers. The purposes of this paper are to examine this problem and to illustrate how the implications of sample size can be communicated simply and effectively. The paper is limited to acquisition of militarized trucks: however, similar approaches to consideration of sample size can be used when other materiel items are to be acquired, particularly those with aging characteristics similar to trucks. Most of the work on which this paper is based was done as a part of the "Special Analysis of Wheeled Vehicles (WHEELS)."[1] Substantial contributions to the part of the WHEELS study dealing with sample size for durability tests were made by Johnson.[2]

Until the early 1950's only one or two trucks were procured for all developmental and operational test activities at each major phase of a truck acquisition program. Since then there has been a trend to increase the number of vehicles procured for these purposes. In recent years, perhaps eleven or twelve vehicles would be typical: three each for durability testing at engineering, service, and environmental test sites; and two or three vehicles for other testing. The durability testing provides data with respect to most truck performance and cost characteristics as well as durability characteristics. The increased testing provides a better basis (i.e., more performance and cost data and more confidence in the results) for program decisions on suitability of the design and of production vehicles for Army use, and for establishing policy decisions with respect to management of the fleet (e.g., policies for vehicle replacement, maintenance, manpower, and overhaul). Further, the larger number of test vehicles permits concurrent testing at different test sites, which speeds up recognition of problem areas and reduces the total time consumed by testing. It also permits testing of several representative body styles instead of just one.

DURABILITY REQUIREMENTS

The dictionary defines "durability" as the quality of enduring or the ability to withstand wear and tear. Of course, a quantitative measure of durability is needed if it is to be used as a characteristic in a requirements document or specification. Military standard MIL-STD - 721B[3] contains the following definition of durability: "See reliability of which this is a special case." From the definition given for "reliability," this means that durability is a probability that an item will perform its intended functions for a specified interval under stated conditions.

The following is a typical durability specification for a truck:

> "The vehicle shall have a .50 probability...of completing the first 30,000 miles of operation without a replacement or overhaul of the engine, transmission, transfer case, front and rear axles, and frame. Replacement is considered to have ocurred when repair or corrective action exceeds... organizational and direct support levels. The vehicles shall (have)... the following operational cycle: (a) 25% highway-50% with rated towed load; (b) 60% secondary road-50% with rated towed load and (c) 15% cross-country-25% with rated towed load."

In general, the thrust of vehicle durability characteristics is an attempt to limit the need for higher level maintenance, for replacement of major components, and for overhaul or replacement of the vehicle itself.

Vehicle durability is often stated in this form (i.e., as a probability of achieving a stipulated number of miles without the need for replacement of a major component). It is also stated as an average mileage to first failure of any major component or as average miles to overhaul or rebuild. Another form is the probability of achieving stipulated mileage without the need for depot overhaul, rebuild or disposal. Current Army criteria for vehicle replacement are stated in Technical Bulletin TB 750-98-23, Maintenance Expenditure Limits. This bulletin contains tables which provide the maximum permissible expenditure at one time for maintenance below the depot level, depending on the vehicle's age, mileage, weight class and acquisition cost. If a technical inspection indicates that required maintenance exceeds the Maintenance Expenditure Limit, then that vehicle would be turned into a depot.

Until recently the rationale for selecting the form in which to state durability (more than one form is sometimes specified) and the specific required level (for each form), tended to boil down to knowing that this level of durability was relatively acceptable based on current experience. Now we are beginning to use more disciplined approaches for establishing durability requirements, with the general aim being to provide the overall operational capability needed at the lowest possible cost. Our ability to systematize the acquisition of materiel items in this way is rather rudimentary, however. Formidable real-world obstacles inhibit both the collection of field experience data that corresponds to durability characteristics that can be engineered into trucks and the measurement of durability achievement.

DURABILITY TESTING

Definition

"Durability tests" are tests that determine the ability of the vehicles (or other items) to continue performing satisfactorily for a long time; that is, the word "durability" is used in its qualitative dictionary sense. The test vehicles are operated a large number of miles (usually related to a durability or life requirement), carrying out numerous missions under varied environmental and use conditions as representative as possible of the anticipated mission performance envelope. Such tests are sometimes referred to as "durability/reliability," "life," or "endurance" tests.

Conduct of Tests and Use of Test Data

Durability tests provide varied performance and cost data to support program and policy decisions. Certain data are unique to durability tests and are not obtainable elsewhere. These are data that serve as a basis for quantitative estimates or evaluations of durability and reliability characteristics, and data on capabilities and costs as the vehicle ages. A durability test of prototype vehicles should normally be conducted to determine suitability of the design for Army use, and there should be another durability test at the start of production. In addition, it is extremely important that substantial testing be conducted as early in development as possible in order to speed up the process of arriving at a mature vehicle design. The emphasis at this early stage is on thorough investigation of all problems that occur in order to determine corrective action needed to eliminate possible causes of vehicle failure. Durability tests provide data to support analyses of life cycle costs, which in turn provide bases for policy decisions. Policies for vehicle replacement and for Maintenance Expenditure Limits are examples of policies that are based on such economic analyses.

If durability tests are required at more than one location to obtain representative worldwide conditions, then the preferred approach is to conduct a complete test at each site; however, program considerations may dictate using the same vehicles, moving them from one location to the other. Another possible approach is to test fewer vehicles at each site and then attempt to combine test results from the different sites, although this tends to make the statistical validity of the results highly questionable. In general, at least a "minimum durability test" as described below should be used at each site except for tests in support of engineering design rather than management decision. Test results must be assessed in light of good technical and management judgment, since there is no way that the test itself can perfectly duplicate field conditions. An example here is the inability to accurately simulate deterioration in the field of certain components (such as rubber items) no matter how large the sample. Other examples are the difficulties of simulating such things as turbulence of operator and maintenance personnel, operational abuse of vehicles, accidents, battle damage, and shortages of replacement parts.

Refinement of the estimates (from test data) of performance and cost characteristics, including durability and reliability, must be made subsequent to initial fielding of the vehicles. This requires a management information system based on collection of data from the field.

Assessment of Durability and Reliability

The primary factors determining durability test duration and sample size are the estimates or evaluations that must be made of durability and reliability. Estimates or evaluations of other characteristics are not usually limiting factors. To assess durability quantitatively, a large number of vehicles must be operated until durability failure occurs or a stipulated high mileage is reached. To a degree, quantitatve assessments can be made with a sample size as small as three vehicles.

Usually, assessment of reliability requires a shorter test and fewer test vehicles than assessment of durability, because primary concern is with the ability of the vehicle to perform one mission at a time. However, this may be offset in two ways. First, mission reliability needed usually has a rather high probability factor (e.g., the Army usually will not be willing to have a substantial percentage of its vehicles unable to perform a single mission). Second, vehicles do not have the same reliability throughout their lives. The finer the age requirements in which the Army wants to know reliability, the larger the sample size needed (assuming test duration is fixed by durability considerations). For example, if the Army wants to know how reliablity changes when averaged over each 2000-mile increment, the sample needed would be five times that if reliability averaged over 10,000-mile increments were acceptable. Thus, reliability could become the limiting factor in determining test size.

Clearly, if the number of items to be procured for field use is relatively small, then statistically valid demonstration of durability is simply not compatible with the program. This is also true with respect to reliability, especially if reliability is quite high.

Test Duration

Durability tests should preferably be continued beyond anticipated replacement life rather than terminating when data adequate to support a program decision are available. Data developed through such testing are required for development of the data base to support fleet management decisions and to support economic analyses (including determinations of economic life). Program decisions, including those related to assessments of durability and reliability need not be delayed until the end of durability testing.

Sample Size

Although estimates of durability and reliability could be made simply by extrapolating from the results of the test of a single vehicle, such estimates could be quite far from the average characteristics of the entire vehicle population that the test sample represents. The larger the fraction of the total population and the longer the test of each vehicle, the closer the test estimates are to the average for the entire population. Clearly, the most important consideration in answering the question of how much testing is enough is just how good our estimates of durability and reliability have to be. The relationship of sample size to the precision of the estimates of these characteristics is discussed in some detail in the following paragraphs, which illustrate the potential impact of the general approach to the problem on the range of possible choices available to decision makers.

ALTERNATIVE APPROACHES

Background

DA guidance has been provided which specifically requires that coordinated test programs (CTP) address test duration, sample size, and associated test risks to developing and using agencies. The guidance is being executed and enforced on all new acquisition programs prior to the final funding and schedule decisions. While test duration and sample size are now usually surfaced in a timely fashion, all possible alternative approaches to durability testing are not being fully explored. These alternative approaches may involve lower resource consumption for testing, yet provide sufficient data to permit making the necessary decisions with high confidence. Throughout this area, there seems to be a communications breakdown. Although statistical handbooks contain a great deal of useful data, the statistician is not communicating to the manager the various alternative approaches to his particular durability testing problem, and the full significance of the various possible decisions the manager might make with respect to test duration and sample size. It is also true that managers are not asking the right questions because of lack of knowledge of the possibilities that exist. One apparent area of great confusion involves the distinctions between design requirements and estimates of achievement based on a test. Failure to make this distinction properly has commonly resulted in a perfectly good vehicle or component being unable to pass a test; or, as industry representatives have pointed out, the need to substantially overdesign with respect to the true capability needed simply to pass the test.

The following paragraphs illustrate possible approaches to durability testing which deserve consideration, and also illustrate the kind of information that should be presented to vehicle managers. Certain approximations are made which a purist would resist. These approximations introduce relatively little error into the decision process as compared to the errors introduced by the difference between the actual field situation and the assumptions inherent to any of the mathematical/statistical models and formulations.

Testing by Attributes Criteria

General. From the viewpoint of test statistics, there is a sharp difference between testing by attributes criteria (e.g., testing each vehicle to 15,000 miles and simply determining whether a durability failure occurs or not) and testing by variables criteria (e.g., continuing testing of each vehicle until durability failure does occur and determining mileage of the occurrence). The simplest test and evaluation procedure and also the one requiring the least assumptions concerning the durability characteristics of the vehicle is an attribute type demonstration plan.

Sample Size and Discrimination Power. If a good quantitative estimate of durability is required, then large test sample sizes are needed. This is particularly true in the case of testing by attributes. For example, approximately 130 vehicles would have to be tested to distinguish between 82 and 90 percent durability. Much smaller sample sizes (perhaps seven or nine vehicles) are usually adequate for all other purposes. For example, a sample size of seven vehicles permits distinction between 40 and 90 percent durability. There would be little risk of failing the test if the vehicles were as good as they should be (90 percent durability), and little risk that extremely bad vehicles (40 percent durability) would pass the test. In order to avoid playing a numbers game, there must be a strong basis for belief that the vehicles submitted for test do, in fact, have 90 or 95 percent durability. The basis for such belief would normally be engineering analysis of relevant field and test data, and prior contractor testing of the vehicles in question. Vehicles with true durabilities in the 50 to 80 percent range would be about as likely to pass the test as to fail. However, the vehicle manager may be willing to take these risks as long as the test is capable of pointing out gross mistakes (i.e., little risk of accepting 40 percent durability) at the time a program decision has to be made. The manager's justification for taking substantial risk with respect to small mistakes (i.e., durability lower than our basis of belief, say in the 50 to 80 percent range), would lie in the judgment that a larger test sample would involve excessive acquisition and test costs relative to the risk and consequences of fielding such below par vehicles. Table 1 illustrates the way approximate discrimination power for different sample sizes could be displayed. A discussion of the statistics underlying attribute type acceptance criteria is provided in the US Army Materiel Command Engineering Design Handbook, AMC PAM 706-109.[4]

TABLE 1
DISCRIMINATION POWER OF TEST vs DURABILITY TEST SAMPLE SIZE

Number of test Vehicles	Probability of No Durability Failure Good*	Bad*
3	80%+	20%-
7	83%+	40%-
20	87%+	64%-
50	89%+	75%-
130	90%+	82%-

*There would be less than a 10 percent risk that vehicles with good durability would produce unacceptable test results; and there would be a 10 percent risk that vehicles with bad durability (e.g., 40 percent in the case of a test with sample size of seven vehicles) would produce acceptable test results.

Minimum durability test. Generally speaking, a test of three vehicles under representative varied operating/environmental conditions until a specified high mileage is a minimal test for providing any valid quantitative durability or reliability data at all. If all three vehicles operate satisfactorily throughout the test without major problems, this indicates that the vehicle is good. If all three have premature durability failures, then the vehicle is bad. On the other hand, if one or two fail in this way, there is no clear indication as to whether the test samples represent vehicles with good or bad durability. For example, vehicles with 20 percent durability might (at a 10 percent risk level) produce only one failure; yet much better vehicles with 80 percent durability (10 percent risk) might produce two failures. Clearly, a good quantitative estimate of durability cannot be obtained from this test.

On the other hand, it is possible that such a test will permit a program decision to be made. If there is a sound basis for believing that the vehicle design at this stage of development should have matured to the point that 80 or 90 percent of the vehicles survive to a specified mileage without a durability failure, then such a test provides confirmation that there are no really gross mistakes. Vehicles with durability in the 30 to 70 percent range would be roughly as likely to pass as to fail the test.

This minimum durability test is often adequate to provide an overall quantitative estimate of vehicle reliability, but not of the behavior of reliability with age or of component reliability. Since there is no quantitative measure of just how good the vehicle's durability is, and since durability has significant impact on vehicle availability and on operating cost of the vehicle fleet, substantial risk is present in important areas with respect to management of the fleet.

Testing by Variables Criteria

Comparative discrimination power. Testing by variables criteria involves determining for each test vehicle the actual mileage at which durability failure occurs. Of course, implied in this approach is that we expect to generate durability failure on essentially all the vehicles within the mileage that individual vehicles could be operated under the limits of the test program. Testing by attributes criteria involves determining the probability of failure before a fixed mileage. This approach has the advantage of not requiring any knowledge or assumptions to be made concerning the distribution of the mileage between occurrences of durability failures. If previous data from similar vehicles permit making a reasonable assumption concerning the distribution of miles to durability failure, then a variables test will permit demonstrating the durability requirement with comparable discrimination power using a smaller number of vehicles. The procedure is more complex. It is necessary to compute from the test data the mean and standard deviation of the mileage to durability failure prior to evaluating the probability of completing a specified number of miles without durability failure. Table 2 shows a comparison of sample sizes that approximately match in discrimination power (for certain specific hypothetical test situations). Details on variables testing plans based on the assumption that the mileage to durability failure is normally distributed are given by Lieberman and Resnikoff.[5] Variables testing plans based on other assumptions are also provided in the literature; e.g., increasing failure rate distributions by Barlow and Gupta[6], lognormal distribution by Gupta[7], and the exponential distribution by Sobel and Teschendorf[8]. The exponential distribution is not recommended for durability failures of trucks (or other items which have definite wear out characteristics). It would apply for example if a vehicle which has operated 50,000 miles had the same likelihood of durability failure in the next 1,000 miles as a vehicle which has operated only 2,000 miles.

TABLE 2
SAMPLE SIZES WITH SIMILAR DISCRIMINATION

Approximate Discrimination Ratio	Sample Size: Attributes Test	Sample Size: Variables Test
3.5:1	4	3
2:1	9	7
1.1:1	136	73

Average mileage to durability failure and average replacement life. In economic analyses we are usually more concerned with average mileage to durability failure and/or average replacement life than we are with the probability of completing a specified mileage without a durability failure. Since testing by variables involves determining the mileage at which durability failure occurs for each vehicle under test, the test data will permit direct calculation of the mean for the test vehicles. As discussed before, the test sample may deviate somewhat from the entire population of vehicles. The discrimination power of the test or confidence interval should be presented somewhat differently than above if average mileage to failure is of paramount interest. To illustrate such a presentation, consider a vehicle for which a projected average mileage to durability failure is 30,000 miles. Suppose a number of prototype vehicles are operated at a particular test site until each vehicle fails. The average miles to failure under test conditions can now be directly determined. The mean miles to failure for the entire vehicle population would be related to the test statistic approximately as shown in Table 3. For a more detailed discussion of this type of acceptance criterion see AMC PAM 706-110.[9]

TABLE 3
CONFIDENCE INTERVAL vs DURABILITY
TEST SAMPLE SIZE

Number of Test Vehicles	Confidence Interval Related to Test Mean (miles)*
3	± 10,000
7	± 5,000
20	± 2,700
50	± 1,700
130	± 1,000

*Life is assumed to be normally distributed with a standard deviation equal to 30 percent of the mean. This assumption is somewhat risky with sample size as small as three. Further, it is assumed that the precision of the test must be such that there must be no more than 10 percent risks (each) that a true mean above or below the interval shown in the table, would have produced the observed result. The confidence interval shown is based on a 30,000 mile average durability life and should be changed in direct proportion to such durability life.

Extended Minimum Durability Test. The minimum test discussed under testing by attributes can be extended to be significantly more powerful in contributing to the vehicle manager's decisions by continuing to operate surviving vehicles at least until durability failure occurs (preferably beyond anticipated overhaul life). With such a test, a rough estimate may be made of average mileage to durability failure (e.g., the estimate would be good to approximately $\pm$ 10,000 miles for a 30,000 mile vehicle, as shown in Table 3).

Small Sample Size Management Considerations.

Several significant points have been made above with respect to management of acquisition programs in which the sample of trucks available for durability testing is quite small. Sample sizes of seven (or even smaller in some cases) may be able to provide the data needed by management under the following conditions:

a. Engineering analysis of relevant field and test data and prior contractor testing provide a strong basis for belief that the vehicles to be tested will meet their durability requirements.

b. Management is willing to make a decision to proceed with the program based on testing that is only adequate to detect gross errors. The justification for taking substantial risk with respect to the vehicles being moderately below expectations is that a larger sample would involve excessive cost relative to the risk of fielding vehicles that are somewhat below par.

c. Preferably, the program schedule is arranged so that the program decision (to be made in light of the test data) will be made at or near the completion of testing of all vehicles. Each vehicle is tested at least until durability failure occurs. If this is not feasible, enough samples must be provided for test to enable the program decision to be made with acceptable risk (e.g., in the sense noted in Table 1) based on operation of each vehicle until a stipulated mileage. In this case, if the program decision is favorable, testing will be continued on each vehicle at least until durability failure occurs (preferably beyond anticipated overhaul life), in order to permit some refinement of estimates of performance and cost characteristics, to include durability and reliability.

d. Further refinement of these estimates of performance and cost characteristics will be made subsequent to intial fielding of the vehicles based on valid data feedback.

Extrapolation from Previous Experience.

In most cases, the majority of components incorporated in new vehicles are proven components; only a few components are new or modified. Accordingly, durability data on the proven components may be applied with good engineering judgment to the new vehicle in light of its projected replacement life. Hence, it may be necessary to test only the durability of the new and modified components. An "extended minimum durability test" of the new and modified components may suffice to supply the decision makers with what they need.

CONCLUSION

There is no simple answer to the best approach to the testing of durability or to the proper selection of test duration and sample size; nor can formulas or statistical tables provide answers without communication to the decision maker of their implications and the exercise of judgment on his part. Several examples have been given of how sample size considerations can be presented in the hope of shedding some light on this communications problem.

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PROJECT BULLETS - A SYSTEM ANALYSIS

(COL Richard I. Wiles, LTC William H. Reno, and MAJ Charles W. Jarvis - Program Analysis and Evaluation Directorate, Office of the Chief of Staff, U. S. Army)

Since the height of the Vietnam War the Secretary of the Army (SA) and the Chief of Staff (CSA) have had less flexibility in determining Army programs. The principal reasons for this are decreasing or at best, constant budgets and increasing costs driven by inflation. In terms of current dollars the President's FY 75 Army Budget is about 92% of the FY 68 budget at the height of the Vietnam War. In terms of constant dollars or buying power the FY 75 budget is only about 56% of FY 68. Many costs facing the Army have increased faster than the inflationary trends in the rest of the economy. To have a volunteer Army we must pay our soldiers more, and provide greater services to them and their families to insure continued career attractiveness. These costs become fixed in the sense that they are related to the structure and deployment of the force. Aside from changing the size of the force or its deployment, there is little Army management can do to reduce these fixed costs. We must look to other parts of the Army program for fiscal flexibility.

The approved FY 75 Budget request includes $1.8B for Research, Development, Test and Evaluation (RDTE) and $2.6B for procurement in a total appropriation of $20.3B. Unlike manpower, and operations and maintenance (O&MA) costs, RDTE costs are not driven by the size and structure of the force but by the requirement to insure that the force is provided with modern weapons sufficient to counter the potential threat. As RDTE costs are not force related they can be considered even more fixed than military pay and operations and maintenance. What is left are the procurement accounts. If there is to be increased fiscal flexibility we must look for it here. Of the procurement appropriations in the approved FY 75 Budget request, ammunition at $0.89B is by far the largest, accounting for about 34% of the procurement dollars.

Size of the Ammunition Program

During the past decade the Army has spent over $13B for the procurement of ammunition. For the five year period ending with FY 80, the Army has programed to spend $5B for the procurement of ammunition. This procurement program will provide the ammunition needed to meet current training, rebuild our war reserve stockpiles, and replace obsolete and obsolescent munitions.

In addition to the expenditures for ammunition hardware items, the Army recently has spent over $600M on the ammunition production base and programed an additional $1.8B during the period FY 76-80. Over 80% of the $1.8B will be for modernization and expansion of the production base.

Procurement of ammunition hardware items and support of the production base constitute the ammunition program. Additionally, the Army must use Military Construction, Army (MCA) funds to provide storage facilities for the war reserve stockpile and O&MA funds for storage operations and maintenance of the war reserve stockpile. RDT&E funds are needed also to develop new munitions for both old and new weapons.

Management of the Ammunition Program.

Before Project Bullets, ammunition management could be classified as micro-management, since different agencies were responsible for, and provided intense management of the various aspects of the program. Requirements determination was managed by the Assistant Chief of Staff for Force Development (ACSFOR). (This responsibility is now assigned to the Deputy Chief of Staff for Operations and Plans (DCSOPS).) Procurement, production base support, distribution and maintenance were managed by the Deputy Chief of Staff for Logistics (DCSLOG). (The first two are now the responsibility of the Chief of Research, Development and Acquisition (CRDA) while distribution and maintenance remain with DCSLOG.) Research and Development was managed by the Chief of Research and Development (now CRDA). There was no agency to assist the CSA and Vice Chief of Staff (VCSA) in providing macro-management for all aspects of ammunition. (Prior to March 1972 the Directorate for Ammunition in ODCSLOG did provide a degree of macro-management.)

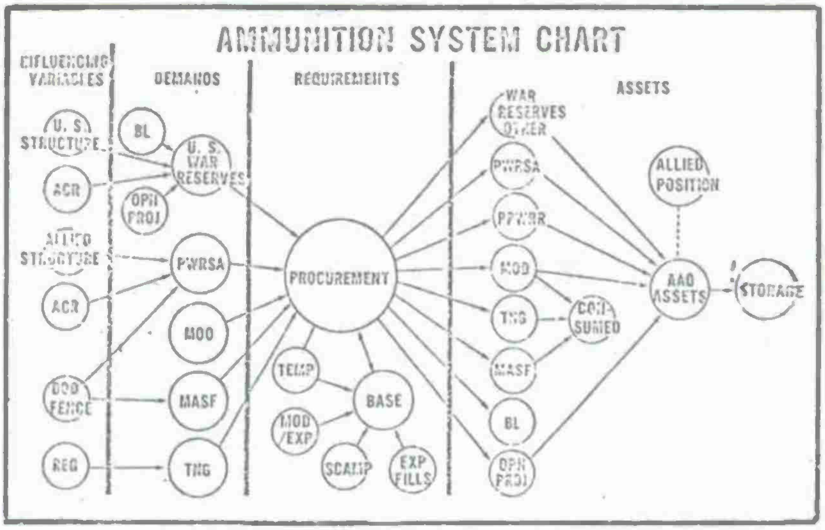
Origin of Project Bullets

During the summer of 1973, the Vice Chief of Staff's (VCSA) primary assistant for resource management, the Assistant VCSA (AVCSA) Lieutenant General James G. Kalergis, asked the Director of Planning and Programing Analysis (now the Director of Program Analysis and Evaluation (PA&E)), Major General J. R. Thurman, to look into the ammunition program. The reason for the review was to insure that the Army was getting the most for its dollars spent on ammunition. The VCSA, General Fred C. Weyand indicated some areas of special concern. He expected to be personally involved. Subsequent study planning was done with his guidance in mind.

Preliminary analysis revealed the magnitude of the ammunition program and its relation to other programs. It was determined that an analysis of the scope envisioned could not be accomplished in one step but must be done in discrete steps. (Eat the elephant one bite at a time.)

The Model

A model of the ammunition system was developed. An early version of the model is at Exhibit 1. We believe the model was the first attempt by anyone to depict graphically the Army Ammunition System. It is, admittedly, a gross aggregation of the complex parts of the system. Many of the nodes could themselves be expanded into models more complex than the one shown. Nevertheless, it has served many useful purposes.



ACRONYMS

AAO	AUTHORIZED ACQUISITION OBJECTIVE
AAO ASSETS	SUMMATION OF ALL AMMUNITION ELEMENTS THAT ARE CONSIDERED ASSETS TOWARDS THE AAO
ACR	AMMUNITION CONSUMPTION RATE (ROUNDS/WEAPON/DAY)
BASE	PRODUCTION BASE
BL	UNIT BASIC LOAD
D–P	TIME BETWEEN D-DAY AND DAY WHEN AMMUNITION PRODUCTION EQUALS AMMUNITION CONSUMPTION
EXP FILLS	PREFERRED VERSUS ALTERNATE AND EMERGENCY FALL-BACK MUNITIONS FILLS
MASF	MILITARY ASSISTANCE SERVICE FUNDED.
MOD	MODERNIZATION OF AMMUNITION HARDWARE
MOD/EXP	MODERNIZATION/EXPANSION PROGRAM
OPN PROJ	AMMUNITION/MUNITIONS DESIGNED FOR OPERATIONAL PROJECTS

ACRONYMS (CONTINUED)

OTHER WAR RESERVES	WAR RESERVES POSITIONED IN CONUS
PPWRR	PRE-POSITIONED WAR RESERVE REQUIREMENTS (US)
PWRSA	PROCUREMENT WAR RESERVE SUPPORT ALLIES
REG	REGULATIONS (TM'S)
SCAMP	SMALL CALIBER AMMUNITION PRODUCTION
STORAGE	AMMUNITION STORAGE (CONUS, NATO, AND USARPAC)
STRUCTURE	ARMY FORCE STRUCTURE
TEMP	TEMPERATURE OF THE PRODUCTION BASE A MEASURE OF IT'S STATE OF READINESS
TNG	UNIT TRAINING REQUIREMENTS
U.S. WAR RESERVES	SUM OF ALL U. S. WAR RESERVE MUNITIONS (CONUS AND OVERSEAS)
ALLIED POSITION	INCLUDES ALLIED PRODUCED AMMO, ALLIED PRODUCTION CAPABILITY AND AMMUNITION PROCURED THROUGH MAP

EXHIBIT 1

It shows the interrelationships of the parts and has allowed us to look at the system as a whole. Further, it has permitted categorization of parts of the system as influencing variables, requirements, demands, and assets. Finally, it provides discipline for further study by identifying discrete elements which can be examined in detail without losing the perspective of how an element fits into the system.

The Analysis Brief

As an additional discipline, the Project Bullets Team developed a study format called an Analysis Brief. The Analysis Brief, like the Commanders Estimate of the Situation and Staff Study in their respective fields, merely standardizes analysis of the components of the ammunition system. The outline of the Analysis Brief is at Exhibit 2 below.

ANALYSIS BRIEF

1. REFERENCES

2. PURPOSE

3. BACKGROUND

4. ANALYSES

5. CONCLUSIONS/RECOMMENDATIONS

EXHIBIT 2

Army Management Development

As mentioned previously the VCSA had particular interest in Project Bullets and had expressed a desire to be personally involved. It was decided that this could best be accomplished by submission of monthly progress reports. The progress report itself highlights significant findings since the previous report, indicates important followup actions, and outlines future efforts of the Project Bullets Team, other staff agencies, and commands. The progress report is supported routinely by three inclosures. The first is the latest version of the System Model. Next is the Study Schedule. An example is at Exhibit 3. The first column of the schedule identifies the study objective in relation to elements of the Ammunition System. The next column indicates related studies by PA&E, the Army Staff or other agencies. The final column provides pertinent remarks and the current status of the study efforts. The Study Schedule is further supported by current Analysis Briefs. The final inclosure is a Milestone Chart. This chart displays progress toward overcoming selected shortcomings which were identified during the course of the study. Additional inclosures are added, as required, to portray the status of related Project Bullets actions.

PROJECT BULLETS STUDY SCHEDULE

The following display lists examples of those elements of the Army ammunition program currently under study by the Investment Programs Analysis Team, PA&E and agencies of the Army Staff.

STUDY OBJECTIVE	PA&E OR RELATED STAFF ACTION (COMPLETION DATE)	REMARKS (REMARK DATE)
INFLUENCING VARIABLES		
• Ammo Rates	ODCSOPS (OACSFOR) ammo rate study (Europe, NEA, SEA). SAG, chaired by Dir Rqmts ODCSOPS (OACSFOR). PA&E member.	Results of CAA simulation were completed and SAG approved rates for further staffing. On 17 May ACSFOR approved rates for programing and planning purposes. Comments on study from major commands have been received and are being reviewed for incorporation into current or future study efforts. Results of study extensively used in development of the 76-80 POM. (Sep 74)
	ODCSOPS Nonnuclear Ammo Combat Rates Methodology Improvement - Part II (AMMIP II). Final report due Dec 74. PA&E member.	SAG formed Jul 74, chaired by Mr. Vandiver (ADUSA-OR). Purpose is to develop and incorporate improvements in nonnuclear ammo rates study methodology to be used for AMMORATES P76-82 Study. Second meeting scheduled for 25 Sep 74. (Sep 74)
	ODCSOPS/OACSI review of Soviet combat ammo rates. (Apr 74)	Results used internally by ODCSOPS in review of AMMORATES P76-80 Study. Significant finding - Soviet combat consumption rates vastly greater than U.S. rates. (Sep 74)
	ODCSOPS review of WWII/Korean rates versus current rates. (Nov 73)	Results used for internal review of computer based ammo rates. (Sep 74)
REQUIREMENTS		
• Training ammo	ODCSOPS review of U.S. training allowances to determine validity of requirements. (Nov 73)	Training allowances in CTA challenged in many instances. Study now at TRADOC for review. (Sep 74)
	ODCSOPS (OACSFOR)/OACSI review of Soviet training allowance.	Soviets by comparison shoot much less. Example: U.S. 105 howitzer is 208 Tng Rds/Yr; USSR 122 gun howitzer is 15 Tng Rds/Yr. This in-house analysis is being used by ODCSOPS and TRADOC in the study described below. (Sep 74)
	TRADOC special analysis of training ammunition requirements.	Study will address training ammunition requirements and integration of simulators in training to improve cost effectiveness. Specific attention will be given to rifle proficiency, artillery, and tank gunnery. (Sep 74)
• Basic load	PA&E review.	Basic load ammunition represents normally a 3-5 day combat supply for initial consumption in the event of hostilities. Basic load requirements have been reduced by 15.5K short tons. Oct 73 study determined basic load cost to be $104M. (Sep 74)
• MASF	PA&E review.	Laos reverted to MAP in FY 75. Ammunition program for RVN has been withdrawn from Army budget and placed in separate Defense Assistance to Vietnam (DAV) account administered by DOD. Congressional intent is for RVN to revert to MAP in FY 76. (Sep 74)

EXHIBIT 3

Army Staff Involvement

The Project Bullets Team could have accomplished very little without the support and assistance of the Army Staff. Most of the information needed for individual analysis was provided by the Staff. The Staff also served as teachers to the team. They educated us on the inner workings and hidden mechanisms of the various components of the ammunition system.

Last but definitely not least, our discussions with them provided the seeds of ideas for improvements in the system. Indeed many of the ideas were more than seeds but were well germinated. Similar help was received from the Office of the Deputy Under Secretary of the Army (Operations Research), the Concepts Analysis Agency, the Armament Command, the Project Manager for Production Base Modernization and Expansion Planning, and the Army Materiel Command Ammunition Center.

Copies of draft analysis briefs were submitted informally to interested staff officers for comment prior to being incorporated into Progress Reports. Additional information and ideas resulted from this informal coordination.

Initially, the draft analysis briefs were the only documents furnished to an agency outside the Office Chief of Staff, however, all facts were checked with appropriate agencies. Shortly after the project got underway, Project Bullets efforts were given wider dissemination. Subsequently progress reports were distributed after review within the Office Chief of Staff. The current distribution list is at Exhibit 4.

Where Project Bullets Team analysis indicated a shortcoming, this fact was brought to the attention of someone who could do something about it. This was usually done informally by analyst to analyst contact or memo from the Director of PA&E to an appropriate official of the agency involved. Formal tasking documents rarely were used.

THE ANALYSIS

After modeling the system and establishing a progress reporting procedure and accompanying discipline, the team was ready to proceed with detailed analysis.

The System Model (Exhibit 1)

The nodes on the system model became the subjects of most of the detailed analyses. These discrete analyses could be made with the knowledge of what other elements of the system affected the element under study and what other elements were affected by it. The model became dynamic. As additional knowledge was gained from these analyses, the model was changed. It became almost a living thing.

Distribution of Project Bullets Progress Reports

Deputy Under Secretary of the Army (Operation Research)

Deputy Chief of Staff for Logistics

Office of the Deputy Chief of Staff for Logistics
(Log Plans, Ops & Sys Directorate)

Office of the Deputy Chief of Staff for Logistics
(Supply & Maintenance Directorate)

Office of the Deputy Chief of Staff for Operations and Plans
(Requirements Directorate)

Office of the Chief of Research Development and Acquisition
(Munitions Div, Combat Spt Sys Dir)

Office of The Inspector General
(Spl Insp Div)

Headquarters U.S. Army, Europe

Commanding General, U.S. Army Concepts Analysis Agency

Deputy Commanding General, U.S. Army Armaments Command (AMC)

U.S. Army Audit Agency

EXHIBIT 4

Quick Fix

The first analysis after development of the model was called Quick Fix. It was so called as its purpose was to get a feel for the world-wide ammunition asset picture. It was an attempt to answer the question, "Is our current asset position balanced and located where we want it?" Taking the 15-85 principle from business (namely that 15% of a firms product line accounts for 85% of its profit) we set out to find the 15% of the ammunition line items which would account for 85% of the AAO. We didn't quite get that far. We identified 25 line items (6%) which represented 53% of the dollar value of the AAO assets on hand. These were all killing rounds which would be used in combat. Based on requirements at that time, we were able to determine that the Army was in reasonably good shape with regard to its AAO and the distribution was appropriate.

Influencing Variables

The influencing variables are, by and large, external to the Army ammunition system but drive it never-the-less.

Force structure in conjunction with ammunition consumption rates (ACR) drive requirements. The force structure is determined by the force planners. ACR are a function of weapons density (itself a function of force structure), enemy forces, and nature of combat. War gaming and computer models developed and used by the U.S. Army Concepts Analysis Agency, provide the basis for the ACR. ACR are determined for different levels of combat (intense, sustained), different theaters for U.S. and selected Asian Allies forces. Many assumptions used by war gamers and computer modelers are based on Department of Defense guidance.

Army regulations provide guidance for prepositioning requirements, operational projects and training requirements.

An Aside: Demands vs Requirements

Initially we categorized the second portion of the ammunition system model (Exhibit 1) as "demands" and the third as "requirements". It didn't take long to find that we had the terms reversed. The Army Dictionary (AR 310-25) was helpful here. It defines a (military) requirement as "an established need justifying the timely allocation of resources to achieve a capability to accomplish approved military objectives, missions or tasks."[1] A demand, on the other hand, is "a valid requirement for materiel placed on the supply system by an authorized customer... and is measured in terms of frequency and quantity."[2] We modified the model accordingly. (Exhibit 5)

The Ammunition Equation

The categorization of the parts of the model lead to the ammunition equation, viz:

Demands = Requirements - Assets

This is, of course, an oversimplification as demands are also a function of the condition of the base. If the base is ready to produce ("hot"), we will need less of a stockpile to tide us over to the time when the output of the base equals combat consumption than if the base is laid-away ("cold"). This is discussed in more detail in the section on Demands (pg 15).

Requirements

Recall that requirements are "established need(s) justifying the timely allocation of resources to achieve a capability to accomplish approved military objectives, missions or tasks." In the system model, requirements are further stratified in sub-categories for analysis. These sub-categories are discussed individually in the following paragraphs.

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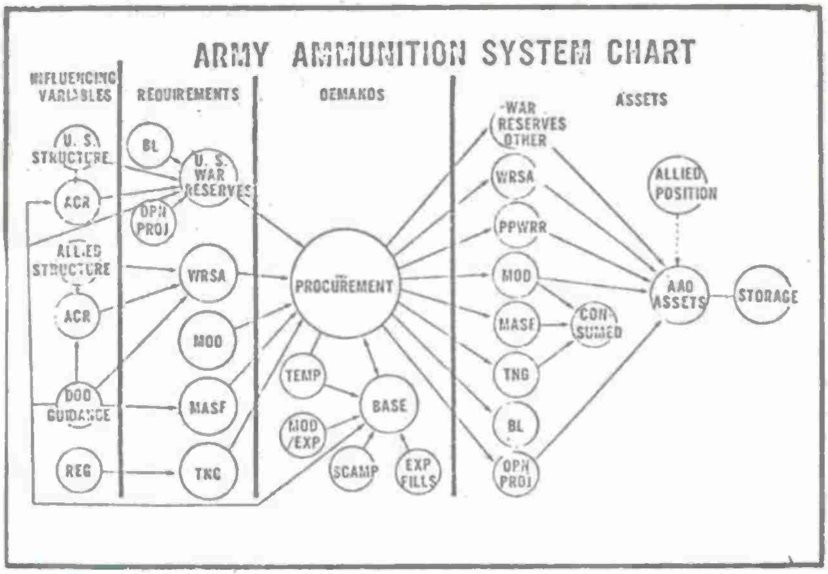
1. AR 310-25, pg 330.
2. Ibid, pg 173.



EXPLANATION OF TERMS

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ALLIED POSITION	INCLUDES ALLIED PRODUCED AMMO, ALLIED PRODUCTION CAPABILITY AND AMMUNITION PROCURED THROUGH MAP
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BL	UNIT BASIC LOAD
DAV	DEFENSE ASSISTANCE TO VIETNAM
EXP FILLS	PREFERRED VERSUS ALTERNATE AND EMERGENCY FALL-BACK MUNITIONS FILLS
MASF	MILITARY ASSISTANCE SERVICE FUNDED
MOD	MODERNIZATION OF AMMUNITION HARDWARE
MOD/EXP	MODERNIZATION/EXPANSION PROGRAM
OPN PROJ	AMMUNITION/MUNITIONS DESIGNED FOR OPERATIONAL PROJECTS

EXPLANATION OF TERMS

OTHER WAR RESERVES	WAR RESERVES POSITIONED IN CONUS
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REG	REGULATIONS (TM'S)
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STRUCTURE	ARMY FORCE STRUCTURE
TEMP	TEMPERATURE OF THE PRODUCTION BASE A MEASURE OF IT'S STATE OF READINESS
TNG	UNIT TRAINING REQUIREMENTS
U.S. WAR RESERVES	SUM OF ALL U. S. WAR RESERVE MUNITIONS (CONUS AND OVERSEAS)
WRM-A	WAR RESERVE MATERIEL - AMMUNITION
WRSA	WAR RESERVE STOCKS ALLIES

EXHIBIT 5

• U.S. War Reserve Requirements. U.S. War Reserve Requirements are a function of consumption rates and weapons density. Weapons density, in turn, is a function of force structure and the deployment. Planners use the force requested by the theater commanders and the deployment assumptions approved by the JCS based on forces available in the Joint Strategic Capabilities Plan (JSCP). The force availability of the JSCP represents the best estimate of deployments for the next fiscal year. The Program Objective Memorandum (POM) force is the force the Army is programed to have during the POM years. The POM depicts deployment schedules for the POM force for given scenarios. There is a significant difference between the Prepositioned War Reserve Requirement (PWRR) for the JSCP force and deployment schedules and the POM force and deployment schedules. The primary difference is in the larger force deployments projected for the POM outyears. The Army regulatory structure is being changed to more closely align current distribution requirements with projected outyear deployments.

• Basic Loads. Basic loads are stocks of ammunition kept by units for use in wartime. The composition of basic loads are determined by commanders. Basic loads are commonly reckoned to be about a 3-5 day supply. Composition of the basic load is based on the enemy and type fighting expected and ability to be resupplied. At the time of the study of basic loads the value of authorized basic loads was about $105M.

• Operational Projects. At the time of our review, operation project stocks were worth $99M. Operational project stocks are set aside for specific operational purposes. The majority of these stocks are bulk items needed for constructing barriers (e.g., mines and explosives), however, there are also requirements for conventional munitions for small arms and crew served weapons. The latter are required for specific contingency missions. Current regulations require that operational projects be reviewed annually, however, there were several "requirements" for obsolete munitions. While the requirements for some of the obsolete munitions was justified by a specific operational need, further analysis revealed that in other cases the projects had not been reviewed annually as required, hence the "requirements" for obsolete ammunition. Major commands have revalidated their operational projects. They are now being reviewed by the Army Staff.

• War Reserve Stocks, Allies (WRSA). Like U.S. War Reserves, WRSA is a function of consumption rates and weapons density which is itself a function of force structure. WRSA constitutes a large portion of the ammunition Authorized Acquisition Objective (AAO). When the 75-79 POM was developed, the Army was uncertain of the force structure which should be used to establish the WRSA requirement. OSD acknowledged this deficiency and provided more definitive guidance for the 76-80 POM. Meetings also were held with representatives of the appropriate overseas commands, MAAGs, missions attache offices, and the Army Staff. The purpose of these meetings was to validate accurate allied weapons densities for OSD approval in determining requirements for the allied forces.

• Modernization. We spend about $220M a year for modern ammunition items. About half is for chemical and nuclear munitions which are beyond the scope of this paper. The remainder is for conventional ammunition requiring new production equipment or facilities or both. Included are such items as improved conventional munitions (ICM) and high-fragmentation projectiles. Hardware procured under this category is to meet the Initial Operation Capability (IOC). After the IOC is filled, the item is procured for other requirements and is considered as AAO assets.

• Military Assistance Service Funded (MASF). MASF has become an historical category. During the present budget cycle, the Congress eliminated MASF and established a new Defense appropriation to provide support for South Vietnam called Defense Assistance to Vietnam (DAV).

• Training. The training category includes requirements for peacetime and mobilization training. Peacetime authorizations are specified in Common Tables of Allowance (CTA's). In the past, about $170M worth of ammunition has been authorized for training for any given year. CTAs are under review within the Army Staff and at Training and Doctrine Command (TRADOC).

Assets

Skipping Demands for a moment, Assets will be discussed next as they are categorized in much the same way as requirements. Project Bullets analyses revealed that not all assets were counted in calculating the PWRR. This anomaly is discussed in more detail below.

• War Reserves, Other. Included in this category are war reserves which are not prepositioned. These are exclusively stored in depots in the continental U.S. (CONUS). Some of the NATO war reserve, contingency stocks, and stocks required to fill a wartime pipeline are in this category.

• WRSA. WRSA stocks are located in the US and overseas. Allied owned assets are considered when determining WRSA shortfall.

• PWRR. Authorization for PWRR is contained in Army Regulation 11-11. The disconnect between JSCP forces and deployment schedules and the POM force and deployment schedule has been explained. The impact of this disconnect is that ammunition may not be at the proper place rather than not being available at all. The AAO, in conjunction with assets and current consumption, determines the procurement program and is based on the POM force and deployment schedules not the JSCP force and deployment schedules. Thus, if we buy out the AAO we will have the required ammunition on hand. Use of AR 11-11 results in a slightly different quantity being in the PWRR category. The difference would be absorbed by the war reserves, other category. AR 11-11 is under active revision and should, at least partially, correct the problem. In the meantime the PWRR includes "safety" levels which should insure that committed forces have the ammunition required.

• Modernization. Initial procurement of modernization items is to meet the IOC. Some modernization items are consumed in familiarizing troops with these new munitions. The balance is included in AAO assets.

• MASF. All MASF ammunition is considered to be consumed as that is the purpose of the program. As previously noted it is now of historical interest.

• Training. At the outset we thought that the inventory of ammunition assets for training would follow the classical inventory sawtooth curve (Exhibit 6) or some variation. We found that while there may be a sawtooth curve, it is a very fine toothed saw. Ammunition is replenished at almost the same rate it is consumed. Therefore, at any one time there is about $170M worth of ammunition designated for training. About 60% of this is service ammunition (killing rounds), the same ammunition which would be used against an enemy in war. The remaining 40% are training peculiar munitions; inert rounds, simulators and blanks. Ammunition which would be required for mobilization training is also included in the AAO. Our review revealed that while training assets were considered when determining AAO shortfall and thus procurement needs that these assets were not considered by the oversea commands when determining war reserve requirements. The revised AR 11-11 will require the oversea commands to count service training ammunition assets as PWRR assets in determining their PWRR shortfall.

• Basic Load. Our review of basic loads revealed two points. First, in spite of the fact that basic load authorizations are determined by commanders, reported assets exceeded authorization by about 20%. Additionally, as with training assets, basic load stocks were not considered when determining war reserve requirements. The revised AR 11-11 also recognizes this. Additionally, the excess basic load stocks have been restratified, primarily as PWRR.

• Operational Projects. In the discussion of operational projects requirements determination, it was pointed out that many "requirements" for obsolete munitions were found. While some of these requirements are justified, it should not be surprising that a review of operational project assets revealed shortages of many of these munitions. Updating the requirements should eliminate many of the requirements for which there are no assets.

• Storage. Ammunition not properly stored and maintained will deteriorate and have to be replaced before the end of its otherwise useful life. Ammunition not safely and securely stored may result in incidents which are destructive to life and property. To determine if our ammunition stocks are properly, safely, and securely stored and maintained, the Project Bullets Team reviewed storage in three geographic locations - Europe, the Pacific and CONUS.

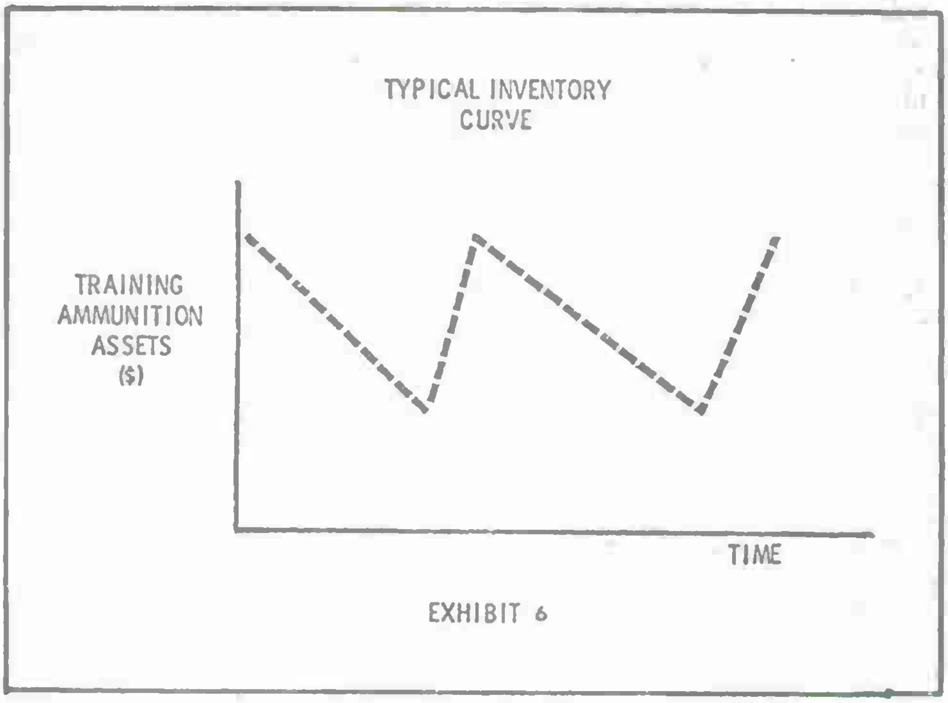

EXHIBIT 6

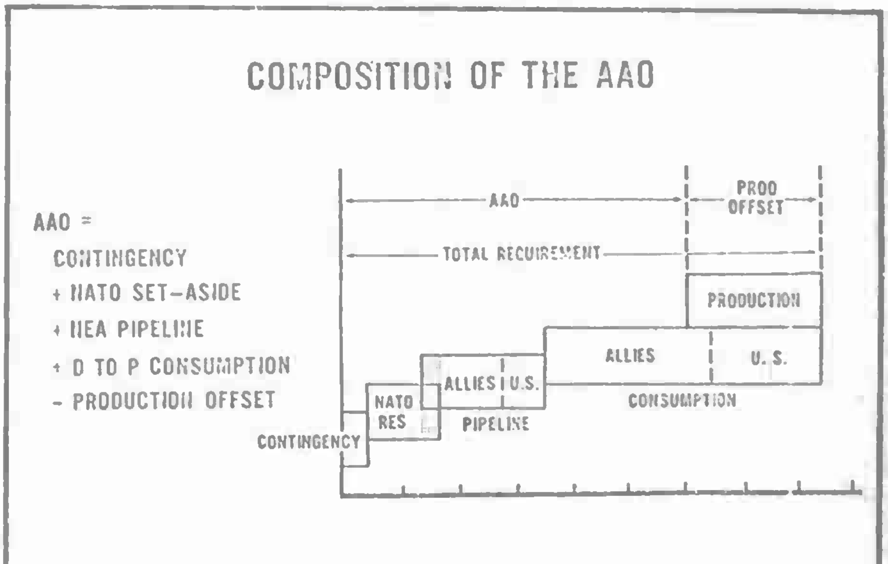

EXHIBIT 7

In early 1973 a team headed by VADM Eli Reich of the Office of the Assistant Secretary of Defense for Installation and Logistics (OASD(I&L)), visited representative U. S. Military ammunition storage sites in Europe. The report of the Reich group revealed significant weaknesses in the storage of stocks at U. S. Army facilities. An audit by the U. S. Army Audit Agency (USAAA) revealed other weaknesses. On site surveys by a member of the Project Bullets Team in late 1973 verified the magnitude of the corrective action required. U. S. Army Europe (USAREUR) has submitted a four phase program to correct the weaknesses. The phases each correspond to fiscal years. The first phase (FY 74) utilized Secretary of Defense authorized contingency funds. The subsequent three phases are included in the FY 75 appropriation and the 76-80 POM (76, 77 portions). A portion of the funds required is coming from NATO infrastructure. Another portion may come from Duetsch-Mark off-set funds but the bulk will come from the U.S. Appropriation. The funds required are divided between the Military Construction and Operations and Maintenance Appropriations. The program will correct weaknesses arising out of neglect during the Vietnam War when attention and resources were focused elsewhere. By the end of Phase IV USAREUR should be able to bed down its PWRR in reasonably adequate, safe, and secure facilities in the United Kingdom, Germany and Italy.

In late 1973 the Project Bullets Team was planning to participate with a Headquarters DA DCSLOG team to make a survey of Army ammunition storage facilities in the Pacific. As plans were being finalized it was learned that OASD(I&L) was preparing to form a team to look at representative storage sites of each of the services at about the same time. Upon consultation with the OASD(I&L) team chief, BG Louis Rachmeler, it was determined that the two surveys could and would be combined to cause the least inconvenience to the Pacific Commands. The Army element was composed of two groups to provide broader coverage in the time alloted and constituted half of the total team. Every major Army conventional ammunition storage site was visited by one or both of two Army survey groups. While weaknesses were discovered they were not of the magnitude of those in Europe. Independently, ODCSLOG was reviewing the requirement for PWRR and other stocks in the Pacific. As a result it appears that most of the weaknesses will be corrected by the reduction of stocks. A formal program to correct the remaining weaknesses has not yet been developed; however, self-help programs have been initiated. The Army Inspector General has made these weaknesses a matter of interest for inspections in the Pacific Area.

As yet no on-site surveys have been made in the CONUS by members of the Project Bullets Team. As a surrogate, we reviewed reports of visits and inspections in files of the DOD Explosive Safety Board (DDESB) and the HQDA Office of the Provost Marshal General (OPMG). Within the DDESB files we were looking for ammunition safety deficiencies which persisted over a period of years. Similarly within the OPMG files we were looking for uncorrected security deficiencies. Most of the munitions stocks in the CONUS are stored in AMC Depots. The review of the files indicated that these AMC depots are relatively free of safety and security deficiencies.

The few deficiencies discovered were brought to the attention of the AMC Chief of Staff. Other deficiencies were discovered at various installations under the command of Forces Command (FORSCOM) and TRADOC. Relatively small quantities of ammunition are stored at these installations. The results of our review were brought to the attention of appropriate HQDA Staff Agencies for followup action.

Demands

Simplistically, Demands are Requirements less Assets. In actuality it is not that simple. Basic to the understanding of Demands is an understanding of the Authorized Acquisition Objective (AAO). The AAO is depicted at Exhibit 7. It is composed of stocks required for a contingency, a NATO war and the pipeline required to support an Asian War. To these reserves must be added stocks which would be consumed in mobilization training and combat operation by US Forces and Allies in an Asian war between the day the war starts (D-Day) and that day when production from the ammunition production base equals consumption. This day is called P-Day. This gross requirement must be reduced by the amount of ammunition which would be produced between D and P days. The stocks required for a portion of the NATO war may be counted toward the Asian pipeline provided that those assets which are counted for both purposes are stored in the CONUS. Thus the AAO equals contingency stocks plus NATO stocks plus Asian pipeline stocks (minus authorized overlap) plus Asian D to P consumption minus Asian D to P production. The variable within the demand portion of the system is D to P time.

The Base. D to P time is a function of the readiness of the production facilities and workers; in the jargon of the production mobilization planners, the "temperature" of the base. A facility which is producing at maximum is "hot". One producing at some economic level below maximum is "warm". One which is out of production in layaway is "cold". Thus D to P is a function of the temperature of the base. Production planners would like never to buy out the AAO for then the base would go cold. There are in fact, two AAO's computed for each line item of ammunition; a warm base AAO and a cold base AAO. The cold base AAO must be larger than warm base because of the longer D to P which results from a "cold" start. On the other hand, it is more expensive to maintain a warm base than a cold one. The added expense must be offset against the cost of acquiring and maintaining a larger AAO for a cold base and the cost of heating the base when required.

Production Base. The production base being used now consists primarily of 18 Government Owned Contractor Operated (GOCO) plants. This base is largely left over from World War II. Much of it was reactivated for the Korean War and again for the Vietnam conflict. At the present time it is being used to rebuild our stocks which were depleted by Vietnam. The base, being old, is well worn and inefficient, it pollutes the environment and does not comply with the Occupational Health and Safety Act (OSHA). Additionally, many modern munitions cannot be manufactured using the existing base. Recognizing this the Army has developed a modernization and expansion plan - a plan to modernize existing facilities so that they are efficient, do not pollute and complies with the OSHA; and to expand the base to accommodate the manufacture of modern munitions and fill other production voids. The modernization and expansion plan will require about $6B and take until the mid 1990's to complete.

The Small Caliber Ammunition Production (SCAMP). This plan is a part of the modernization and expansion plan. Under this plan automated equipment will be acquired to replace existing facilities. SCAMP facilities will operate with a minimum of workers and provide attendant labor savings. This program is under review to insure that we do not acquire unwarranted excess capacity.

Alternate Fills. Analysis of explosive requirements and production capabilities indicate that it would be very expensive to modernize and expand to meet requirements for currently approved explosive fills. Approved fills are the most effective of those which meet military requirements for safety and storage. They are not necessarily the least expensive. Some alternatives are known which are slightly less effective (about 10%), meet military requirements for storage and safety and are cheaper. These are called approved alternatives. Still other alternatives are known which are about as effective as the approved alternatives, are much cheaper than preferred or approved alternatives but it is not yet known if shells and bombs filled with these alternatives meet military requirements for storage and safety. These matters are currently under study by the Army. The work is to be finished in mid 1975.

RESULTS TO DATE

The analysis of the Army Ammunitions System (Project Bullets) has been underway for over a year now. The Project Bullets Team has completed its review of Requirements and Assets and has monitored corrective actions for the VCSA. Monthly progress reports have been provided to key officials within the Office Chief of Staff from inception to date. Additionally, individual reviews and analyses have been furnished to interested staff agencies and commands. Complete progress reports have been provided to selected agencies responsible for or interested in selected portions of the ammunition system. Presently distribution is being made to those agencies shown at Exhibit 4. One of the results of Project Bullets was to focus high level Army management attention on ammunition problems. The Project Bullets Team cannot take full credit for this attention as VCSA and AVCSA awareness of ammunition problems resulted in the initiation of Project Bullets. The fact that the VCSA and AVCSA were concerned about ammunition problems focused attention of other Army managers on these problems.

Perception of the System

Distribution of the Progress Reports has resulted in those responsible for portions of the system having an awareness of how they fit into the total system. A briefing prepared at the direction of the AVCSA has been used to acquaint others with Project Bullets and the Ammunition System.

- Model Changes. As a result of increased knowledge about the system there have been changes in the system model. It has grown. Strengthening the system to overcome perceived weaknesses has also resulted in model changes. The latest version of the model is at Exhibit 5.

- Procedural Changes. Procedural changes have also resulted from efforts to strengthen the system. The revision of AR 11-11 is typical of these.

INTO THE FUTURE

The Project Bullets Team has not finished its job. Actions started by Project Bullets to strengthen the system must be followed to completion. More review and analyses are required in other areas. These apply especially to the center portion of the model-demands.

The Production Base. A considerable portion of our resources are being devoted to a review of the production base. The objective is, as always, to insure that the Army is getting the most for its investment dollar. During the course of this review we will look at several specific aspects of the base. We have seen that the temperature of the base affects the size of the AAO through the determination of D to P time. We will be looking for cost effective methods of reducing D to P time and a corresponding reduction in AAO.

We plan to look at the modernization and expansion plan to see if Army requirements are met. We will look at the Small Caliber Ammunition Program with the same objectives. We will also track the efforts to qualify additional munition explosive fills for use in munitions destined for indefinite storage.

Reducing Inventory Requirements. One way to reduce the AAO and storage requirements is to reduce the requirement for stocks to fill pipelines. Our analysis of the pipelines reveals that the transit times used are probably valid. Likewise transshipping times (time required to change mode of transportation and form convoys) are probably valid considering methods presently used. We are not sure that the transshipping methods are the best. We will examine alternative methods. The alternates may improve throughput times, reduce pipeline requirements and AAO. Among the alternates we plan to look at are containers and barges.

SUMMARY

Project Bullets was initiated within the Office of the Chief of Staff, Army in the Summer of 1973. The purpose of the project was to insure that the Army was getting the most for its ammunition dollars. The ammunition system has been modeled. Detailed reviews of portions of the system have been and are being conducted by the Project Bullets Team and Army agencies outside OCSA. The Project Bullets Team has sought to relate all these efforts to the ammunition system. As a result the Army ammunition system has been strengthened. Project Bullets will continue until all initiated actions are completed.

SCENARIO ORIENTED RECURRING EVALUATIONS "SCORES"

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US Army Logistics Center

Within the US Army Training and Doctrine Command (TRADOC), as many research activities as possible are related to scenario situation evaluations. The use of scenarios in accomplishing combat developments research is referred to as Scenario Oriented Recurring Evaluations (SCORES). The process uses a scenario as an integrating mechanism to incorporate appropriate expertise and reliable data to provide a flexible approach in evaluating force packages. The process focuses on capabilities and limitations of existing forces and evaluates the changes possible with the introduction of doctrinal, organizational and materiel improvements.

Within the US Army Training and Doctrine Command, three integrating centers are responsible for the combat development effort. They are the Combined Arms Center at Fort Leavenworth, Kansas; the Logistics Center at Fort Lee, Virginia; and the Administration Center at Fort Benjamin Harrison, Indiana. The Army service schools are assigned the mission of supporting the integrating centers in the accomplishment of the combat developments. For example, the Combat and Training Development Divisions within the Quartermaster, Ordnance, Missile & Munitions, and Transportation Schools assist the Logistics Center in developing logistics concepts, doctrine, materiel requirements, organization and ADP systems design. All doctrinal, organizational and materiel developments are evaluated in the SCORES Process.

The scenarios which will be used by TRADOC in SCORES will be designed to provide a variety of situations varying from large land-mass operations to actions in underdeveloped regions. TRADOC's current plans call for 7 scenarios for use in the SCORES Process.

Since TRADOC research activities are related to the SCORES Process, operations research analysts working at the integrating centers and schools become involved in scenario evaluations. Within the Logistics Center's evaluations of the Airborne D Package and the Middle East I (Light Corps) and Middle East II (Heavy Corps) evaluations, Logistics Center's ORSA personnel have contributed essentially in providing data and manipulating that data. For example, prior to the accomplishment of the D Package analysis, most scenario planning factors were found in FM 101-10-1 on a basis of pounds per man per day. That approach is satisfactory for Class I (subsistence) but it does not provide the sensitivities needed for ammunition, major end items and POL requirements. The Logistics Center Operations Analysis Directorate is, therefore, committed to developing more useful planning factors. I will describe their approaches in Class V (ammunition) and Class VII (major end items).

C/3-319 FA

CONSUMING WEAPONS

WEAPON	QTY	AVG DAILY CONSUMPTION S/T	× COMBAT POSTURE FACTOR	= LOGC DAILY CONSUMPTION S/T
1. HOWITZER LIGHT TOWED 105MM,M102	6	9.82	2.41	23.66
2. LAUNCHER GRENADE 40MM	3	.0011	2.00	.0022
3. MACHINE GUN, M60 7.62MM	6	.03	2.37	.07
4. PISTOL, CAL.45	1	.000	2.36	.000
5. RIFLE, M16A1 5.56MM	88	.004	2.50	.01
	104	9.8551	2.35	23.7422

Figure 1

Figure 1 illustrates an approach taken in computing ammunition requirements for an artillery battery. As shown the battery has 104 weapons which consume various types of ammunition. It is obvious that the Howitzers drive the tonnage problem. The Logistics Center data base provides the quantities of weapons and the average daily consumption in short tons. The average daily consumption factor in the Logistics Center's data base is obtained from supply bulletins. These factors are based on total monthly ammunition resupply requirements over extended periods of time. While these averages are adequate for planning total ammunition requirements for a theater of operations, they are not sensitive to the day to day changes in combat postures that take place in the brigade and lower levels. To provide for variations, the Logistics Center's research analysts developed a combat posture factor. The factor shown for the attack was developed by analysts using a variety of sources. FM 101-10-1 provided historical experience from World War II and the Korean conflict. The COLED-V studies on Vietnam provided consumption rates for that conflict. Other Department of the Army major study efforts such as the Army Logistic Support Concepts - Airlines of Communication (LOGALOC II) also addressed this problem. When the combat posture factor was applied to the average daily consumption, the tonnages shown in the last column provided a workload for which the capabilities of ammunition and transportation units could be evaluated.

EQUIPMENT LOSSES BY COMBAT POSTURE (PER SEQUENCE)

(DESTROYED/RECOVERABLE)

Item \ Posture	4 atk, 1st day	5 atk, suc days	9 def, suc days	12 pursuit
TANKS APCS, SHERIDANS	.06 / .12	.03 / .07	.02 / .06	.01 / .02
TOTAL LOSS:	.18	.10	.08	.03
TOWED ARTY (INCLUDING ANTI-AIR)	.06 / .05	.04 / .02	.03 / .03	.01 / .005
TOTAL LOSS:	.11	.06	.06	.015
SP ARTY (INCLUDING ANTI-AIR)	.04 / .06	.02 / .02	.02 / .03	.01 / .01
TOTAL LOSS:	.10	.04	.05	.02
OTHER CREW-SERVED WEAPONS	.06 / .03	.05 / .03	.05 / .03	.01 / .005
TOTAL LOSS:	.09	.08	.08	.015
WHEELED VEHICLES	.04 / .02	.02 / .02	.02 / .01	.001 / .001
TOTAL LOSS:	.06	.04	.03	.002
HELICOPTERS-				
OBS	.07 / .02	.05 / .02	.03 / .01	.04 / .01
ATK	.09 / .02	.06 / .02	.04 / .01	.05 / .01
UTL	.04 / .02	.03 / .01	.02 / .01	.02 / .01
CGO	.01 / .01	.01 / .01	.01 / .01	.01 / .01

Figure 2

The problem of providing losses of major end items required analysis by operations research personnel. Various studies underway including the Combined Arms Combat Developments Activity's war game of the SCORES scenarios and data obtained from the recent Middle East conflict contributed to the Logistics Center's methodology. Figure 2 provides a table of factors which can be used to provide equipment losses by combat posture. These factors are then applied to the equipment in a particular unit. Figure 3 shows the losses sustained by the 2d Battalion, 5th Armored, 1st Cavalry Division. The figure to the left of the slash refers to the quantity of each item in the left hand column that was destroyed during a particular sequence. The figure to the right refers to items which were damaged but considered recoverable. Together the figures represent the total combat losses of this particular unit for the entire ME-I scenario.

COMBAT LOSSES FOR 2-5 ARMOR
(DESTROYED/RECOVERABLE)

SEQUENCES	3	4	5			
EQUIPMENT / POSTURES	9	9	4	5	12	TOTALS
TANKS (54)	1/3	1/3	3/6	2/4	1/1	8/17
APCS (24)	0/1	0/1	1/3	1/2	0/0	2/7
VTRS (7)	0/0	0/0	0/1	0/0	0/0	0/1
MTR CARRIERS (4)	0/0	0/0	0/0	0/0	0/0	0/0
.50 CAL's (24)	1/1	1/1	1/1	1/1	0/0	4/4
WHEELS (96)	2/1	2/1	4/2	2/2	1/1	11/7

Figure 3

During the past year the Logistics Data Base has provided much of the basic data used to determine support requirements for the TRADOC scenarios. Several of the reports generated by the data base are very useful in the formats available; however, in many cases, they have only provided the raw data for manual requirements computations on the part of our LOGEX Directorate and the Logistics Center's associated schools. Our goal is to eliminate as much of this manual work as possible; and, eventually, do all the detailed requirements work on the computer. We have made some initial progress toward this end, including the development of a system we call SCALE.

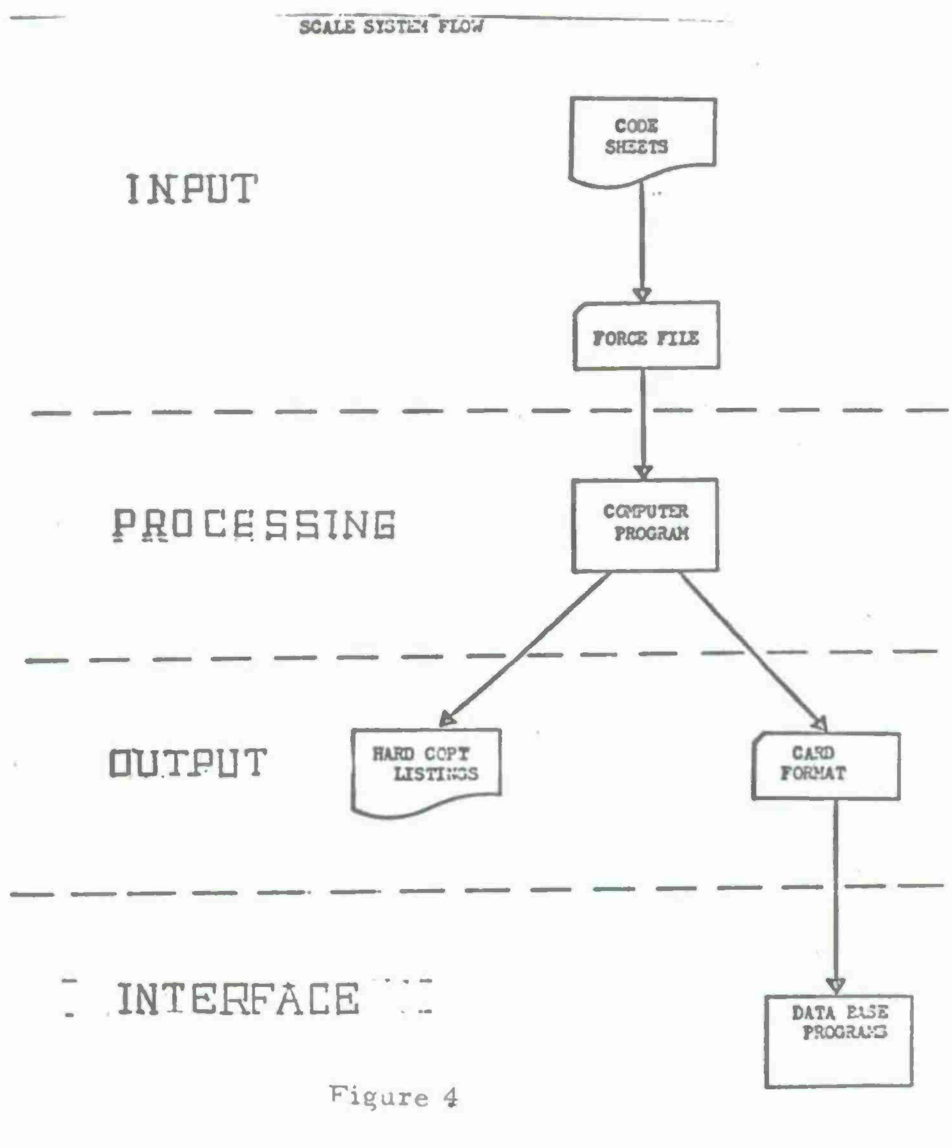

Figure 4

SCALE is an outgrowth of the trend to develop support requirements and evaluate capabilities in as much details as possible. We found there was considerable need for an automated method to sort-out or "arrange" the scenario forces in terms of types of units, and changing locations and combat postures for each day of the scenario.

Figure 4 illustrates the flow in the SCALE system. Input to the SCALE system is created by a prescribed method of recording each unit's activity during each day of the scenario, including unit location and combat posture. This information is converted into a card file which feeds a computer program that processes and arranges the data. There are several types of outputs, including card formats designed to interface with the Logistics Data Base Programs.

PARENT UNIT	UNIT IDENT	UNIT NAME OR DESIGNATION	TYPE STANDARD UNIT REQMT CODE	UNIT STRENGTH	PARENT STRENGTH	LEVELS 123CC
1	80000	1ST CAVALRY DIVISION	00			1
	20300	HHC 1CAV DIV	A 17004H00000	194		1
	222A0	HHT 1/9 CAV	A 17105H00000	191		1
	22200	A TRP 1/9 CAV	A 17107H00000	156		1
	223C0	B TRP 1/9 CAV	A 17107H00000	156		1
	22400	D TRP 1/9 CAV	A 17103H00000	136		1
			•		833	

Figure 5

Figure 5 illustrates an output troop list. This output is simply a program generated troop list, which provides a means of validating the input data and keeping up with any unit changes that may be made in the scenario.

DAY	AREA	S.R.C.	CBT POST	NUMBER UNITS	TYPE UNIT	UNIT NUMBER	UNIT NAME OR DESIGNATION	UNIT STRENGTH	LOAN INFO
8	5	09036G90000	I		C	15100	HHC 80TH ORD BN(AMMO DS/GS)	89	
8	5	09036G90000	I	1					
9	1	03500H2JA00	H		B	12500	14TH CML DET(CBR EL)	5	TO 11
9	1	03500H2JA00	H	1					
9	1	05510H2FB00	I		B	12800	89TH ENG DET(FFTG-FT) 20 ENG BDE	6	TO 11
					B	12900	90TH ENG DET(FFTG-FT) 20 ENG BDE	6	TO 11
9	1	05510H2FB00	I	2					

Figure 6

Figure 6 provides a force roster by area by day. This is one arrangement of output demonstrating the amount of detail possible from this system. The example is taken from ME-II, and shows for each day of the scenario the actual units located within each area, and their combat postures and strengths. The provision for identifying areas can be used to represent actual geographical areas; or, as in this example, arbitrarily designated areas. The Area 5 indicated here represents COSCOM units in ME-II, and the Area 1 represents the 1st Cav Division. The last column is a provision to identify attachments and detachments that occur in the theater. There are several other reports similar to this one; however, this is representative of the greatest detail.

The SCALE System was developed in-house by the Logistics Center and is operational on the CDC-6500 at Fort Leavenworth. The system was used on a limited basis with ME-II to feed the ammunition methodology and will also be used with the European scenario. One of the major features of this system is that it provides a means of permanently documenting the scenario. Once a scenario has been created, it can be maintained indefinitely for future refinement or application to a study or project. Although SCALE was developed primarily for our logistics efforts, it appears it may be useful in other areas of SCORES.

There are several other improvements in our data support capability that are planned.

(1) Automatic combat losses involves using the output of SCALE to produce actual major item combat losses - both destroyed and recoverable; for every day of the scenario, depending on the combat posture of each unit during that day. This builds on the methodology described previously.

(2) The second item involves modifying the data base problems to accept Unit Identification Codes rather than Standard Requirements Codes which is one of the limitations of our present capability.

(3) The third project is to develop the capability to compute discrete repair parts requirements for deploying forces. This will be important to the Logistics Center's repair parts efforts as well as SCORES. It will provide a basis for departing from pounds-per-man-per-day factors in Class IX.

(4) The last item is to fully automate the Logistics Center's ammunition methodology, which presently involves considerable manual effort.

The Utilization of a Simulation Tool in Logistics Planning and Evaluation

Mr. O. W. Roush

U.S. Army Logistics Evaluation Agency

1. Introduction.

a. The Simulation and Gaming Methods for the Analysis of Logistics (SIGMALOG) project was initiated some ten years ago by the DA DCSLOG to develop, test, and apply simulation tools and methodologies. Their use was intended for the study of Army logistics problems encountered in the support of strategic and tactical operations and for assisting the DCSLOG in the discharge of his missions to "review and validate logistics analyses by application of operations research, systems analysis, and economic analysis techniques" and to "evaluate the logistics portions of contingency plans."

b. Originally, the work was oriented to the analysis of logistics procedures in oversea theaters. Consequently, a group of computer-assisted, deterministic simulation models was contracted for, each capable of calculating requirements for a specific logistics function in a theater of operations. Examples of these time-phased requirements include certain combat service support units; prestock and resupply materiel by tonnages, line item numbers, and Department of Defense Ammunition Codes (DODAC); and intra- and intertheater transportation to move those computed requirements. These models and the methodology for their application to the analysis of theater logistics problems are the first phase of the system.

c. Subsequently, the DCSLOG initiated action to develop a means to assess the Army's capability to provide the required support. The resulting four modules, which form the second phase of the system, accomplish this objective.

d. In summary, SIGMALOG I assists analysts to determine detailed Army logistics requirements within functional areas of supply, transportation, medical/replacements, maintenance, and construction in support of contingency plans or Army studies. SIGMALOG II compares current and projected combat service support units, selected ammunition rounds and major items of equipment, and intertheater transportation assets with the previously computed requirements to indicate national capability to accommodate one, two, or three simultaneous operations.

e. The proponent and user of the SIGMALOG System is the U.S. Army Logistics Evaluation Agency (LEA), an organization responsible to the Directorate of Logistics Plans, Operations and Systems. This Directorate, in turn, is an element of the Office of the U.S. Army Deputy Chief of Staff for Logistics.

f. The system is programmed on an IBM 7094 computer at the New Cumberland Army Depot, Pennsylvania, and on a UNIVAC 1108 at the U.S. Army Research, Development and Acquisition Information Systems Agency, Radford, Virginia. The system models are run in an irregular sequence and vary from 10 minutes for the fastest to 200 minutes of central processor unit time for the slowest. The analyst team has varied from five to nine military/civilian members and is dependent upon computer programmer/operator and logistics technical liaison assistance in varying degrees. It is imperative that a hard core of trained and experienced civilian analysts be maintained to insure timely continuity and a quality product.

3. SIGMALOG I - Description. The components of SIGMALOG I are a set of data base programs and logistics-function simulating, computer-assisted models. See Figure 1.

a. Force Employment Data Automation (FEDA) Programs.

(1) These are a series of ADP programs developed to provide automatically certain portions of the large volumes of input data required by the Data Base Programs (DBP) and the Force Employment Model (FEM). The FEDA Programs reduce significantly the manual coding and verification processes required formerly. In addition, they provide the data more efficiently and timely.

(2) Army data source files used by the SIGMALOG System are maintained by various organizations in various formats. Selected data from these files must be extracted in specific formats. The theater time-phased force and deployment list (TPFDL) contains the A and B card records of the Joint Chiefs of Staff (JCS) Deployment Reporting (DEPREP) System, in addition to other type cards of DEPREP required for the particular application. The JCS Geo-Location File includes the geographical locations of all pertinent areas and destinations worldwide to which troop units can be assigned. This file provides the data for a location-theater region cross-reference table. The JCS TYPEA File provides a cross-reference source to transpose unit records from the unit type code (UTC) control to standard requirement code (SRC) control.

(3) The FEDA Programs produce as output three magnetic tape files and a series of hard-copy reports. Two files contain the FEDA troop list data regarding theater TPFDL unique units. Data Base Program (DBP) II processes these files to match the unique Table of Organization and

Equipment (TOE) units with authorized units as an authenticity verification. The third file contains FEDA troop unit deployment data and movement data for the tactical units. It is an input source for the Force Employment Model.

b. Data Base Programs (DBP) II, III, V, VI, VII.

(1) These routines accumulate information from three sources, reformat the data elements to provide compatibility with the processing procedures of the entire system, and copy the data on magnetic tapes. The restructured data serve as input to certain other models in the system.

(2) The FEDA-provided troop list is an initial source to the DBP. Among other Army automated files which serve as a second input source are the Computerized Movement Planning and Status System (COMPASS) File, the TOE Master File, and the DCSLOG Data Processing Center (DDPC) Unit Weight File. The third input source is card data provided by the analyst.

c. Force Employment Model (FEM).

(1) The FEM simulates the deployment and employment of theater military forces and the variable postures of combat and combat support forces. Produced from this simulation are certain related workloads, troop lists, and strength aggregations. These provide input to the subsequently-processed functional models.

(2) FEM programs require data from FEDA and DBP magnetic tape files and analyst-prepared cards. The tape files contain information defining characteristics of the troop units and their equipments. The analyst must provide, for the deployment and employment of troop units, certain policies such as specific time on position and location of employment. Also, routing rules must define theater arrival time and intratheater routing. Four different modes, or combinations of modes, of transportation are considered: air, surface, split air (personnel)/surface (equipment), and split air (personnel)/prepositioned equipment.

(3) Further, the model simulates activities of additional groups of personnel. Based upon analyst-defined parameters, computations are completed for quantities of indigenous or local-hire laborers, refugees collected and supported, prisoners of war (PWs) captured and confined, and indigenous laborers required to augment type B units.

(4) Output products are hard-copy reports and magnetic tape files. For analysis, the reports provide details relative to employment and intratheater movement of units,

various strength aggregations of unit personnel, PWs, indigenous laborers, refugees, etc Files for further processing in subsequent models contain these same data in appropriate format.

d. Medical/Replacements Model.

(1) The Medical routines compute workload imposed on a medical system while supporting theater military operations. Echelon workloads are presented in terms of hospital beds required and distribution of patients through evacuation, returned to duty, and death. Time-phased personnel replacements for all non-returned to duty, killed in action, and missing in action are required. Such quantities determine the impact of receipt, processing, and intratherater movement of personnel on the Materiel, Construction, and Transportation Models.

(2) Troop-strength information is received from a FEM tape file. Medical policies pertaining to hospitalization and evacuation and casualty-causation factors are card input by the analyst. Certain invariant data, such as hospitalization experience, are contained in program data banks. Output reports provide medical requirements in terms of fixed and non-fixed hospital beds. The Materiel Model calculates support for patients occupying beds and the Construction Model computes medical facility requirements by echelon.

(3) Regional time-phased replacements are generated by the Replacements routines. Gross values, i.e., sums of the wounded in action, disease and non-battle injured, killed in action, and missing in action, are reduced by returnees to duty. Resulting net replacement requirements are transported in from an out-of-theater source by the Transportation Model.

(4) Detailed and summary reports are produced for review and analysis. Magnetic tape files are prepared for processing by the Materiel, Construction, and Transportation Models, if required.

e. Materiel Model.

(1) This model quantifies selected operational aspects of a theater supply system. Requirements are in terms of receipt, storage, and shipment of materiel. Upon these materiel tonnages are based a significant portion of the intratheater transportation requirements and the facilities needed to store the supplies.

(2) Tape file input from FEM, modified by Medical/ Replacements values, contains troop strengths to be supported

in theater segment regions for appropriate time period intervals. Troop strength is classified by "user", a term denoting an aggregation of personnel who consume materiel at a common rate. Input card data define user consumption rates in pounds per man per day, theater resupply and stock-level policies, and requests for optional tape and hard-copy output reports. A 30 by 20 consumption factor matrix defines the user-consumption factor relationships upon which consumption, and therefore resupply, is based.

(3) A supply system is represented by a chain of nodes, signifying supply-handling activities or depots, at which specified levels of materiel are received, stored, and shipped. These sites are connected by links over which supplies in specific quantities are moved.

(4) The model presents the customer with the option of specifying prestock levels or of permitting the program to calculate required levels. Prestocks, or TR-1, are quantities of materiel stored within the theater. Their purpose is to sustain the forces, both those in-theater on D-Day and those arriving prior to a defined post-D-Day date, and include a safety level.

(5) The simulation of resupply begins with the consumption of materiel by users. Initially their demands are met from prescribed and basic loads of supply available at the unit level. Exhaustion of these quantities creates a demand for replenishment, which is met by pulling the proper amounts from the direct-support node. This replenishment action causes the node to examine its stock status, i.e., stock level, in relation to its computed stockage objective. The stockage objective is the computed stock level the node must attain by the next time period increment. If the stock level has fallen below the stockage objective, a replenishment action is generated. It is transmitted to the next supporting node in the chain which satisfies the demand, examines its own stock level in terms of its stockage objective, and so on through the defined system. The last node(s) in the theater chain pulls from the CONUS source to attain its required stock level.

(6) Materiel is considered in the model by supply class or subclass category. The 10 DOD-defined classes of supply may be examined in any combination of 20 categories.

(7) Resupply activities calculated at each node include the number of short tons by materiel received, stored, and shipped, by category and time period interval. Category quantities of materiel stored at a node provide the basis for storage facility construction requirements. Shipments of materiel over the resupply links account for major

transportation loads. In addition to hard-copy reports, the program records these values on tape files to be processed by other SIGMALOG models.

f. Transportation Model.

(1) This model computes requirements for Army transportation units and independent cargo carriers to receive, discharge, and move troop units, personnel replacements, and resupply materiel.

(2) The transportation analyst has, within this model, the capability to determine the location, time period of occurrence, and degree of deficiency of any line of communication (LOC) constraints. These LOCs may be defined as precisely as the customer desires within the analyst's resources. The model is capable of accomplishing movements over five transportation modes--pipeline, air, rail, highway, and inland waterway. In accomplishing movements, the model computes the actual number of transportation troop units required and reports any deficiencies in net capacities. This permits a comparison between customer estimates and model-calculated requirements.

g. Construction Model.

(1) The Construction Model computes engineer construction requirements, i.e., construction battalions and materiel, to support the study in question. The computations consider four categories of construction performed: construction of new facilities, conversion of previously constructed facilities, maintenance of LOC facilities, and repairing of facilities damaged by enemy action. The requirements for facilities are computed as functions of units in the theater, theater troop strength, materiel stockage, utility requirements, and LOC activity. The model also reflects the various degrees of refinement and services to which facilities may be provided using the Engineer Functional Component System (EFCS).

(2) The model computes gross theater facility requirements, reduces these by the existing usable facilities, and reports net or new construction requirements. War damage repair and LOC maintenance effort are functions of the existing and newly constructed facilities. Manhours of work in three categories--horizontal, vertical, and indigenous--and construction materiel requirements are calculated by region and time period. The number of required engineer construction units is dependent on manhours of work.

(3) Output of the model includes several mandatory and optional reports, as well as a tape file for input to the Transportation Model.

h. Maintenance Model.

(1) The model calculates maintenance required to support (a) divisions and separate brigades and (b) all other US Army units.

(2) The model program develops a file of maintenance requirements generated by type Army units as based on current equipment authorizations and maintenance data. Using the FEM's time-phased Unit Location File, it develops a master file of theater maintenance requirements by equipment category, military occupational speciality (MOS), region, and time period. The model then calculates requirements for direct support and general support maintenance units and compares these quantities with maintenance units contained on the TPFDL. The analyst may adjust the requirements to portray the activities of supported units and may assign a percentage of divisional direct support maintenance to non-divisional units.

(3) The model provides reports on the maintenance generated by each type unit and on total maintenance requirements for each region by time period. Additional reports indicate overages or shortages of maintenance units.

i. Major Item Resupply Model.

(1) Determined here is the time-phased major item resupply of selected line item numbers (LIN) of equipment for the deployed force, and the percentages of air and surface movement of these required assets to the theater. The customer may select computed or specified prestocks quantiities.

(2) Analyst-prepared data include parameters defining loss rates, stock levels, percent of air shipment rates, etc. Selected authorized LIN densities are calculated from data contained on DBP and FEM files. Applying loss rates to these data produce replacement requirements. Another routine computes prestock levels and time-phased stockage objectives. Resupply calculations relative to each internodal movement link and each nodal storage point are performed. End results are time-phased movements of LINs lost by the user, quantiities to be moved between nodes and to be stored at the nodes, and total quantities to be transported intertheater by air and by sea in order to maintain stock levels.

(3) The tape file output containing intertheater air-sea quantities of LINs for resupply serves as the source input to the SIGMALOG II Major Item Resources Module for comparison with available assets.

(j) Ammunition Resupply Model.

(1) A basis for determination of time-phased resupply requirements for selected items of ammunition, identified by DODAC, is available through this model. Calculations are dependent on weapon density, tactical activity, expenditure and loss rate data, and stockage levels.

(2) Analyst-prepared data include policies and factor modifications by weapon system subset and by user code. These factors are translated by the program to the DODAC associated with each subset and user code. Tape data from FEM files provide troop unit information and an equipment file from one of the DBPs provides LIN authorization per troop unit.

(3) Ammunition is considered in rounds by type, fuzes, charges, propellants, primers, grenades, etc. The model can accept known prestock quantities or can compute required D-Day levels. Options also exist to apply variable expenditure rates as a result of differing intensities of combat and loss rates for ammunition in transit and in storage.

(4) Compulsory and optional hard-copy reports show time-phased resupply requirements. A magnetic tape for input to the SIGMALOG II Ammunition Resources Module presents the requirements to be compared with CONUS assets.

4. SIGMALOG II - Description. The components of SIGMALOG II are four modules. Their function is to compare requirements written on certain SIGMALOG I files with assets enumerated on Army-maintained files.

a. Combat Service Support Units Resources Module. The module reports differences between time-phased combat service support unit requirements and available comparable units as reported on the U.S. Army Force Accounting System (FAS) Data Bank file. Surplus or shortage of each type of unit is listed. This module, as well as the other three, can accommodate concurrent requirements for one, two, or three theaters.

b. Major Item Resources Module. The purpose of this module is to compare time-phased resupply requirements for specified major end items, identified by LIN, with available and projected assets reported in the U.S. Army Logistics Data Bank. Reports indicate which item resources are adequate and those that require possible production acceleration.

c. Ammunition Resources Module. This module compares quantities of time-phased resupply requirements for specified

DODAC items with available assets reported on the Worldwide Ammunition Reporting System (WARS) file.

d. Intertheater Transportation Module.

(1) The purpose of this module is to determine the numbers of strategic airlift and sealift vehicles needed to satisfy the intertheater transportation requirements generated in a maximum three-operation exercise.

(2) A linear programming (LP) package is used to allocate airlift and sealift resources to minimize fleet sizes necessary to support specified movement requirements for the deployment of troops and materiel. Strategic vehicle asset quantities are obtained from the Joint Strategic Objectives Plan, the Joint Strategic Capabilities Plan, and Movement Capabilities studies.

5. Prior Applications. The SIGMALOG analyst team has been tasked by the DA DCSLOG to perform studies for both U.S. Army Pacific (USARPAC) and U.S. Army Europe (USAREUR) planners, as well as for his own staff.

a. An evaluation of the logistics portion of an operations plan, stipulating the defense of an Asian area, was performed in 1969-1970. All logistic functional areas were investigated during this exercise. An extension of this study led to a joint venture with the Engineer Strategic Studies Group (ESSG) of the U.S. Army Corps of Engineers. Selected SIGMALOG-generated data were employed by Engineer planners in preparation of the Base Development Annex to that particular operations plan.

b. In 1970, a request was initiated by USARPAC planners for assistance in evaluation of the logistics aspects of an operations plan in yet another Asian area. Particular emphasis on the analysis of the capability of the transportation network of that area was desired.

c. An evaluation of the logistics aspects of a major European plan was undertaken at the request of the USAREUR DCSLOG in 1971. USAREUR transportation action officers made use of data from this analysis to assist in contract negotiations with certain NATO nations.

(1) USAREUR planners next requested assistance in a study of alternative lines of communications. This study was also a vehicle to further another ESSG cooperative study. ESSG had developed a model to generate base development data and publish the reports in JCS-required format. This model, the Computer Assisted Simulation for Theater Level Engineering (CASTLE), was modified to accept automatically the more

sophisticated SIGMALOG I requirements in place of its own gross estimates.

(2) This exercise differed from past analyses in that it was not an evaluation of an existing plan but an application to assist theater planners in the preparation of logistics requirements for the plan.

d. A revised troop list and certain support policy changes resulted in an update study being conducted for USAREUR in 1973. Fixed-bed allocations on the latest troop list had been increased significantly in comparison with the prior troop list, and closely paralleled the build-up sequence and quantities generated in the previous SIGMALOG evaluation.

e. Most recently, a two-phased study was conducted by the SIGMALOG team to evaluate certain aspects of a new concept for LOC support during the early stages of a conflict in Europe.

(1) The first phase was based upon a DA DCSLOG request to determine the feasibility of the concept. SIGMALOG-generated logistic support requirements served as a critical source for a program change request presented to OSD by the Secretary of the Army.

(2) The second phase of this study was conducted at the request of the USAREUR DCSLOG. Logistics support requirements, incorporating the revised LOC support concept, were computed. Special emphasis was given to prepositioned theater supplies and to TPFDL combat service support unit changes.

6. Current and Projected Applications.

a. The philosophy of a centralized CONUS SIGMALOG capability versus a decentralized capability in major oversea theaters has been debated over the years. Before the present drastic USARPAC reorganization was initiated, planners in the theater had reached the point of verification that the SIGMALOG programs would compile with relative ease on a Honeywell 6060 computer, one on-site, prime, hardware candidate among several under consideration. USAREUR planners are presently conducting a feasibility study in that theater.

b. Representatives of Allied nations, especially the U.K. and Australia, have received extensive briefings on the system and have expressed interest in acquiring a working capability.

(1) In early 1973, SIGMALOG I was selected, from among several under consideration, as the logistics planning tool to be used by the combined United States/Republic of Korea Operational Planning Staff, United Nations Command. This logistics analysis procedure is the first of its kind in the Korean Army. Automated files, which Korean logisticians were required to build to define troop unit and equipment characteristics, are finding new and varied uses as their worth is realized. Not only are they proving invaluable to Korean logistics planners, but are also providing a source for interchange of commonly needed logistics data between U.S. and ROK planners in combined projects.

(2) LEA analysts have provided technical assistance to the combined staff at the request of CINCPAC and with the concurrence of the DA DCSLOG. This assistance has been in the form of technical documents and reference material, guidance and advice by telephone, training of U.S. officers prior to their departure for a Korean tour, and training of both U.S. and ROK personnel during several on-site liaison visits.

c. Investigations are in progress to effect more efficient procedures by linking the SIGMALOG System to other operating models, as with SIGMALOG-CASTLE.

(1) Working groups are investigating a connection between the Concepts Analysis Agency's force roundout model, Force Analysis Simulation of Theater Administrative and Logistic Support (FASTALS), and SIGMALOG. Numbers of logistics combat service support units on any troop list under study, based upon a less sophisticated FASTALS methodology, may be revised when computed on workload generated by the more refined SIGMALOG methodology. It is hypothesized that a laborious operation plan post-preparation evaluation might be precluded if the quantities evaluated were prepared by a methodology agreeable to both the DA DCSLOG and the theater DCSLOG, prior to submission of the plan for final approval.

(2) The SIGMALOG FEDA can accept automatically A and B cards from the JCS DEPREP System. This procedure, to be integrated into the Joint Operations Planning System (JOPS), requires logistics resupply input on the G card. An investigation is in progress to determine what data elements SIGMALOG might provide.

7. Conclusion. The SIGMALOG System is a tried and proven logistics simulation tool which is limited in its application only by the resourcefulness of its customer. The System forces logistics planners to think in logical, finite detail because this is the method by which they must describe their procedures to be simulated. By permitting

the System to accomplish the many complex and inter-related computations ordinarily performed manually or sometimes only estimated, it frees the analyst so that he may consider alternatives. The ultimate should be more economical and efficient logistics policies and systems, and more precise quantification of logistics requirements.

SUBJECT: Air Movement Planning System (AMPS)

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1. INTRODUCTION

a. The Army has recognized for quite some time that Army units have needed a better way to produce aircraft load plans for an air movement. During evaluation of the C-5 aircraft for Army use it was found that the method available at the unit level for finding individual aircraft loads was primarily a manual pencil and paper exercise. Eighty-three percent of the Army produced C-5 load plans were being rejected by Air Force load planners. The increased capability and complexity associated with this larger, more versatile aircraft amplified the Army's problem of planning for air movement and established a definite need for a responsive and accurate method for developing load plans and manifests.

b. This paper reports on the development of the Air Movement Planning System (AMPS) which was prompted by introduction of the C-5 aircraft and intended to reduce the problems of load planning at the unit level. AMPS is a computerized model for planning cargo loads for Air Force transport aircraft which includes the C-5, C-141, and C-130. It's purpose is to provide Army units having an air movement mission with an automated method of preparing effective load plans and manifests for aircraft of Military Airlift Command (MAC) and Tactical Air Command (TAC).

c. Earlier automation of aircraft load planning involved three systems:

(1) The Computerized Airlift Planning System (CAPS) was developed by the Continental Army Command (CONARC) as early as 1967. This system matched movement data against a file of manually prepared "type loads" and was centralized at CONARC headquarters. The input movement data was gross level information on Army equipment items. It served the purposes of gross planning requirements of the headquarters level, however, it was remote from the units providing the input data and did not serve detailed planning needs of those units.

(2) The Automated Air Movement System (AAMS) was developed by the XVIII Airborne Corps at Fort Bragg, North Carolina to provide them a manifesting capability. At the time XVIII Airborne Corps had most of the

air movement requirements in the Army and needed something that could prepare a manifest that would express what they were moving; and to do it at the time they were going to move. This required that it be realistic data and not standard or type (gross) data. This system, though it did not plan loads, rapidly produced manifests using pre-edited data on loads that had been manually assembled by Army and Air Force unit representatives.

(3) The Automated Load Planning System (ALPS) was developed by the Army C-5 Evaluation Group at Charleston AFB in 1972. This effort was undertaken to overcome the Army's inability to prepare acceptable load plans for the C-5 aircraft. Objectives for design of this system was to provide a means to plan a load as well as manifest it. Further, that it should not utilize type data but should use specific data describing the unit and specific data on aircraft for the move.

d. These systems were in various stages of development in 1973 at the time of the CONUS reorganization of the Army. Responsibility for all of them was assigned to the Logistics Center by the reorganization. The Logistics Center evaluation of the three systems led to decision to use the ALPS system as a base, incorporate desirable features of the others, and continue to develop a load planning system for Army unit use. The resultant system, AMPS, is addressed by this paper.

2. DESIGN OBJECTIVES

a. Some of the objectives considered in the design of AMPS are briefly discussed in the following paragraphs:

(1) Efficiency of aircraft utilization. The system is required to maximize aircraft utilization to reduce the cost of air transport; and to minimize the number of aircraft required to land the force in the objective area in the shortest time possible.

(2) Plan and manifest. The system should be capable of planning a load as well as preparing manifests. Planning must include optimum selection and placement of cargo items within the aircraft in order to achieve balance of the load in terms of Air Force requirements.

(3) Actual current data. Input data must represent cargo items exactly as they will be loaded. Standard or type data cannot be accepted since the system requires specific dimensions, weights, and center of gravity. The data must be accurate, thus it demands currency.

(4) Priorities. The system should have means of recognizing the unit commander's priorities for sequence of delivery of items to the objective area. Tied closely with priorities within unit is the matter of unit integrity and priorities between units. Unit integrity is important to each of the units and to the superior organization because of administrative problems, such as controlling and assembling units, and rapid move out from the destination airfield.

(5) Link related equipment and crews. The system must be capable of identifying related pieces of cargo and forcing them to be loaded as a unit. Drivers and crew members of the cargo items must be loaded onto the same aircraft as the item.

(6) Operation on CS_3 equipment. The system should be capable of operation on the type of equipment available under the CS_3 system (Combat Service Support System). The reason for this is that each Army division and corps will be provided with CS_3 equipment thus making it available to practically all potential AMPS users. This equipment is to be an IBM 360/30 at divisions and a 360/40 at corps. Each will have 256K core and a normal range of peripheral devices including disk storage.

(7) Restricted to air-land operation. Most of the units do not have air-drop requirements. Additionally, the logic applied for air-drop loading cannot be based on aircraft utilization as air-land operations are, but will vary drastically depending on the mission, size of drop zone, etc. For these reasons system design for the proposed standard multi-command use system excluded air-drop planning.

3. APPLICATION

a. To satisfy the above objectives the same logic that is used by the Air Force loadmaster and aircraft commander has been simulated in a computer program. The program is written in the COBOL programming language for the IBM 360 series equipment and is constructed with a root segment and seven overlayable segments requiring approximately 185K bytes of core memory for operation.

b. The program is concerned with use of data from two files; the cargo file and the aircraft file. The cargo file represents all items of cargo and passengers to be loaded, and the aircraft file contains the aircraft available for loading. Each of the files is constructed from input data provided in punch card form by the user and loaded onto disk files during the input phase. Also during this phase user-selected priorities and options are examined and program variables set for proper program control. Although the program has several options, the aircraft file is the basic controlling file. Having selected the "next available" aircraft from the aircraft file, the program then extracts from the cargo file items of the appropriate cargo class for the aircraft. Cargo class is assigned by the program during the input phase based upon examination of the dimensions entered on the input card. This extraction continues until the combined weight of the extracted items exceeds the Allowable Cargo Load (ACL) for the aircraft under consideration. With this list of potential items for loading, the program then branches to the appropriate routine to accomplish the positioning and balancing of items on the aircraft.

c. There are two positioning and balancing routines: one for the C-5 aircraft and a common one for both the C-141 and C-130 aircraft. These routines are very similar in logic with differences occurring basically because of differing aircraft characteristics and size. The program considers cargo items as rectangles for placement within the larger rectangle represented by the loading deck of the aircraft and employs a heuristic approach to position cargo items and balance the aircraft. Following the pyramid loading principle the routines start with the heaviest and widest item of cargo and load it either forward or aft of the planning center of gravity. As each item is loaded remaining space available is maintained by keeping track of how much of the aircraft width has been filled at each aircraft station number. Loading continues, alternating right and left, fore and aft, until a constraint of ACL or floor area is reached. At this point balance is tested and, if necessary, the entire load is shifted to as near optimum balance as constraints allow. If this fails to provide a load within balance limits, a new planning center of gravity is computed and another iteration begins. If several iterations fail to produce a balanced load with these cargo items, cargo items are reduced from the load and balance is attempted again.

d. When an acceptable balance is achieved, program control is transferred to the passenger loading routines. Passengers identified with cargo on the load are loaded first, and general passengers fill remaining space.

e. The entire process is reiterated until either the cargo or aircraft file is exhausted. When this occurs, contents of whichever file remains is printed, to indicate cargo not loaded or available aircraft not required.

4. INPUT

a. Input to establish the two required files is prepared and maintained by the unit. The cargo file contains information on personnel as well as cargo items.

(1) Personnel. The personnel data includes appropriate identification plus the priority, if any, assigned by the unit commander. When appropriate, personnel are linked to pieces of equipment by putting the bumper number of the equipment item in the personnel card. This assures that the person will be loaded on the same aircraft as the piece of equipment.

(2) Equipment. Cargo input includes identification that is useful to the unit; dimensions; weight; and center of gravity exactly as that piece of equipment is to be ready for loading. For example, a loaded truck must be described with dimensions, weight, and center of gravity computed with the load on the truck. Additionally, the input identifies the number of inches which can be reduced by telescoping a trailer under the prime mover or mating a semi-trailer to its' tractor. Related items of equipment are considered together in the same manner as personnel to assure loading on the same aircraft. Use of the same bumper number on related pieces causes the program to combine these items and consider loading as one item.

(3) Aircraft. The aircraft file input is constructed by the Army unit from information supplied by the Air Force. This input is flexible as to the environment for use of AMPS. If in a planning situation the specific detail on each aircraft is not known, however, the program is provided the types of aircraft, planned allowable cargo loads by type, and a ratio of types. For an actual operation specific numbers and actual allowable cargo loads for each type and model of aircraft are provided.

5. OUTPUT

a. Output of the system is a set of load plans and manifests which provide a diagram of the loaded aircraft; and cargo and personnel manifest data required by the Air Force. The schematic diagram (Fig 1) is a representative picture of the aircraft floor area with rectangular outlines for each item of cargo. Within each rectangle, assuming sufficient space, is an index reference to the manifest, brief identification of the item, weight, and fuselage station where the center of gravity of the item impacts the aircraft.

* * * * * * *   AMPS TEST, HUNTSVILLE - FEB 13,1974   * * * * * * * * *

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*******AIRCRAFT DATA***********DESTINATION****MISSION NUMBER******ALW WT******ALW CU******DEPART AFLD**********CHALK NO.******PAGE NO.*****
*** CARRIER*A/C NO.*A/C MOD  *              *                   *           *           *                    *              *          **
***   MAC  *04-9999*  C-5    *     NA       *    PROG TEST 01   *  187,000  *  383,984  *       NA           *        1     *     1    **
***************************************************************************************************************************************
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C-5   AIRCRAFT LOAD PLAN DIAGRAM (NOT TO SCALE). ALL CARGO LOADED FACING FWD

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FWD                                                                                                                       AFT
     517      648      779      910     1,040    1,171    1,302    1,433    1,564    1,695    1,826    1,957    2,088
      '        '        '        '        '        '        '        '        '        '        '        '        '
------------------------------------------------------------------------------------------------------------------------------
           ************************************************************************
           *      # 1           **          # 3               *             ************************************************
           *      CG   706      **       CG 1,001             *             *    *                                         *
           *TRK 2-1/2T M-35     **    TRK-TR WKR M543         *      # 5    *    *              # 8                        *
           *       WT 21,000    **        WT 34,340           *   CG 1,326  *    *            CG 1,705                     *
           *     B# 1-007       **      B# 1-014              * TRK-TR 10-T M26 *    STLR LOW BED                          *
           *                    **                            *   WT 42,000 *    *            WT 42,520                    *
           ****************************************************   B# 1-015  *    *         B# 1-015                        *
                      *********************                   *             *    *                                         *
                      *      # 2          ****************    *             *    *                                         *
                      *      CG   929     * *                 ***********************************************************
                      *TRK 2-1/2T M-35    * *                 *                         ***************************
                      *      WT 19,000    * *   # 4           *                         *# 6*# 7**# 9*#10*#11*#12*
                      *     B# 1-003      * *                 *                         *    *   **   *    *    *  *
                      *                   * *                 *                         ***************************
                      ******************************************
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C A R G O   M A N I F E S T

ITEM#	DESCRIPTION OF ITEM	BUMP#	UNIT	WEIGHT	CG FUS STA	MOMENT	FWD FUS STA	AREA	REMARKS
1	TRK 2-1/2T M-35	1-007	TEST001	21,000	706	14,826,000	566	187	
2	TRK 2-1/2T M-35	1-003	TEST001	19,000	929	17,651,000	795	187	
3	TRK-TR WKR M543	1-014	TEST001	34,340	1,001	34,374,340	851	237	
4	TLR 1-1/2T M-105	1-003	TEST001	3,100	1,124	3,484,400	1,034	95	
5	TRK-TR 10-T M26	1-015	TEST001	42,000	1,326	55,692,000	1,206	276	
6	PALLET 40X48		TEST001	2,000	1,641	3,282,000	1,617	13	
7	PALLET 40X48		TEST001	2,000	1,697	3,394,000	1,673	13	

Figure 1

AIR MOVEMENT PLANNING SYSTEM U.S.ARMY TRANSPORTATION SCHOOL, FORT EUSTIS, VA. DATE 07/03/74 TIME 10/46/34 PAGE 16

* * * * * * * AMPS TEST, HUNTSVILLE - FEB 13,1974 * * * * * * * *

AIRCRAFT DATA (CARRIER / A/C NO. / A/C MOD)	DESTINATION	MISSION NUMBER	ALW WT	ALW CU	DEPART AFLD	CHALK NO.	PAGE NO.
MAC / 04-99999 / C-5	NA	PROG TEST 01	187,000	383,984	NA	1	2

ITEM#	DESCRIPTION OF ITEM	BUMP#	UNIT	WEIGHT	CG FUS STA	MOMENT	FWD FUS STA	AREA	REMARKS
8	STLR LOW BED	1-015	TEST001	42,520	1,705	72,496,600	1,440	408	
9	PALLET 40X48		TEST001	2,000	1,753	3,506,000	1,729	13	
10	PALLET 40X48		TEST001	2,000	1,809	3,618,000	1,785	13	
11	PALLET 40X48		TEST001	2,000	1,865	3,730,000	1,841	13	
12	PALLET 40X48		TEST001	2,000	1,921	3,842,000	1,897	13	
	SUBTOTALS	CARGO	12	173,960	1,264	219,896,340			
	SUBTOTALS	PAX	35	6,850	1,741	11,925,850			
	T O T A L S			180,810	1,281	231,822,190			

LOAD PLANNED BY------------------------ AIR MOVEMENT PLANNING SYSTEM

DATE----------------------------------- 07/03/74

SIGNATURE OF LOADING AGENT-------------

DATE-----------------------------------

SIGNATURE OF UNLOADING AGENT-----------

DATE-----------------------------------

Figure 1

b. Following the schematic is a cargo manifest showing all the detail previously mentioned. If passengers were loaded on the aircraft the personnel manifest (Fig 2) will follow.

c. Summary statistics (Fig 3) are produced after each tenth load. These show number of loaded and remaining aircraft by type; percentage utilization of ACL and area used by type of aircraft; number of cargo items loaded and remaining; and number of passengers loaded and remaining.

d. Final output is a list of equipment items which were not loaded, or if the equipment file is emptied before the cargo file this would be a list of aircraft not used. This section is of particular importance for the unit since it represents to the planner a flag of potential problems. For example, from this list the planner can see what items cannot be moved within the allotted number of aircraft. With this knowledge he can assess the degradation of the mission if the equipment cannot be moved; consider alternative pieces of equipment for substitution which can be moved with available aircraft; consider means of partially dismantling larger items so as to fit within available aircraft; request Air Force to provide additional aircraft; etc. In the unlikely case of aircraft remaining, the planner may return the unused aircraft to Air Force or consider switch of surface moves to air transport.

6. CONCLUSION

It is believed that the AMPS system will produce load plans that will satisfy the Army units' requirements and in a way that will also stay within any restrictions that may be stated by the Air Force in respect to use of their aircraft. We are assured that the system will be available where needed because the hardware system that it is designed to operate on will be provided to each division and corps as part of the CS_3 system (Combat Service Support System). The various functions and options that are built in give adaptability and flexibility to respond to and accommodate any of the operational situations that may come up. This provides the Army unit planners with a simulation capability not previously available and allows for early load planning which provides an ability to identify problems and achieve solutions before actual movement time.

AIR MOVEMENT PLANNING SYSTEM U.S.ARMY TRANSPORTATION SCHOOL, FORT EUSTIS, VA. DATE 07/03/74 TIME 10/46/34 PAGE 17

* * * * * * * * AMPS TEST, HUNTSVILLE - FEB 13,1974 * * * * * * * * *

AIRCRAFT DATA			DESTINATION	MISSION NUMBER	ALW WT	ALW CU	DEPART AFLD	CHALK NO.	PAGE NO.
CARRIER	A/C NO.	A/C MOD							
MAC	04-9999	C-5	NA	PROG TEST 01	187,000	393,984	NA	1	3

P A S S E N G E R M A N I F E S T

LINE#	RANK	NAME	SSAN	WEIGHT	UNIT	BUMP#
1	RNK	PASSENGER 153	111 11 1111	200	TEST001	1-014
2	RNK	PASSENGER 65	111 11 1111	200	TEST001	1-014
3	RNK	PASSENGER 63	111 11 1111	200	TEST001	1-015
4	RNK	PASSENGER 275	111 11 1111	200	TEST001	1-015
5	RNK	PASSENGER 270	111 11 1111	200	TEST001	1-015
6	RNK	PASSENGER 11	111 11 1111	161	TEST001	1-015
7	RNK	PASSENGER 12	111 11 1111	162	TEST001	1-015
8	RNK	PASSENGER 13	111 11 1111	163	TEST001	1-015
9	RNK	PASSENGER 14	111 11 1111	164	TEST001	1-015
10	RNK	PASSENGER 132	111 11 1111	200	TEST001	1-003
11	RNK	PASSENGER 112	111 11 1111	200	TEST001	1-003
12	RNK	PASSENGER 58	111 11 1111	200	TEST001	1-007
13	RNK	PASSENGER 61	111 11 1111	200	TEST001	1-007
14	RNK	PASSENGER 321	111 11 1111	200	TEST001	
15	RNK	PASSENGER 320	111 11 1111	200	TEST001	
16	RNK	PASSENGER 318	111 11 1111	200	TEST001	
17	RNK	PASSENGER 317	111 11 1111	200	TEST001	
18	RNK	PASSENGER 316	111 11 1111	200	TEST001	
19	RNK	PASSENGER 213	111 11 1111	200	TEST001	
20	RNK	PASSENGER 212	111 11 1111	200	TEST001	
21	RNK	PASSENGER 211	111 11 1111	200	TEST001	
22	RNK	PASSENGER 315	111 11 1111	200	TEST001	
23	RNK	PASSENGER 216	111 11 1111	200	TEST001	
24	RNK	PASSENGER 215	111 11 1111	200	TEST001	
25	RNK	PASSENGER 214	111 11 1111	200	TEST001	
26	RNK	PASSENGER 306	111 11 1111	200	TEST001	
27	RNK	PASSENGER 229	111 11 1111	200	TEST001	
28	RNK	PASSENGER 228	111 11 1111	200	TEST001	
29	RNK	PASSENGER 280	111 11 1111	200	TEST001	
30	RNK	PASSENGER 311	111 11 1111	200	TEST001	
31	RNK	PASSENGER 310	111 11 1111	200	TEST001	
32	RNK	PASSENGER 309	111 11 1111	200	TEST001	
33	RNK	PASSENGER 235	111 11 1111	200	TEST001	
34	RNK	PASSENGER 222	111 11 1111	200	TEST001	
35	RNK	PASSENGER 231	111 11 1111	200	TEST001	
		T O T A L S		6950		

LOAD PLANNED BY------------------------------- AIR MOVEMENT PLANNING SYSTEM

DATE-- 07/03/74

SIGNATURE OF LOADING AGENT------------

DATE--------------------------------

SIGNATURE OF UNLOADING AGENT----------

DATE--------------------------------

Figure 2

```
AIR MOVEMENT PLANNING SYSTEM    U.S.ARMY TRANSPORTATION SCHOOL, FORT EUSTIS, VA.    DATE 07/03/74  TIME 12/00/52    PAGE    48
* * * * * * * *                 AMPS TEST, HUNTSVILLE - FEB 13,1974                                         * * * * * * * * * *

$$OPTION VAL,SOP,LIS,NODEC,PLA,MAT,TEL,NORES,PRI,INT,NOGEN,COP= 1,LNC=55

*********************************************************
*********************************************************
*********************************************************
*********************************************************
*********************************************************
**********                                     **********
**********      S T A T I S T I C S            **********
**********                                     **********
*********************************************************
**********TYPE A/C---NOT LOADED---LOADED       **********
**********-----C-5---          0         0     **********
**********---C-141--          25         7     **********
**********---C-130--           7         3     **********
*********************************************************
**********UTILIZATION---WEIGHT------AREA       **********
**********-----C-5---          0         0     **********
**********---C-141--          48         0     **********
**********---C-130--          70         0     **********
*********************************************************
**********--CARGO----NOT LOADED---LOADED       **********
**********-STANDARD-          34        24     **********
**********--OUTSIZE-          14        40     **********
**********PASSENGERS         141       267     **********
*********************************************************
*********************************************************
*********************************************************
*********************************************************
*********************************************************
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Figure 3

A METHODOLOGY FOR DEVELOPING ALTERNATIVE CONSOLIDATION AND CONTAINERIZATION POINT LOADING POLICIES

Mr. John A. Scanga

General Research Corporation

BACKGROUND

The Direct Support System (DSS) was developed by the Army for the purpose of reducing supply response time to customer direct support units (DSUs). This objective was to be accomplished by supplying the DSUs direct from the Continental United States (CONUS) sources thereby reducing inventories in the traditional oversea storage depots. Reduced inventories in these depots result in a distribution structure more akin to a direct origin-to-destination system.

In relying on direct supply support from CONUS, advantage can be taken of advances in shipping technology, namely utilization of cargo containers and faster ships that reduce handling and shipping times. Two consolidation and containerization points (CCPs) were established in CONUS as part of the DSS system. The CCPs were established to function as materiel accumulation centers and perform container loading operations. One CCP was established on the East Coast at the New Cumberland Army Depot, New Cumberland, Pa., to serve the U.S. Army, Europe (USAREUR) and the other at Sharpe Army Depot, Lathrop, California for Pacific customers.

PROBLEM

There are three principal functional requirements for CCP operations which reduce transportation costs and average response time.

1. Minimize the number of consignees in each container.
2. Maximize the amount of cargo in each container.
3. Minimize the time cargo is held at the CCP for consolidation and loading.

Operational experience established that a lack of sufficient cargo volume for the average consignee makes it impossible to meet all three objectives.

As a result, the question arose: "Could an optimum CCP operational policy be determined that would satisfy DSS operational requirements?" The low volume of cargo for many customers necessitates loading more than one consignee in most containers. It is clear that a geographical re-grouping of consignees would expedite container routing in the theater. GRC was requested to investigate both CC loading policy and cluster arrangements.

A computerized Simulation Model for Loading (SIMLOAD) was developed to systematically examine the relationship among loading factors, using as a criteria the number of containers loaded under alternative policies, such as: CCP hold times, the number of different consignee loadings per container, and the effect of alternative cluster arrangements.

APPROACH

The approach used to analyze CCP operational data and DSS system parameters included the following steps:

1. The CCP facility and operations were visited on repeated occasions to gather information for development of the model.
2. The types of data available, mechanized and manual, were also analyzed in order to establish actual CCP operational characteristics to be simulated.
3. The requirements of the CCP operation and the data which represented its performance were used in developing a computerized model of the system.
4. Results were organized into suitable presentations and compared to actual operations as a validity check of the modeling effort.
5. Alternative policies were simulated to analyze their impact on the loading plans.

MODEL DESCRIPTION

The model (SIMLOAD) is a constrained simulation model that evaluates alternative loading policies and distribution plans for customer delivery. The model correlates the variables; priority, consignee, hold time, and cluster groupings to optimize loading factors using historical CCP shipment data as input. The model is capable of handling up to ten consignees simultaneously and any combination of one through ten maximum hold times.

The input data required are:

1. Maximum number of consignees per van and pallet
2. Maximum hold time employed for pallets and vans
3. CCP volume data by day by DSU/droppoint
4. DSU identification codes by cluster or droppoint
5. Loading policy by pallet type and van size
6. Priority of materiel designator for loading pallets and vans (if priority II materiel is split between the two containers).

The initial version of the model described in General Research Corporation's (GRC) report number OAD-CR-29* was developed to simulate the East Coast CCP. At the time the model was developed, the supply of all van

* General Research Corporation, "A Methodology for Developing Alternative Consolidation and Containerization Point Loading Policies" J. Scanga, February 1974.

sizes was more than adequate. As a result the model was developed to load vans in the folliwing sequence; 40 foot vans if sufficient materiel was available, if insufficient materiel was available, the model attempted to load a 35 foot van, and if less than half of a 35 foot van was available the materiel was loaded into a 20 foot van. An unexpected shortage of vans on the East Coast and incorporation of West Coast CCP data into the program dictated changes to the model. The model has been revised to randomly select a van for loading based on the percentage of 20, 35 and 40 foot vans loaded at each CCP. The model is being expanded by the Logistics Control Office, the Army's custodian of the model, to accept variations in time-to-scheduled sailings. Other DSS study results show that vans are held at the POE waiting for ship sailings. It is obvious that by holding the van at the CCP instead of the POE will result in CCP improved loading performance. The model correlated scheduled ship sailing date with CCP hold times to estimate its effect on van loading performance.

SOMLOAD accumulates daily CCP receipts by priority for each DSU. The model attempts to ship to one consignee. Ships direct to any consignee if established criteria are met. If a maximum is not available within the allowable hold time, other consignees (not to exceed the established maximum) as specified are used to round out the load. The model is programmed to insure that materiel at the maximum allowable hold time is shipped regardless of container loading factor.

Results of the comuptation are expressed on computer listings as 10 x 10 matrices. The hold time in days is on the veritcal axis.

The number of consignees are on the horizontal. This allows the manager to compare a 1-day hold time, 1 consignee loading criteria with 99 other criteria from 1 day hold time, 2 consignees through a 10 day hold time, 10 consignee load policy.

The output matrices are:

1. Total number of pallets and vans loaded.
2. Number of vans not economical (< 50 percent loaded).
3. Average number of days per pallets and vans (CCP hold time).
4. Average number of consignees (either DSU or droppoints) per pallets and vans.
5. Average cube per pallet and van.
6. Number of pallets and vans that were shipped direct to the consignee.

INPUT DATA

Historical CCP receipt and shipment data were obtained from the CCP at New Cumberland, in the form of magnetic tape. The computer tapes were processed through a series of programs that copy, remove labels and headers, select DSS/DSU records within specified restraints, summarize DSU receipt volume, and unite output records on magnetic tape. The resultant output is a data record, by DSU, by priority, containing volume of materiel received at the CCP by day for a given time period.

A basic input to the simulation model is the physical characteristics of the various containers used by the CCP. SEAVAN and pallet capacities are depicted in Table 1.

SEAVAN containers used in surface shipments are available in three sizes, 20,35 and 40ft length models, (the other dimensions are a standard 8 x 8ft). Commercial usage dictates the use of 50 percent capacity as a minimum loading criterion. On a profit-loss basis, a 50 percent load is usually considered the break-even point.

Optimum loading refers to the volume estimated to be loaded under good loading conditions, usually considered to be 80 percent capacity. Maximum loading is the volume of the container that can be packed under ideal conditions.

Two types of pallets are used for air shipment the 463L and the mini pallet. The 463L pallet is a metal frame type platform with restraining straps to tie down the cargo. The 463L measures 88 x 108 inches, while the mini pallet is 40 x 48 inches.

Another input requirement is the assignment of DSUs to cluster groups. Clusters are used to geographically group consignees to facilitate economical loads and to minimize transport requirements. An illustration of a cluster is shown in Fig. 1 and represents the 1972-1973 arrangement of units in USAREUR. The configuration of a cluster determines the consignees assigned to specific containers for eventual distribution. However, it should be noted that cluster configuration is not the sole determinant of consignee assignment. If a sufficient volume of materiel for one consignee is available for loading within the hold time restraint ther would be only one consignee. When, as is the usual case, multiple consignees are required for minimum loading, the consignees designated must belong to the same cluster. The clustering shown in Fig. 1 aggregates all DSUs within a cluster into one droppoint which is a centrally located DSU that accepts all cargo for these DSUs within the cluster.

PREPARING DATA FOR INPUT TO MODEL

Output of the Droppoint Program (DROPPT) is used as an input to the model. Figure 2 is a schematic of DROPPT processing. This FORTRAN program assigns DSUs to a cluster and forms volume records by priority to their assigned drop location. A computer card deck containing DSU's AK (for USAREUR) numbers is used as a finder's deck in assigning the DSUs to a cluster. Every change in cluster partioning requires a manual rearrangement of this data deck.

The processed CCP volume data records are compared on DSU identification code to that of the finder's deck. When a match occurs, the DSU's data record is assigned it's cluster identification and the DSU volume data is summed into its assigned droppoint.

Table 1

CCP CONTAINER LOADING SPECIFICATIONS

Container	External cube (cu ft)	Minimum	Optimum	Maximum
463L pallet		250	300	335
Mini pallet		--[a]	--[a]	50
20-ft SEAVAN	1,280	500	800	1,000
35-ft SEAVAN	2,240	1,000	1,600	2,000
40-ft SEAVAN	2,560	1,100	1,800	2,300

[a]Because mini pallet loading is restricted to one delivery, minimum and optimum capacities are not applicable.

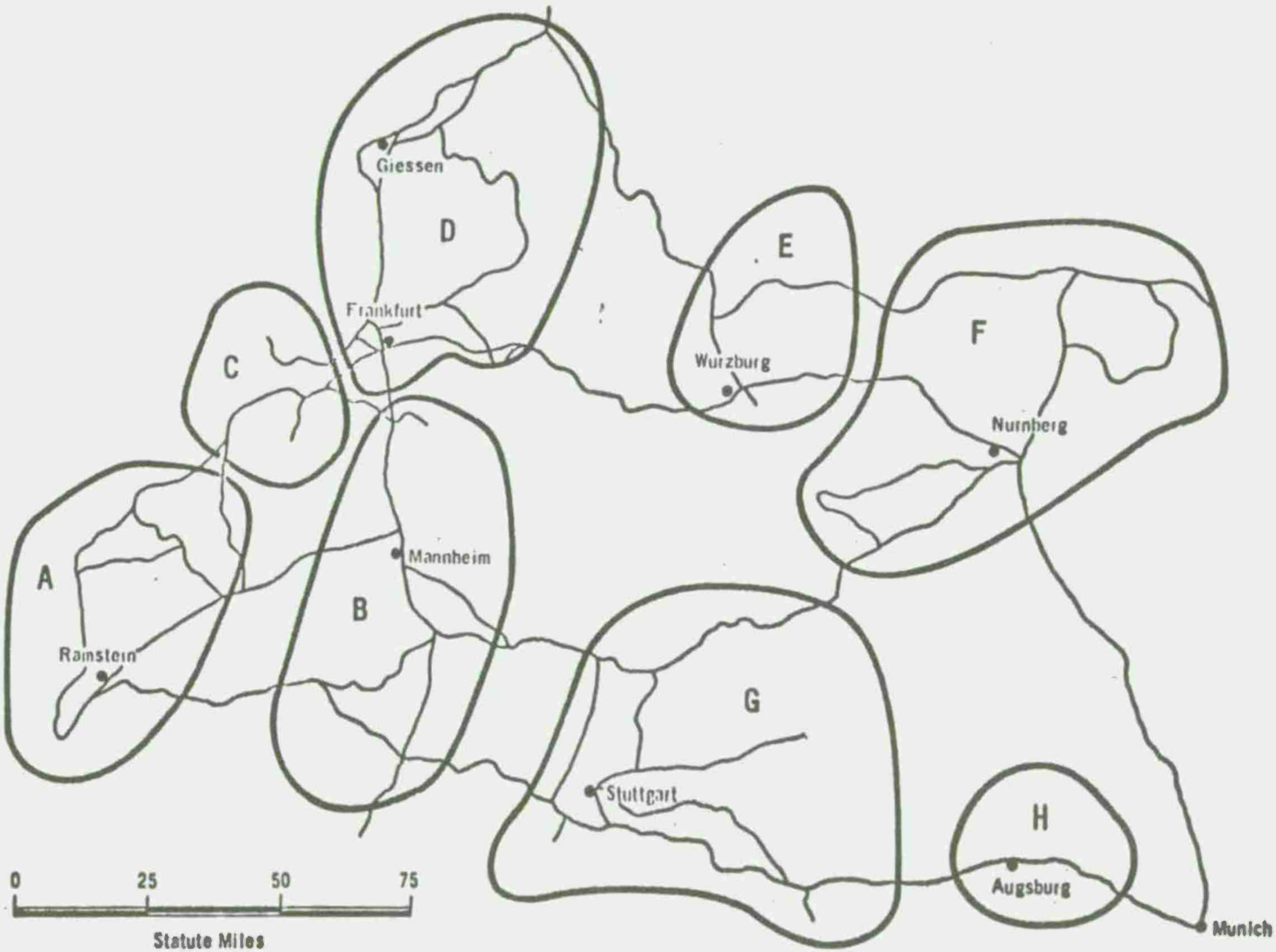

Fig. 1— USAREUR proposed Clustering of DSUs

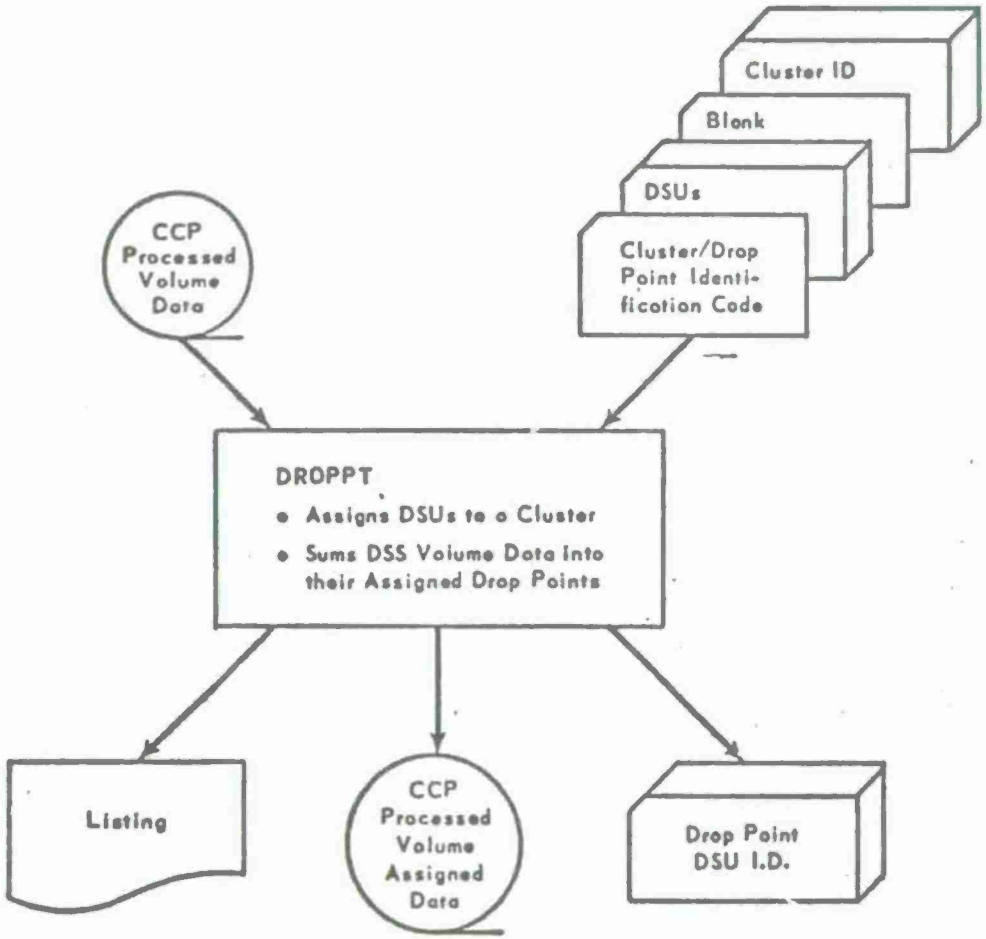

Fig. 2— Schematic of DROPPT Processing

The output is in the form of a computer listing, card deck and magnetic tape.

RESULTS

Two sets of results are provided the DSS manager. The first set deals with the volume of materiel to be shipped each consignee, i.e., DSU, cluster or droppoint. The second set are results of SIMLOAD operation and describe CCP performance for specified criteria. The former results are utilized by the manager to group DSUs into clusters and/or droppoints in order to prepare multiple inputs to SIMLOAD for comparison. SIMLOAD is not designed to give the absolute optimum loading policy but is intended to present the logistics manager with relative measures of loading effectiveness within the constraints under which the model operates.

VOLUME ANALYSIS

CCP receipt data were analyzed in terms of volume received and DSU/cluster destination. Table 2 presents the volume of cargo shipped during two 60-day periods. Note that 45 of the 111 units in the sample received less than 500 cu ft of materiel during the first period. The number of units consigned less than 500 cu ft dropped to 38 in the second period. The CCP in the first period received less than one full 35ft van load of materiel (2000 cu ft) for 63 of the 111 consignees in the sample. There were also 63 consignees with less than 2000 cu ft during the second period. Only 7 consignees had over 10,000 cu ft of cargo at the CCP during the first period. Although this increased to 11 consignees in the second period it still represents less than 10 percent of the total number of consignees. It is obvious from an examination of these data that on a "per unit" basis the volume of cargo is too small to warrant single consignee shipments.

Using the same data as above, Table 3 list the volume by cluster (proposed by USAREUR in 1973). The table reveals that the volume of materiel received at the CCP varied significantly from a low of 6,622 cu ft for cluster "C" to a high of 74, 317 cu ft for cluster "D."

Other analyses were performed to investigate alternative approaches to alleviating the problem caused by low volume customer. One approach satellited low volume units on the parent DSU. For example, the lettered companies of the 703rd Maint Bn (DS) were satellited on the Hqs & A Co. Each lettered company would be required to pick up its materiel at the main DSU (Hqs & A Co). The remaining customers (7 depots, 5 stock record accounts) (SRAs) and 5 Engineer repaired utilities (R & Us) were consolidated into three groups. Combining consignees in the latter manner resulted in satelliting 40 low volume accounts (less the 250 cu ft/mo) on larger customers.

An analysis of combined data was perofrmed to estimate the percentage of materiel in each group. Results depicted in Table 4 indicate that divisions, Maint Bns, and Supply and Services Bns accounted for equal volume of materiel received at the CCP during the 120-day period. These units accounted for 67.5 percent of the volume. Approximately half of the remaining 32.5 percent was for the SRAs. Twenty low volume customers that were not satellited on larger customers, accounted for 5.7 percent of the total.

Table 2

DISTRIBUTION OF ALL MATERIEL
RECEIVED AT NEW CUMBERLAND CCP

(By Volume and Number of Consignees)

Volume received cu ft	Number of consignees	
	Oct-Nov 72	Dec 72-Jan 73
0 - 500	45	38
501 - 1,000	5	10
1,001 - 2,000	13	15
2,001 - 3,000	13	10
3,001 - 4,000	6	5
4,001 - 5,000	6	5
5,001 - 6,000	5	4
6,001 - 7,000	4	5
7,001 - 8,000	3	2
8,001 - 9,000	2	5
9,001 - 10,000	2	1
>10,000	7	11
Total	111	111

Table 3

VOLUME OF MATERIEL RECEIVED
AT NEW CUMBERLAND CCP

Cluster	Volume, cu ft	
	First 60 days	Second 60 days
A	72,307	69,070
B	28,369	46,050
C	6,622	9,047
D	69,080	74,317
E	21,364	23,174
F	54,384	66,056
G	55,314	53,484
H	13,315	23,002

Table 4

VOLUME OF MATERIEL PROCESSED
BY NEW CUMBERLAND CCP

Group	Total cu ft	Percent
Division	170,083	23.3
Maint Bn	169,223	22.5
S&S Bn	162,909	21.7
Area Shops (7 SRAs)	119,353	15.9
Marom Depots (5 SRAs)	68,746	9.2
Engineer R&Vs (5 SRAs)	12,504	1.7
Unsatellited (20 SRAs)	42,943	5.7

SIMULATION RESULTS

INTRODUCTION

Because containers differ in capacity and usage, analyses of loading policies and allied subjects are organized into van and pallet configurations. The vans are associated with surface movement (sea), and the pallets with air shipment. Within the broad categories of vans and pallets, questions arise that must be answered. These questions are discussed in detail in subsequent poritons of the document, e.g., average cu ft per container, holding days, number of consignees, and cluster analyses. Although many simulations were performed during the study, only sample results will be presented.

Assumptions

It was assumed in the SIMLOAD runs that the CCP has sufficient pallets, vans, and personnel available to meet the optimum 1 day hold, 1 consignee load policy. An unlimited availability of aircraft at the airport of embarkation (APOE) and ships at the port of embarkation (POE) is also assumed. Discussions with AMC personnel confirmed that these were valid assumptions for the East Coast. However, ship sailing dates on the Pacific coast vary considerably, requiring a revision to the model to accommodate these variations. The availability of aircraft and ships could have an adverse impact on CCP operations. If one assumes a ship from the West Coast to Korea every 8 days; with the CCP hold criterion set at 3 days, this would result in a situation where uneconomically loaded vans would wait at the POE for as long as 8 days before shipment, if the van arrives just after a ship has sailed. If CCP loading times are coordinated with ship sailing schedules, holding the vans at the CCP for additional cargo can increase the space utilization without increasing overall order shipping time.

Results

SIMLOAD results are presented in the form of a 10 x 10 matrix which yields 100 solutions for each of 6 parameters (total number loaded, number uneconomical, number direct ship, average days hold, average number of consignee, and average cu ft). Model runs produce the above results for 20,35, and 40 ft vans, the three types combined and 463L, mini and combined pallets.

Tables 5 and 6 are examples of SIMLOAD outputs for vans and show total number of vans loaded and the number uneconomical. More detailed information can be obtained in the GRC report previously referenced.

Using Table 5 as a guide the number of consignees are read across the top and number of days vertically. For example, a loading criteria of 1 day hold and 1 consignee per van would result in the shipment of 3,345 vans. A look at Table 5 for the same criteria shows that 32,208 of the 3,345 vans shipped would be considered uneconomically loaded (less than 50% full).

Table 5

20, 35 AND 40 FOOT VANS
Total Number of Vans

No. of Days	1	2	3	Number of Units 4	5	6	7	8	9	10
1	3345	1809	1299	1026	885	778	723	685	659	625
2	2015	1074	756	599	519	450	411	395	377	362
3	1516	806	571	445	389	345	324	296	287	280
4	1186	613	452	355	315	281	256	245	243	229
5	1032	523	383	310	273	249	230	221	219	216
6	927	471	349	283	252	232	218	210	207	203
7	832	414	307	247	227	211	208	197	202	197
8	756	364	277	234	216	207	102	197	297	193
9	700	336	265	225	203	206	195	197	196	192
10	670	319	256	216	201	200	195	196	195	191

Table 6

20, 35 AND 40 FOOT VANS
Vans not Economical

No. of Days	1	2	3	Number of Units 4	5	6	7	8	9	10
1	3228	1660	1120	819	658	531	470	426	392	362
2	1839	864	505	334	247	181	136	128	113	103
3	1310	571	312	184	125	79	62	53	52	43
4	947	364	185	110	63	39	24	18	21	16
5	770	277	132	70	36	24	18	15	13	11
6	653	223	102	47	26	15	8	6	8	5
7	531	171	65	28	11	4	4	2	2	2
8	441	128	46	14	7	7	1	1	1	1
9	369	105	34	15	6	4	2	2	2	2
10	332	90	36	10	5	3	2	2	2	2

The loading criteria currently employed is 6 days hold with a maximum of 4 consignees per van. Referring to Table 4, a 4-6 loading criteria produces 75 vans all of which are economical (from Table 5).

A comparison of three loading criteria for the six parameters for all vans is shown in Table 7.

Table 7 shows that a 1- day hold time combined with a maximum consignee level of three would result in shipping 1,299 vans over a 120-day period. Of this number 1,120 would be uneconomical. Comparing the 3-5 and 4-6 criteria we see that there is little difference in the average number of days materiel is held at the CCP 4.5 to 4.9. This combined with the 2.8 vs 3.7 consignees per van and other factors (fewer vans, fewer uneconomical, and greater volume) makes the 4-6 loading criteria the better one to apply to the East Coast CCP.

Another analysis can be performed by comparing results of model runs for various cluster arrangements. Table 8 presents results of several model runs of two loading criteria for each of seven cluster arrangements. The data cover a 60-day period. Priority 2 materiel was used to top off pallets whenever appropriate. At the time of this analysis all Priority 1 materiel was required to be shipped using a 1-day hold time and a maximum of 4 consignees per pallet.

The cluster grouping shown in the table include: (1) the routes in existence, (2) groupings as proposed by USAREUR, (3) current routes with one droppoint per route, (4) consolidated division Maintenance and S&S units with the other DSUs served individually, (5) same as (4) with DSUs served through 8 Droppoints, (6) consolidating MATCOM depots and SRAs, balance as in (4), and (7) same as (6) except the 20 miscellaneous DSUs are served by Air.

Based on the information in Table 8, item 3, (current cluster, utilizing the droppoint method) would provide the most effective approach. Although fewer vans would be required in item 7, a significant increase in the number of air pallets shipped is required. Note however, that utilization of the droppoint method of delivery places the task of delivering to the customer on USAREUR's transportation system.

This analysis in itself, does not solve the DSS distribution problem but it does provide the DSS manager with the necessary visibility so that he can make a more intelligent decision regarding DSS clustering and CCP loading policy.

COMMENTS

1. SIMLOAD provides the Army with an inexpensive and rapid method for estimating the effect of loading policies in CCP performance.

Table 7

COMPARISON OF THREE LOADING LOADING CRITERIA
FOR VANS FOR ONE SIMULATION RUN

	Loading Criteria		
Parameter	1 day hold 3 Consignees	3 day hold 5 Consignees	4 day hold 6 Consignees
Total Number of Vans	1299	383	283
Number Uneconomical	1120	312	47
Average Number of Consignees	2.6	2.8	3.7
Average Number days hold	1.0	4.5	4.9
Average Volume (Cu ft)	262	595	1167
Number Direct Ship	207	41	24

Table 8

DSS USAREUR
ALTERNATIVE DELIVERY SCHEMES
(60 DAYS DATA BASE)

	VANS (6 Days Hold-4 Consign.)			PALLETS (1 Day Hold-4 Consign.)		
	No.	No. Un-Econ	No. Direct	No.	No. Un. Econ.	No. Direct
Current Routes (8) by DSU	336	43	18	452	318	52
USAREUR's New Clusters (8 Drop Points)	328	51	24	260	17	130
Current Clusters (8)- 8 Drop Points	276	0	153	257	13	129
Consolidate Units-Other DSUs Served Individually	315	13	46	395	211	82
Consolidate Units-8 Drop Points for Other DSUs	296	0	54	338	141	50
Consolidate Units, MATCOM Depots and SRAs-Other DSUs Served Indv.	306	11	59	375	184	88
Consolidate Units, MATCOM Depots and SRAs-Other DSUs by AIR	263	0	49	411	122	131

2. Changes in loading policies were made based on SIMLOAD results. CCP container loading performance improved after each policy change.

3. There is a need for a more detailed analysis of ship sailing schedules to determine optimum CCP hold time, unless ships are available on a daily basis.

4. SIMLOAD does not encompass an evaluation of loading policies as they affect the total DSS transportation costs. Preliminary work on a CCP cost model has been completed; additional effort is requir d to complete the cost model.

FACILITIES CAPACITY FACTOR STUDY

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ROCK ISLAND, ILLINOIS 61201

BACKGROUND

The Joint Conventional Ammunition Production (JCAP) Panel in their final report made the recommendation to the Secretary of Defense regarding shift schedules shown in Figure 1. It should be noted that the cited shift schedules should represent our best estimate of the amount of production time that will be achievable in the event of mobilization. The purpose of the study was to determine if the 2-8-5 (2 shifts per day, 8 hours per shift, 5 days per week) shift basis, recommended in the JCAP report, was the maximum shift schedule that could be sustained for long periods of time under mobilization conditions. However, if the study found that some other shift basis was more appropriate for maximum sustained operation, the OSD would, naturally, adopt this larger number. The Deputy Assistant Secretary of Defense for Production Engineering and Materiel Acquisition directed that action be initiated, in coordination with appropriate service representatives and the JCAP/CG to further explore this recommendation. This study was initiated by JCAP/CG as a result of the OSD direction to prepare for participation with OSD and the military service to explore the application of the 2-8-5 concept to non-continuous manufacturing operations across-the-board in DOD. The JCAP study team participated with the OSD study team in the OSD effort to evaluate the 2-8-5 factor and the OSD results have been incorporated into the JCAP study.

STUDY METHODOLOGY

The outline given in Figure 2 describes the basic elements of our study methodology. The central aspect of our study involved visits to gather data on 21 production lines. These production systems were then computer-simulated to determine the upper boundary of sustained operation in each of the plants simulated in reference to shift basis. The results of these simulations, plus the data gathered from the Army/Navy Management Questionnaire and the ADPA Survey of industry practices, were used to perform the evaluations leading to the study conclusions and recommendations. These conclusions and recommendations were then formalized into a final report. The primary literature search was performed at the Texas A&M Library and at the Wright-Patterson Machineability Library. The DDC (Defense Documentation Center), the Open Literature, and the Kaiser Study were searched for pertinent information. The on-site plant visits included non-continuous operations such as production of fuzes, small arms, primers, load assemble and pack, and metal parts. Industrial facilities, government-owned and contractor operated (GOCO), and government-owned and government-operated plants (GOGO) were surveyed. These plants were both

JCAP RECOMMENDATION

THE SECRETARY OF DEFENSE SHOULD SPECIFY THAT RETENTION, MODERNIZATION, AND EXPANSION OF THE CONVENTIONAL AMMUNITION PRODUCTION LINES BE PLANNED TO MEET MOBILIZATION REQUIREMENTS ON A 2-8-5 SHIFT BASIS AT A PRODUCTION EFFICIENCY OF 80 PERCENT, EXCEPT FOR PROPELLANT AND EXPLOSIVE PLANTS WHICH SHOULD BE PLANNED ON A 3-8-7 SHIFT BASIS AT A PRODUCTION EFFICIENCY OF 90 PERCENT.

Figure 1

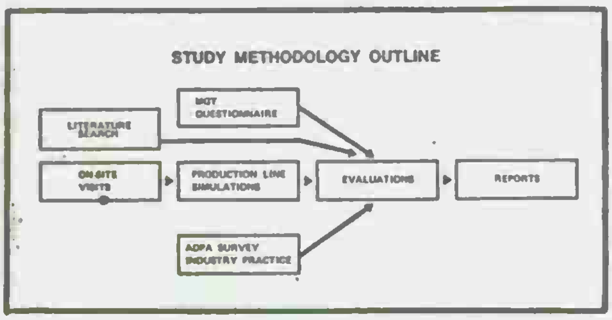


Figure 2

KAISER ENGINEERS' STUDY

RECOMMENDATIONS FOR FACILITY CAPACITY FACTORS*

FOR NON-CONTINUOUS PRODUCTION

	FACTOR	ADJUST FOR MTCE/SAFETY	NET
LAP	2.5-8-5	.5 Shift	2-8-5
METAL PARTS	3-8-5	20%	2-8-6
SMALL CALIBER	3-8-6	1.0 Shift	2-8-6

*Kaiser Engineers' Reports and Letters of 12 Mar 70 and 1 Dec 72

Figure 3

LABOR DEPARTMENT BULLETIN NO.917

19 CASE STUDIES

- 3 SHELL MANUFACTURE
- 16 METAL PARTS MANUFACTURE

SUMMARY

- 7 DAY WEEK IS NOT FEASIBLE
- 6 DAY WEEK IS FEASIBLE
- 8 HOUR DAY & 40 HOUR WEEK IS BEST FOR PEACETIME
- 8 HOUR DAY & 48 HOUR WEEK IS BEST FOR WARTIME

Figure 4

ADPA ADVISORY GROUP REPORT

MOBILIZATION DEFINITIONS

CLASS 1

DECLARED WAR WITH ALL WARTIME CONTROLS OVER MATERIALS, PERSONNEL AND PRICES ENFORCED. THE GENERAL CONSENSUS IS THAT SUCH A SITUATION WOULD BE BROUGHT ABOUT BY PEARL HARBOR TYPE OF ATTACK WHICH WOULD SERVE TO GALVANIZE PUBLIC OPINION IN FAVOR OF COOPERATING WITH A WAR EFFORT

CLASS 2

UNDECLARED WAR WHERE DEFENSE PRODUCTION MUST COMPETE WITH CONSUMER PRODUCTION, WITH ONLY MINIMAL CONTROL OVER SUPPLIES OF RAW MATERIALS, PERSONNEL AND PRICES. THE CONSENSUS IS THAT ANOTHER VIETNAM TYPE OF WAR MOST CLOSELY APPROXIMATES THIS SITUATION, WITH PUBLIC OPINION AGAINST UNITED STATES INVOLVEMENT

Figure 5

Army and Navy production facilities. The production line simulations were done with the HOCUS (Hand or Computer Universal Simulator) and the GPSS (General Purpose Simulator System). The HOCUS system was run principally by Picatinny Arsenal on a CDC 6500 computer and the GPSS at Eglin Air Force Base on an IBM 360-65 computer. The American Defense Preparedness Association (ADPA) Survey of industry practice was conducted by members designated by this industry group. The management questionnaires were sent by the JCAP study team to plant commanders, plant managers, and OSD personnel likely to have background appropriate to the study area, such as members of the ARMCOM staff, members of NAVORD, members of the service staffs, and DCASA teams. Upon completion of these areas of the study methodology, an overall evaluation of the data was performed and a final report was prepared. The final report was submitted to OSD for action.

In order to set the stage for the discussion of each of the manufacturing categories, I plan to present a summary of the results of each of the major elements of the study methodology.

LITERATURE SEARCH

In our literature search and in the discussions of shift factors for non-continuous production, repeated references were made to the Kaiser Engineers' Study performed for the Army. Figure 3 portrays the exact nature of the Kaiser Engineers' recommendations as drawn from and validated by the two letters and the actual reports. Thus, one could say that in terms of net productive hours, the Kaiser Engineers' Report did reflect 2-8-5 and 2-8-6. However, it is important to emphasize that the Kaiser Engineers' recommendations are based upon maximum sustained economic production under mobilization conditions. It is this economic constraint which distinguishes the guideline of maximum sustained production under mobilization conditions without economic constraints portrayed in our study from the Kaiser study using economic constraint. The same observation applies to the recommendations of the Joint Conventional Ammunition Panel which also based its proposal on maximum sustained economic production under mobilization conditions.

There were 19 case studies in the Labor Department Bulletin (summarized in Figure 4) that addressed production facilities that were similar to our shell metal parts lines. Three of these were identified as specifically producing artillery shell metal parts. While the study is dated and many changes in operating environment have occurred, the end result is of interest. In summary, during World War II it was found that Sunday work had severe limitations for these type facilities. In at least one case it was found to be counter-productive to have a Sunday shift. These case studies indicate that the six day week was best during World War II mobilization for these type plants. The overall conclusion of the study was that in peacetime, eight hour shifts and 40 hour weeks were best.

The results of the literature search indicated that for non-continuous processes on the average probably not more than 120 hours of production will be realized out of a possible 168 hour work week, regardless of the shift employed.

AMERICAN DEFENSE PREPAREDNESS ASSOCIATION ADVISORY GROUP REPORT

The next element of the study addresses the report of the ADPA Advisory Group chaired by Mr. Kenneth S. Cole of Chamberlain Manufacturing Corporation. This was a Blue Ribbon Group which met at ARMCOM Headquarters, Rock Island, Illinois on 18 and 19 October 1973. This group had the task of developing a report which would reflect the industry viewpoint with respect to production shift policies and practices for a modernized base. The group held strong convictions that there were additional issues over and beyond the question of establishing norms for non-continuous production in a mobilization situation. Specifically, the group raised a basic question as to what mobilization environment should be used. The group advocated abandoning the use of shifts and the adoption of a more basic unit in terms of hours per week. The ADPA Advisory Group strongly felt that it was essential to differentiate between a war time mobilization in which the War Powers Act and all associated controls removed many constraints that exist in a peacetime environment and a SEA "mobilization" environment in which non-continuous production operations operated under many constraints. The definitions used by ADPA are given in Figure 5. As the ADPA Advisory Group pointed out, this would directly affect the number of production hours that could be realized from the same production line. The ADPA Group stressed that it should be recognized that in either class of mobilization, the base production units would represent at least 90 percent of the initial munitions supply. The group agreed upon the following groupings or categories of non-continuous production operations for establishing norms for the number of productive hours per week: Load, assembly, and pack --- medium and large caliber metal parts --- fuzes and small caliber ammunition --- and raw materials. Participants in the ADPA Advisory Group organized themselves into subcommittees representing these categories which evolved into their final report.

The ADPA Advisory Group made these two recommendations (Figure 6). They felt that private industry should determine how shifts are to be apportioned based upon many complex factors applying only to each individual situation. DOD has no intimate, up-to-date, first-hand knowledge of union agreements, past practices within an area, condition of the Base Production Unit, attitudes of personnel, pending agreements, financial situation, plant physical limitations, vendor/supplier relationships, or any of hundreds of other considerations which go into establishment of working hours. Only the contractor knows what is best for his plant. The persistence of DOD personnel to think only in terms of shifts and to dictate same in modernization programs may be one reason private industry in the past has given such widely diverging estimates of peak production and production costs on like or similar items. Each contractor was applying his knowledge of the local situation to the shift pattern dictated by DOD. The worst outcome of dictated shift policy was the possible formulation of opinions by DOD personnel that Contractor A was "efficient" and that Contractor B was "inefficient". While private industry knows this is not formalized in DOD files, we do know that individual personal opinions exist and that previous thinking in terms of shifts and imposition of shifts on diverse contractors may have contributed to these opinions. To combine equipment and tool limitations is

ADPA ADVISORY GROUP REPORT

RECOMMENDATION 1

DOD SHOULD STOP THINKING IN TERMS OF SHIFTS - BUT SHOULD START THINKING IN TERMS OF HOURS PER WEEK REQUIRED TO ACHIEVE STIPULATED PRODUCTION RATES WITH GIVEN BASE PRODUCTION UNITS

ADPA ADVISORY GROUP REPORT

RECOMMENDATION 2

EQUIPMENT EFFICIENCY, TOOL LIFE, AND DOWNTIME FOR MAINTENANCE SHOULD BE ENTERED INTO COMPUTATIONS ESTABLISHING MAXIMUM INDIVIDUAL MACHINE OUTPUT, OR LINE OUTPUT

Figure 6

ADPA ADVISORY GROUP REPORT

SUSTAINED PRODUCTION UNDER MOBILIZATION CONDITIONS

TYPE INDUSTRY	CLASS 1 HRS/WEEK	CLASS 1 % OVERALL EFFICIENCY	CLASS 2 HRS/WEEK	CLASS 2 % OVERALL EFFICIENCY
LAP	120	78	100	78
FUZE AND SMALL ARMS	132	80	100	80
METAL PARTS	144	75	120	80
RAW MATERIALS	CONT	80	CONT	90

Figure 7

ARMY/NAVY MANAGEMENT QUESTIONNAIRE

ALL OUT MOBILIZATION

% RESPONSE

	MFG CATEGORY					
SHIFT BASIS	LAP	MPTS	SMALL ARMS	FUZE & OTHER	P&E	NON-PLANT
2-8-5	6	29	–	6	–	100
2-8-6	6	–	–	–	–	
2-10-5	6	29	–	6	–	
2-10-6	6	13	–	–	–	
3-8-5	29	29	–	23	17	
3-8-6	41	–	100	65	–	
3-8-7	6	–	–	–	83	

Figure 8

ARMY/NAVY MANAGEMENT QUESTIONNAIRE

PARTIAL MOBILIZATION WITH ECONOMIC RESTRAINTS

% RESPONSE

	MFG CATEGORY					
SHIFT BASIS	LAP	MPTS	SMALL ARMS	FUZE & OTHER	P&E	NON-PLANT
2-8-5	33	66	50	27	–	100
2-8-6	–	–	–	–	–	
2-10-5	7	17	–	–	–	
2-10-6	–	17	–	–	–	
3-8-5	60	–	–	13	17	
3-8-6	–	–	50	60	–	
3-8-7	–	–	–	–	83	

Figure 9

ARMY/NAVY MANAGEMENT QUESTIONNAIRE

PARTIAL MOBILIZATION WITHOUT ECONOMIC CONSTRAINTS

% RESPONSE

	MFG CATEGORY					
SHIFT BASIS	LAP	MPTS	SMALL ARMS	FUZE & OTHER	P&E	NON-PLANT
2-8-5	20	50	50	13	–	67
2-8-6	–	–	–	–	–	–
2-10-5	13	17	–	7	–	–
2-10-6	–	33	–	–	–	33
3-8-5	60	–	–	13	17	–
3-8-6	7	–	50	67	–	–
3-8-7	–	–	–	–	83	–

Figure 10

ARMY/NAVY MANAGER QUESTIONNAIRE

CONCLUSIONS

MFG CATEGORY	HRS/WEEK	SHIFT FACTOR(S)
LAP	120-144	2-10-6 3-8-5 3-8-6
METAL PARTS	120	2-10-6 3-8-5
FUZE & SMALL CALIBER	144	3-8-6
OTHER NON-CONTINUOUS	144	3-8-6

Figure 11

an unnecessary complication of the term "efficiency" and tends to create unrealistic peak production rates. The former can be quantified, while the latter is highly subjective, and affected by intangibles like attitudes, morale, emotions, etc. The ADPA Advisory Group feels that this is a matter of simple economics and is the basis on which contractors bid jobs. Then the contractor "efficiency factor" is reduced to what he can reasonably expect from his personnel.

This table (Figure 7) reflects the consensus of the ADPA Advisory Group on the sustained production levels for both Class 1 and Class 2 mobilization situations. It can readily be seen that the lack of constraints in Class 1 and the presence of constraints in Class 2 has a significant impact on the gross and net hours per week that can be expected.

ARMY/NAVY MANAGEMENT SURVEY ELEMENT

The following tables (Figures 8, 9, 10 and 11) summarize responses of the individuals' best estimate of the shift bases for the shift schedule that could be maintained in the event of an all-out conventional war. For purposes of correlation with the ADPA Advisory Group Report, this mobilization situation would be comparable to the Class 1 definition developed by the ADPA group for its study. The phrase, "non-plant", refers to personnel in a staff role at the time of their response to the questionnaire.

The table in Figure 9 summarizes the individuals' best estimates of the shift schedule that could be maintained in a partial mobilization situation with economic constraints. This situation would be comparable to the Class 2 mobilization environment defined in the ADPA Advisory Group Report.

Figure 10 presents the best estimate of the shift schedule that could be maintained under a partial mobilization situation without economic constraints.

In summary, the three preceding tables portray that, with the exception of metal parts, it is possible to use a planning factor of at least 3-8-5. In the case of metal parts, at least one of the lines was unbalanced because of the forge process that was operating on a 3-8-6 while the remainder operated at 2-10-5. Some of these answers are greatly influenced by the individual's knowledge of mobilization planning and a corresponding tendency to just copy those figures into the questionnaire. In at least one case where the plant manager also answered the questionnaire, the manager's response presented a higher shift basis than the plant commander's. Therefore, it can be inferred that the survey, especially where pertaining to metal parts, can be considered somewhat conservative. The study team recommended the following shift or total hour bases for each type of plant based on this survey as shown in this table (Figure 11). This subjective analysis also indicates that certain imponderables such as the availability of management and engineering personnel, the availability of a pool of skilled personnel and/or an experienced cadre for a future war, and possible future energy and natural shortages must be given some form of consideration in the mobilization planning process. They should not, however, be considered overwhelming in light of the detailed evidence supporting this table.

ON-SITE SURVEYS & SIMULATIONS ELEMENT

The definitions shown in Figure 12 are essential to an understanding of this element of the study. To some extent, the lack of these and other critical definitions have created a misunderstanding of the meaning of "shift base". This is the first of a group of vu-graphs that describe the results of the site surveys and the simulations. We needed to establish the criteria for the number of days per month as a part of these definitions in order to proceed with the simulations. Before presenting the information which relates to each production line that was simulated, it was necessary to address the rationale for the adoption of a specific mean-time between failures (MTBF). The study used 10,000 hours for mean-time between failures. Three assumptions were made to arrive at this number. They are as follows:

1. Burn-in failures were eliminated (i.e., the line has been debugged).

2. Only a major failure would be considered, and a major failure is defined as a station breakdown requiring at least 2 hours repair time.

3. There is a 50/50 chance that each major station would fail once a year. It is recognized that some machines have breakdowns more frequently than once a year; however, most of these are minor problems requiring adjustments, tool changes, calibrations, etc. and do not result in a 2 hour downtime. These minor problems were included in the efficiency factors for each plant. The 50/50 chance for a failure once a year corresponds to approximately 9,000 hours MTBF. However, since simulation runs were made with 50, 250, 500, 750, 1000 and 10,000 hour MTBF, the 10,000 hour runs were used as a realistic evaluation of the degradation that major failures would cause at each plant. This assumption can be compared to actual cases varying from National Presto Industries, which has experienced between two and three failures a year on their forges over the last four years, to Lone Star AAP, which hasn't experienced a major failure in four years on their fuze line. Charts are available for all of the above mentioned MTBF's with the associated simulated capacities. They will be included in the written report so that an evaluation can be made by anyone wishing to analyze the effect that different major equipment failure rates could have on the output of each particular line. The 10,000 hour MTBF chosen for the briefing is equivalent to each station in the simulation having a 95% reliability over 500 hours of operation and is considered a conservative estimate of the equipment capability.

Figure 13 shows the efficiency factors used for each plant to evaluate the expected monthly outputs for each of the shift bases shown. These efficiencies are based on the plant visits and the ammunition plant capacity reports. The numbers in parenthesis represent the scheduled

SHIFT BASE DEFINITIONS

SCHEDULED PRODUCTIVE HOURS

- LENGTH OF SHIFT - SCHEDULED DOWNTIME (I.E. LUNCH, BREAKS, WALKING, START-UP & SHUTDOWN TIME, ETC.)

ACTUAL EXPECTED PRODUCTIVE HOURS

- SCHEDULED HOURS X EFFICIENCY

DESIGN OUTPUT

- EQUIPMENT LIMITED CAPABILITY OF THE LINE PER UNIT OF TIME

EXPECTED MONTHLY OUTPUT

- PRODUCTIVE HOURS/DAY X OUTPUT/HOUR X NO DAYS/MONTH

NUMBER OF OPERATING DAYS PER MONTH

5 - DAY WEEK - 21 DAYS PER MONTH

6 - DAY WEEK - 26 DAYS PER MONTH

7 - DAY WEEK - 30 DAYS PER MONTH

Figure 12

LAP EFFICIENCIES

	2-8-5	3-8-5	3-8-6	3-8-7	2-10-5	2-10-6
IOWA	.764 (6.5)	.764 (6.5)	.764 (6.5)	.57 (6.8)*	.72 (8.4)**	.65 (8.4)**
JOLIET	.768 (7.14)	.723 (6.8)	.672 (6.8)	.61 (6.8)	.72 (8.4)	.651 (8.4)
KANSAS	.831 (7.0)	.831 (7.0)	.831 (7.0)	.631 (7.0)	.79 (8.4)	.71 (8.4)
MILAN	.743 (7.0)	.70 (7.0)	.656 (7.0)	.50 (7.0)	.71 (8.4)	.64 (8.4)
LONE STAR	.75 (7.0)	.72 (7.0)	.69 (7.0)	.52 (7.0)	.713 (8.4)	.65 (8.4)
CRANE	.80 (6.5)	.75 (6.5)	.75 (6.5)	.57 (6.5)	.76 (8.4)	.69 (8.4)
HAWTHORNE	.72 (5.8)	.70 (5.8)	.69 (6.6)	.52 (5.8)	.684 (8.4)	.62 (8.4)
McALISTER	.80 (6.5)	.78 (6.5)	.74 (6.5)	.56 (6.5)	.77 (8.4)	.69 (8.4)

(2-10-5) ≈ .95 (2-8-5)

(2-10-6) = .86 (2-8-5)

(3-8-7) = .76 (3-8-6)

* ASSUMED TO BE SAME AS 3-8-6

** NO DATA AVAILABLE THEREFORE STANDARD PRACTICE PLUS AN ADDITIONAL 20 MIN BREAK WAS ALLOWED FOR 10 HOUR SHIFTS

Figure 13

MILAN ARMY AMMUNITION PLANT

ESTIMATED 10,000 HOURS BETWEEN MACHINE BREAKDOWN

LAP 81MM HE MORTAR ROUNDS

SCHEDULE	SCHEDULED PRODUCTIVE HOURS PER DAY	ACTUAL EXPECTED PRODUCTIVE HOURS PER DAY	DESIGN OUTPUT PER PRODUCTIVE MINUTE	EXPECTED MONTHLY OUTPUT
2-8-5	14.0	11.8	44	650,000
3-8-5	21.0	16.8	44	820,000
3-8-6	21.0	16.7	44	1,080,000
3-8-7	21.0	12.8	44	940,000
2-10-5	16.8	14.2	44	770,000
2-10-6	16.8	12.8	44	800,000

Figure 14

JCAP FACILITY CAPACITY FACTORS STUDY

SUMMARY OF FINDINGS

RELATING TO LOAD, ASSEMBLE & PACK OPERATIONS

SOURCE	SHIFT	HRS/WEEK	EFFICIENCY
KAISER ENGINEERS' STUDY	2.5-8-5	100	80%
ADPA ADVISORY GROUP	2-10-6 3-8-5	120	78%
ARMY/NAVY MGT QUEST	2-10-6 3-8-5 3-8-6	120-144	*
ON-SITE SURVEYS/SIMULATIONS	2-10-6 3-8-5	120	60-80%

* NOT SPECIFIED

Figure 15

SCRANTON ARMY AMMUNITION PLANT

ESTIMATED 10,000 HOURS BETWEEN MACHINE BREAKDOWN

SHELL METAL PARTS

SCHEDULE	SCHEDULED PRODUCTIVE HOURS PER DAY	ACTUAL EXPECTED PRODUCTIVE HOURS PER DAY	DESIGN OUTPUT PER PRODUCTIVE MINUTE	EXPECTED MONTHLY OUTPUT
2-8-5	14.0	11.2	6.70	90,000
3-8-5	21.0	18.8	6.70	135,000
3-8-6	21.0	16.8	6.70	160,000
3-8-7	21.0	16.8	6.70	193,000
2-10-5	17.0	13.6	6.70	110,000
2-10-6	17.0	13.0	6.70	130,000

Figure 16

JCAP FACILITY CAPACITY FACTORS STUDY

SHELL METAL PARTS CAPACITY FACTORS

COMMAND REVIEW OF INDUSTRIAL BASE

NO MODERNIZATION - NO SIMULATIONS

PLANT	HOURS PER WEEK	MAX RATED MONTHLY CAPACITY (IN THOUSANDS)
ARMY		
US STEEL, BERWICK, PA - 8" PROJ MPTS, M106	120	62
RIVERBANK AAP, (NORRIS) - 81MM MPTS, M374	120	460
KISCO CO, INC ST LOUIS' MO - 105MM CART CASE M14	120	1000
NAVY		
AMF, YORK, PA - MK82 BOMB BODY (500LB)	120	90
US STEEL, McKEYSPORT, PA - MK82 BOMB BODY (500LB)	120	90
AMCOT - MK82 BOMB BODY (500 LB)	120	25
INTER CONT MFG CO - MK82 BOMB BODY (500 LB)	120	25
NORRIS INDUSTRIES - MK82 BOMB BODY (500 LB)	120	83
(VERNON) - MK82 BOMB BODY (500 LB)	120	(48)
(MAYWOOD) - MK82 BOMB BODY (500 LB)	120	(35)
AMCO - 8" PROJ MPTS	120	130
LANSDOWNE STEEL & IRON CO - 8" PROJ MPTS (PLUS 57K FROM SAME FACILITY FOR 3")	120	45
NORRIS INDUSTRIES		
VERNON - CART CASE 5"	120	90.4
RIVERBANK - CART CASE 8"	120	80

Figure 17

productive hours obtained by evaluating the actual shift hours of each plant and subtracting the lunch, breaks, and walking times.

LOAD, ASSEMBLE AND PACK ELEMENT

Figure 14 is a typical spread chart showing the Milan AAP load, assemble and pack plant. A spread chart for each of the plants surveyed is provided in the basic document.

A summary of the findings of load, assemble and pack operations is shown in Figure 15. In order to establish comparability, it was necessary, where the source specified its actions in terms of hours, to convert to equivalent shifts and vice versa.

METAL PARTS PRODUCTION LINES ELEMENT

Figure 16 presents the data from the simulation of the Scranton AAP which was typical of the GOCO shell metal parts plants visited in the study. There probably will be a difference in the shift schedule and efficiency between the foundry operations and the rest of the plant. Our results are based on the limiting operation.

The Facility Capacity Factors Study also addressed industrial facilities that were used to manufacture shell metal parts. These plants are listed in Figure 17. For plants that are in existence and where we were not evaluating a modernization project, we have used a different format for the presentation of data. In these plants, we were looking at experience and not projected capability. We, therefore, did not feel that simulations were justified. Furthermore, these were, in general, commercial facilities where data of the depth necessary to run simulations was considered to be proprietary in nature. The only commercial plant where we were able to get information adequate for simulation was National Presto, Inc. We have that plant in the standard format. The data from the simulations do not contradict the 500 hour shift bases that these plants have chosen for a planning basis.

A summary of the findings relating to shell metal parts is shown in Figure 18.

A summary of the findings relating to other non-continuous production is shown in Figure 19. You should notice that the recommended schedule does not apply to small caliber ammunition. The scamp modules require daily maintenance and tool replacement which required approximately one half shift. Therefore, the maximum daily production is limited to two ten-hour shifts.

CONCLUSIONS AND RECOMMENDATIONS

Figure 20 shows the major conclusions of the study effort. It is clear from this study that the recommendations of both the Kaiser Engineers'

JCAP FACILITY CAPACITY FACTORS STUDY

SUMMARY OF FINDINGS

RELATING TO METAL PARTS PRODUCTION

SOURCE	SHIFT	HRS/WEEK	EFFICIENCY
KAISER ENGINEERS' STUDY	3-8-5	120	80%
ADPA ADVISORY GROUP	3-8-6	144	75%
ARMY/NAVY MGT QUEST	2-10-6 3-8-5	120	*
ON-SITE SURVEYS/SIMULATIONS	2-10-6 3-8-5	120	68-70%

* NOT SPECIFIED

Figure 18

JCAP FACILITY CAPACITY FACTORS STUDY

SUMMARY OF FINDINGS

RELATING TO OTHER NON-CONTINUOUS PRODUCTION

SOURCE	SHIFT	HRS/WEEK	EFFICIENCY
KAISER ENGINEERS' STUDY	3-8-6	144	67%
ADPA ADVISORY GROUP	3-8-5.5	132	80%
ARMY/NAVY MGT QUEST	3-8-6	144	*
ON-SITE SURVEYS/SIMULATIONS			
EXCEPT SMALL CALIBER	3-8-5.5	132	60-75%
SMALL CALIBER	2-10-6	120	60-75%

*NOT SPECIFIED

Figure 19

JCAP FACILITY CAPACITY FACTORS STUDY

CONCLUSIONS

THE DISTINCTION BETWEEN THE KAISER ENGINEERS' & JCAP PANEL REPORTS AND THIS REPORT IS ECONOMIC VS. NON-ECONOMIC PRODUCTION RATES

HOURS/WEEK OR MONTH IS MORE PRECISE THAN SHIFTS FOR PRODUCTION PLANNING

THE 7 DAY WEEK IS COUNTER PRODUCTIVE

THERE IS A CONSENSUS ON SUSTAINED RATES FOR NON-CONTINUOUS PRODUCTION

ADOPTION OF THE CONCLUSIONS & RECOMMENDATIONS IN THIS REPORT WILL REQUIRE REVISION OF BASE RETENTION, OPERATING, AND MODERNIZATION PLANS AND PROGRAMS

Figure 20

JCAP FACILITY CAPACITY FACTORS STUDY

CONCLUSIONS AND RECOMMENDATIONS

MFG CATEGORY	HRS/WEEK	EFFICIENCY RANGE
LAP	120	70-75%
METAL PARTS	120	68-70%
OTHER NON-CONTINUOUS PRODUCTION		
EXCEPT SMALL CALIBER	132	60-75%
SMALL CALIBER	120	60-75%

Figure 21

JCAP FACILITY CAPACITY FACTORS STUDY

RECOMMENDATIONS

1. Use hours per week/month in place of shifts
2. Do not use the seven day week
3. Adopt the rates proposed

Figure 22

The planning factors of 120 scheduled hours per week for load, assemble and pack (LAP), metal parts, and small caliber production, and 132 scheduled hours per week for other non-continuous production such as fuzes, primers and propelling charges, are approved for use by the Services in their current planning for modernization/expansion of the conventional ammunition production base. At the recommended efficiency of 70% the planning factors equate to 84 hours per week and 92 hours per week effective production hours respectively.

Figure 23

Study and the Joint Conventional Ammunition Production Panel's Final Report provides an economic shift basis for sustained production under mobilization conditions. The Facilities Capacity Factor Study was conducted, pursuant to the guidelines that recommendations would be in terms of sustained production at mobilization conditions <u>without economic constraints</u>.

The use of shifts as a common denominator can be counterproductive at the local level and should be replaced by hours-per-week. The conversion of hours-per-week into shifts should be recognized as the prerogative of the production manager at the plant level.

Evidence gathered in this study indicates that consideration of a sustained seven day-per-week in non-continuous production operations is not feasible.

Since the factors addressed in this study are fundamental to most aspects of production base management, their approval will require a revision of base retention, operational, and modernization plans and programs.

The study team recommended the shift bases shown in Figure 21. The results of the output of the simulations indicate an upper boundary in hours-per-week that probably can be obtained in some weeks but will be difficult to consistently meet. The simulations take into account the routine time losses and the major and minor maintenance and repairs, but they do not take into consideration vacations, major material and energy failures, shortages, strikes, environmental and legal problems, and catastrophic failures. In addition to these problems, this study is directed to factors for modernization projects which have an historic tendency towards optimism, and it would, therefore, be unrealistic to assume that the maximum boundary found in the simulations is an attainable estimate of the maximum, sustaining rate. The study group has, therefore, taken what it believes to be a realistic position in drawing its conclusions from the four sources used in the evaluations as reflected in Figure 21. The study team made the recommendation shown in Figure 22.

RECOMMENDATIONS

Figure 23 shows the policy adopted by OSD as a result of this study.

DEFENSE SATELLITE COMMUNICATIONS SYSTEM EARTH TERMINAL AVAILABILITY VERSUS LOGISTICS SUPPORT COST MODELING

Dr. K. E. Forry, U.S. Army Communications Command
with Dr. J. Lazaruk and Mr. L. Auchard, USACC

The United States Army Communications Command has operations and maintenance responsibility for 6 AN/MSC-46, 2 AN/TSC-54, 1 AN/MSC-60, and 2 AN/FSC-9 Satellite Earth Terminals (SET's) deployed worldwide in support of increased DOD satellite communications requirements. 4 AN/MSC-60 SET's will be added to USACC's inventory within the next three years.

These increasing satellite communications requirements are placing greater demands upon operations and maintenance to achieve operational availability goals closer to intrinsic system availability than ever before. In the face of increasingly tightening O&M budgets it is imperative that refined methods of logistics and maintenance support be employed to achieve these higher availability goals at the least possible cost of life cycle logistics support.

Earlier this year, it was observed that the availability of the AN/MSC-46 and AN/TSC-54 satellite communications terminals had been gradually decreasing - these trends are shown in Figure 1. Naturally, this has resulted in less time available to accommodate the increasing communication requirements. A partial solution to this problem has been to redesign these terminals for improved reliability and maintainability. New terminals such as the AN/MSC-60 have been designed incorporating redundancy features lacking in earlier models. The problem of downtime resulting from logistics support, however, was not addressed in earlier studies.

To assist USACC logistic management in dealing with this problem, a generalized analytical logistics trade-off model is being used which determines the least cost sparing of on-site spare replaceable modules required to achieve a predicted SET availability goal constrained by various logistic parameters.

This model has been named the Army Communications Command Logistics Trade-off Model (ACCLOGTROM) and is operating on the Fort Huachuca CDC-6500 computer system. The model is a considerably modified version of the SAFEGUARD Logistic Trade-off Model adapted to communications systems.

The mathematical development of the model is based upon conventional definitions and assumptions. System Availability is defined to be the probability that a system of components or Line Replacable Units (LRU's) is operational when required. An LRU is a component or part which can be removed and replaced by plug-in/pluck-out type of repair action. A piece part is a component of an LRU. The LRU availability is defined as the probability that the LRU is operational within its parent system when required.

The computer program implementing ACCLOGTROM consists of the usual input, processing, and output phases shown in Figure 2. Input to the program consists of the following information:

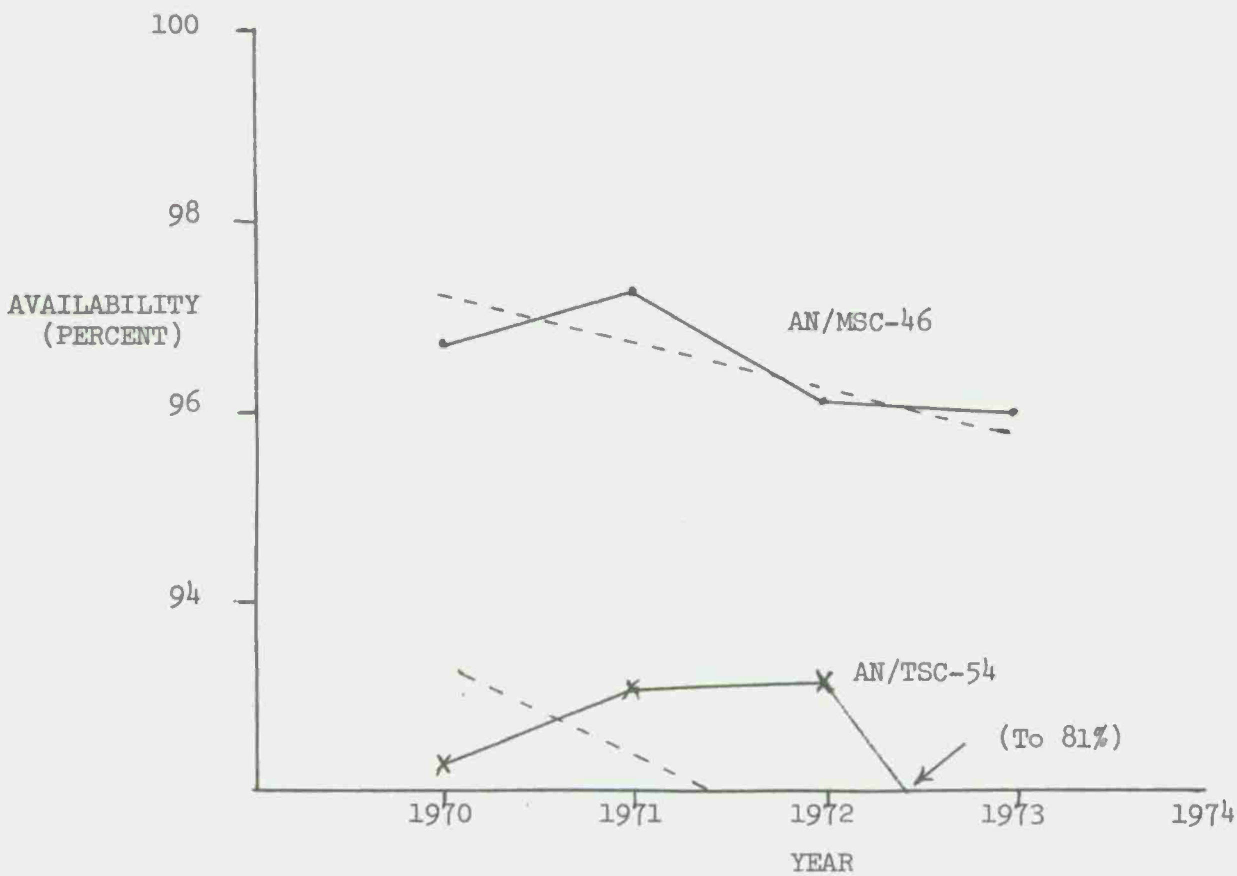


Figure 1

AVAILABILITY TREND
SATELLITE EARTH TERMINAL

INPUT

- AVAILABILITY GOAL
- SYSTEM LIFETIME
- ORDER/SHIP TIME
- PIECE PART PROCUREMENT LEAD TIME
- SITE PIECE PART STOCK
- DEPOT PIECE PART STOCK
- RELIABILITY BLOCK DIAGRAM
- LABOR COST
- LRU DATA
  - PRICE
  - DENSITY
  - FAILURE RATE
  - REMOVE/REPLACE TIME
  - REPAIR TIME
  - WASHOUT RATE
  - DEPOT STOCK
  - PROCURE LEAD TIME
  - REPAIR SKILL
  - TEST EQUIP REQUIRED

→

PROCESSING

1. DETERMINE IF AVAILABILITY GOAL CAN BE ACHIEVED.
2. IF NOT, OUTPUT REPORTS.
3. IF SO, DETERMINE LEAST COST SET OF LRU's TO STOCK ON-SITE TO MEET REQUIRED AVAILABILITY.
4. COMPUTE COSTS AND OUTPUT REPORTS.

→

OUTPUT

1. LISTING OF ALL INPUT DATA.
2. OPTIMAL SITE STOCK LEVEL FOR EACH LRU.
3. MONTHLY LIFE CYCLE COST OF
   - LRU SITE STOCK
   - TEST EQUIP
   - TRANSPORTATION
   - OFF-LINE REPAIR
   - OFF-SITE INVENTORY, PIPELINE, AND WASHOUT
4. TOTAL COST BY SITE AND ALL SITES.

ACCLOGTROM
GENERAL DESCRIPTION

Figure 2

a. The availability requirement or goal desired by management for the system to achieve.

b. The estimated operational lifetime of the system.

c. The estimated order and shipping time between a system location (site) and the next level supply echelon (depot).

d. The estimated procurement lead time to acquire piece parts from a vendor.

e. The probability level of piece part stockage at the site.

f. The probability level of piece part stockage at the depot.

g. The Reliability Block Diagram (RBD) information showing in sequence the LRU's and subsystems of LRU's required for successful system operation. A subsystem level RBD is shown in Figure 3 for the AN/MSC-46 SET.

h. The cost by skill level of maintenance labor.

i. Data for each LRU in the system such as: Price, repair rates, and failure rates.

In the processing phase, the first step is to determine whether or not managements' availability goal is indeed achievable. This is accomplished by computing the availability of the system assuming zero logistics delay for each LRU and comparing the computed value to the requirement. If the goal cannot be met under this condition, the processing is terminated and results are output. If the goal can be met, then a cost/availability optimizing procedure is used to determine the least cost set of LRU's to meet the required availability. When the procedure is complete, various costs are computed and the output phase is initiated.

The output reports consist of a detailed listing of all input data for validity checking. This is followed by a listing of all LRU's in the system by part number showing the recommended number of each LRU to provision on-site. Finally, a cost report is produced which shows the total life-cycle cost prorated on a monthly basis of on-site inventory, test equipment charges, off-line repair, off-site inventory, pipeline, and washout. Other information such as system reliability for a prescribed operating time, system availability assuming zero logistics delay, and a wealth of additional analysis data are available upon request.

The heart of the processing phase is the following mathematical model. System availability A is computed by a mathematical function of the availability A_i of each of the LRU's contained in the system as

$$A = f(A_1, A_2, \cdots, A_n). \qquad (1)$$

Assuming independent failures and repair actions, the function f is determined by standard series and parallel reliability formulas. For example, if all n LRU's in the system are required for successful operation, the

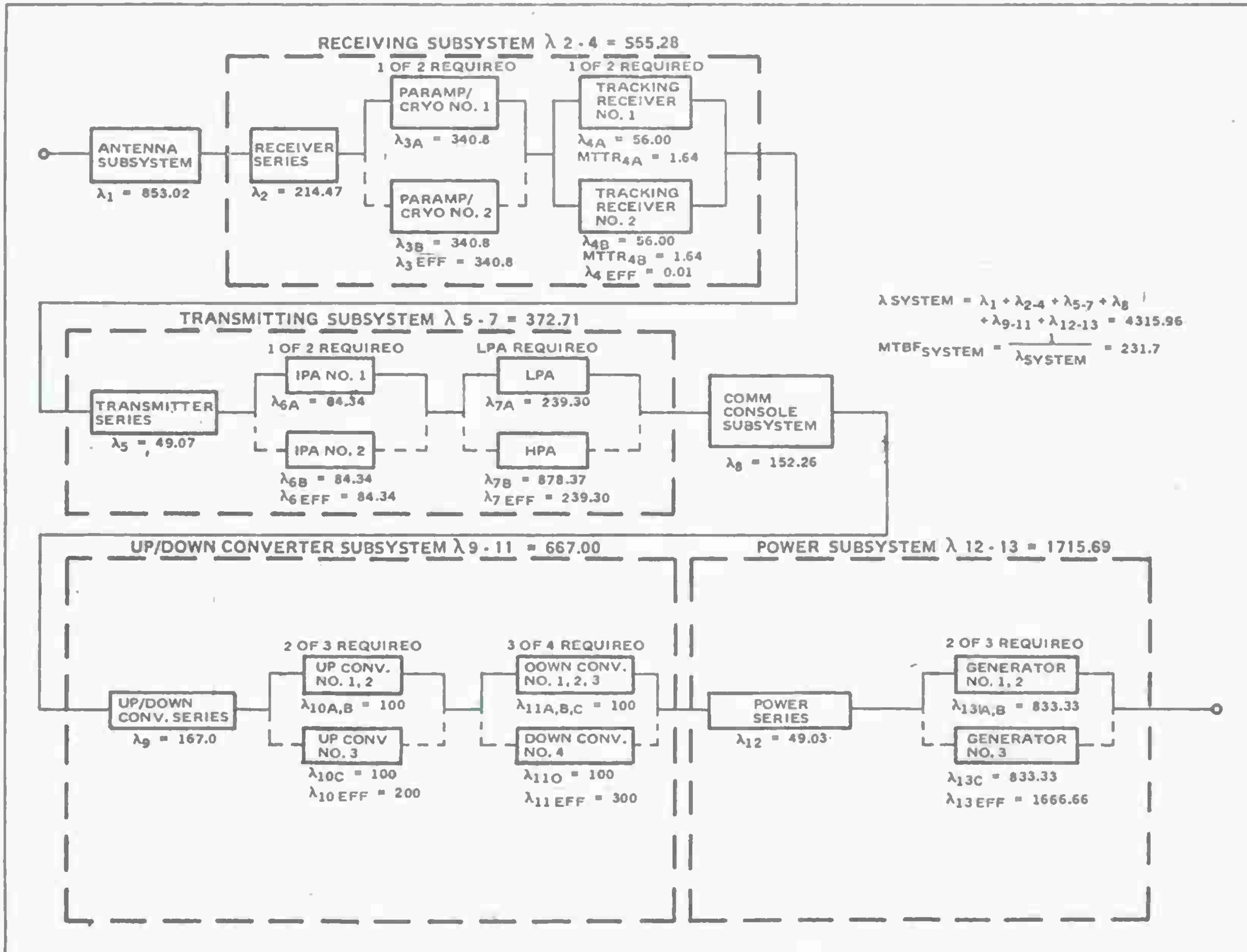


Figure 3 AN/MSC-46 Reliability Block Diagram

system availability is computed as the product of LRU availabilities, or

$$A = \prod_{i=1}^{n} A_i \qquad (2)$$

If there are m of the ith LRU with availibility A_i in redundancy such that k of the m are required for successful operation, the availability A_j is computed as

$$A_j = \sum_{p=k}^{m} A_i^p (1-A_i)^{m-p}. \qquad (3)$$

If,for example, the LRU's whose availabilities are A_4, A_7, and A_9 are all required for successful operation of one of three identical chains of these LRU's and two of the three chains are required for successful operation of the system, the availability A_j of this redundant subsystem is computed as

$$A_j = \sum_{p=2}^{3} (A_4 A_7 A_9)^p (1-A_4 A_7 A_9)^{3-p}. \qquad (4)$$

These few examples serve to illustrate the manner in which system availability is computed by appropriate combinations of subsystems of the LRU's in the system.

It will be shown later that the availability of the ith LRU can be expressed as a function of the on-site stock level N_i initially provisioned for the ith LRU, or

$$A_i = y(N_i). \qquad (5)$$

From this and equation (1), the system availability can be expressed as

$$A = g(N_1, N_2, \cdots, N_n). \qquad (6)$$

If the cost of the ith LRU is C_i, the total cost of the on-site provisioning level is

$$C = \sum_{i=1}^{n} C_i N_i . \qquad (7)$$

Given equations (1), (5), (6), and (7), the model determines the integer values of N_1, N_2, $\cdots$, N_n so as to minimize C while meeting or exceeding the system availability requirement A_G or

$$\min \sum_{i=1}^{n} C_i N_i \qquad (8)$$

$$\text{s.t. } A \geq A_G \text{ and}$$

$$N_i \geq 0 \text{ for all } i .$$

Now, the availability of the ith LRU A_i is computed by

$$A_i = (1 + FR_i \cdot DT_i)^{-1}, \tag{9}$$

where FR_i is the failure rate of the ith LRU and DT_i is the average time to restore the ith LRU to operational status by replacement or repair upon failure.

The average restoration time DT_i is determined from

$$DT_i = MTTR_i + (1 - P_{N_i})(ALT_i), \tag{10}$$

where $MTTR_i$ is mean time to remove and replace the ith LRU, P_{N_i} is the probability that a spare for the ith LRU is in the site inventory given that the initial inventory level was N_i, and ALT_i is the average logistic or replenishment delay time.

The probability $P_{N_i} = 1 - (U_i^{N_i} / N_i! \sum_{k=o}^{N_i} U_i^k / k!)$, (11)

where N_i is number of spares for LRU_i initially provisioned, U_i is the average depletion of site inventory of LRU_i during the average replenishment time and equals $J_i \cdot LDT_i \cdot FR_i$ and J_i is the density or total number of applications of LRU_i in the system.

The average logistics delay time ALT_i depends upon whether the LRU is repairable or not. Further, if the LRU is repairable, ALT_i depends on whether it is repaired on-site or at a depot repair facility. The ALT_i for on-site repairable LRU's is

$$ALT_i = (1-r)\{(1-p)\{(1-q)\{(1-z)(T_L + T_D + T_R) + z(T_D)\} \tag{12}$$

$$+ q(T_D + T_R)\} + p(T_R)\} + r\{(1-z)(T_{PLT} + T_D) + z(T_D)\},$$

and for off-site repair and discard LRU's,

$$ALT_i = (1-z)\{(1-r)\{q(T_R + T_D) + (1-q)(T_L + T_R + T_D)\} \tag{13}$$

$$+ r(T_{PLT} - T_D)\} + z\,T_D,$$

where:

p - is the probability that piece parts are on-site for LRU repair,

q - is the probability that piece parts are at the depot for LRU repair,

z - is the probability that spare LRU's are at the depot,

r - is the washout rate in 0/0 of failures which are not repairable,

T_R - is the time to test and repair failed LRU's,

T_D - is the turnaround time to order, ship, and receive a replacement LRU from the depot,

T_L - is the turnaround time to order, ship, and receive a piece part from a supplier, and

P_{PLT} - is the procurement/production lead time for the LRU.

By application of equations (1) through (13), the least cost set of on-site spare LRU's is determined. Following this, total average monthly cost is computed for the system lifetime L. This cost is the sum of the initial on-site LRU inventory cost, as determined by the optimization, estimated transportation cost estimated monthly repair manpower cost, estimated monthly cost of off-site inventory, supply pipeline,and resupply costs for discarded LRU's.

The average monthly initial on-site inventory cost C_p is

$$C_p = \frac{1}{L} \sum_{i=1}^{n} \sum_{s=1}^{n_s} M_s C_i N_i , \qquad (14)$$

where L = system lifetime in months, n_s = total number of sites,
M_s = 1 if LRU is in system for site s, 0 otherwise, and
N_i = minimum number of the ith LRU stocked on-site as determined by the optimization program.

$$C_{ts} = 2 \sum_{i=1}^{n} \sum_{s=1}^{n_s} M_s S_s J_i F_i W_i C \qquad (15)$$

is the transportation cost for off-site repair,
and similarly, the on-site repair option transportation cost C_{td} is

$$C_{td} = 2 \sum_{i=1}^{n} \sum_{s=1}^{n_s} M_s S_s J_i r_i F_i W_i C , \qquad (16)$$

where r_i = fraction of failures of the ith LRU which are not repairable,
F_i = the failure rate of the ith LRU in failures per month or 720 x FR_i,
W_i = weight of the ith LRU in tons,
C = transportation cost per ton mile.

The monthly cost of off-site inventory, supply pipeline, and repairable discarded LRU's for the on-site repair alternative is

$$I = (1+h) \sum_{i=1}^{n} \sum_{s=1}^{n_s} C_i (M_s r_i J_i F_i PL_i)/L + \sum_{i=1}^{n} \sum_{s=1}^{n_s} C_i M_s J_i r_i F_i , \qquad (17)$$

where h is the inventory carrying charge and PL_i is the production or procurement lead time for the ith LRU in months.

Similarly, for the off-site repair alternative,

$$I = (1+h) \sum_{i=1}^{n} \sum_{s=1}^{n_s} C_i \{ M_s J_i F_i (PL_i r_i + (1-r_i)(E + T_D + T_{R_i})) \}$$

$$+ \sum_{i=1}^{n} \sum_{s=1}^{n_s} C_i M_s r_i J_i F_i , \qquad (18)$$

where E is the depot or factory repair cycle time in months, and T_{R_i} is the time required for removal and replacement of the failed LRU (MTTR).

The off-site inventory and supply pipeline cost for the throwaway LRU's is determined from equation (18) by setting $r_i=1$.

The monthly cost of labor expended in the repair of LRU's is calculated from

$$B = \sum_{i=1}^{n} \sum_{s=1}^{ns} M_s \; J_i \; F_i \; (H_i \; T \; C_L + Q_i \; C_i) \; , \qquad (19)$$

where H_i is the man-hours worked per hour of repair time in integers of 1,2,3, etc., depending upon crew size, T is the repair time, C_L is the cost per manhour worked at skill level L, and Q_i is an estimate of the fraction of LRU cost required for piece parts to repair the ith LRU.

Cost equations for test equipment are included in the analysis, but will not be discussed here. Further, safety stock calculations are available in the model as an option.

A one-page sample of each report produced by the model is included in Figures 5 through 9 . Appropriate explanations and comments are provided on each example.

The following study is included as an example of the numerous studies which the U. S. Army Communications Command has conducted using the ACCLOGTROM.

Six trade-off curves of increasing AN/MSC-46 Satellite Earth Terminal availability goals as a function of the least cost of on-site initial spare LRU stock levels were developed. The first curve was for the existing modified AN/MSC-46 SET. The second curve was for the existing terminal including an active redundant antenna subsystem. Curve three was for the existing terminal with its power supply exchanged with an uninterrupted power source (UPS). Curve four was for the modified terminal including the UPS and redundant antenna. These four curves were developed assuming that LRU's would be repaired at a depot location. Curve five was for the modified terminal with UPS and assuming site repair of failed LRU's. Curve six was for the modified terminal with UPS, active redundant antenna and site repair.

The critical assumptions made were:

a. Total ordering and shipping time to the location site from the depot was five days (Runs 1 thru 6).

b. Repair (individual component) parts procurement lead time was 15 days if parts not in depot (Runs 1 thru 6).

c. Complete LRU (replaceable assemblies) procurement lead time varied with LRU between one to six months (Runs 1 thru 6).

d. Depot stockage of LRU spares was assumed at the 95% level.

e. For the "Depot Repair" runs (1 thru 4) repair parts were assumed stocked at the 95% confidence level at the depot at zero at the site.

f. For the "Site Repair" alternatives (Runs 5 and 6) repair parts were assumed stocked at the 50% confidence level at the depot and at the 95% confidence level at the site.

g. A complete, active redundant, antenna subsystem was assumed for runs 2, 4, and 6.

h. In the UPS runs the generator subsystem failure rate of 833.33 failures per million hours was replaced with an assumed failure rate of one failure per million hours. Also, the 0.25 hours maintenance time for the generator subsystem was replaced by a one-hour maintenance time for UPS.

Results of the six runs are summarized in the chart shown in Figure 5 . The term "System Perfect" as used in this study means perfect or unlimited logistic support such that no average logistics delay is incurred upon failure. The curves in Figure 5 clearly show that the current modified terminal can be improved by the addition of a redundant antenna and UPS. Further, the substantial potential reductions in cost by performing on-site repair is apparent. This type of display enables management to see what can be expected for the investment, thus allowing a more quantifiable and defendable decision, as was the case in this study.

In conclusion, the ACCLOGTROM is an analytical availability versus logistic support cost trade-off model which is being used routinely by the U.S. Army Communications Command in logistics support of worldwide DSCS Satellite Earth Terminals. Additionally, data is being accumulated on other communications systems under the O and M responsibility of USACC for ACCLOGTROM processing and analysis of the logistics support to these systems.

Complete documentation of the ACCLOGTROM including tapes of the CDC-6500 FORTRAN extended source programs are available upon request from the Commander, U.S. Army Communications Command, Office of the Comptroller, Systems and Economic Analyses Division, Fort Huachuca, Arizona 85613.

PREDICTED MSC-46 AVAILABILITY VS. COST

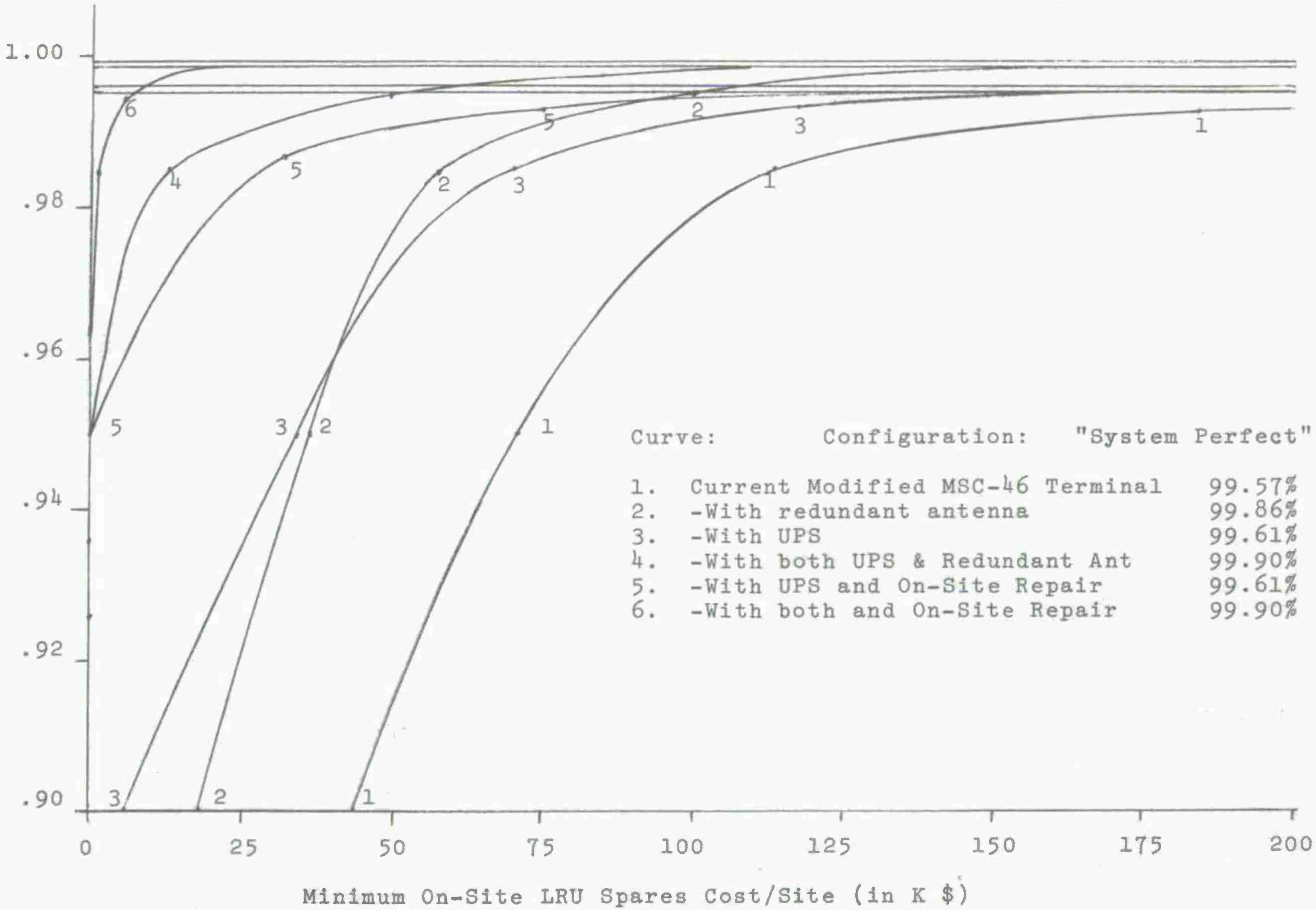


Figure 4

```
LM2100-0001 BEGINNING OF MESSAGES FOR DATA SET   1

RUN NUMBER =          1            DATE = 07/17/74          TIME=      5.82

TEST EQUIPMENT DATA (T04), VERSION      0
LOCATION TABLE      (L08), VERSION      0
MANPOWER COSTS      (M09), VERSION      0
PART DATA           (P03), VERSION 150574
NETWORK DATA        (N11), VERSION 150574

AVAILABILITY REQUIRED=  .899999999999999

SYSTEM PERFECT AV      =  .995508030864276

SYSTEM RELIABILITY     =  .998050406854034

AVAILABILITY WITH INPUT SPARES SET= .651935652572007   <—— AVAILABILITY WITH NO SPARES
COST OF INPUT SPARES SET =        0.00

SYSTEM AVAILABILITY FOR SLACK FACTOR SPARE SET =  .98770935198664673E+00   <—— ITERATION 1

SUM OF VALUES FOR SLACK FACTOR SPARE SET =  .35120E+06
SUM OF VALUES =  .78619E+05

SYSTEM AVAILABILITY =  .9083578688018932

SYSTEM AVAILABILITY FOR SLACK FACTOR SPARE SET =  .9083578688018932E+00   <—— ITERATION 2

SUM OF VALUES FOR SLACK FACTOR SPARE SET =  .78619E+05
SUM OF VALUES =  .78619E+05   <—— TOTAL LRU COST

SYSTEM AVAILABILITY =  .9083578688018932

AR-PRODUCT= .9065825772183906

WEEKLY  ON-SITE    REPAIR TIME        DEPOT     REPAIR TIME       FACTORY   REPAIR TIME       DISCARD   REMOVE TIME
          1  1   .45217400E+00          2  1   .63958944E+01         4  0  0.                     5  1   .34806411E-01

WEEKLY  ON-SITE    REPAIR TIME        DEPOT     REPAIR TIME       FACTORY   REPAIR TIME       DISCARD   REMOVE TIME
          1  1   .29641752E-02          2  1   .76742400E-01         4  0  0.                     5  0  0.

WEEKLY  ON-SITE    REPAIR TIME        DEPOT     REPAIR TIME       FACTORY   REPAIR TIME       DISCARD   REMOVE TIME
          1  1   .85294054E-02          2  1   .21860160E+00         4  0  0.                     5  0  0.

SYSTEM AVAILABILITY =  .9083578688018932
SUM OF VALUES =  .78619E+05

SYSTEM AVAILABILITY WITH NO SPARES = .6519356525720070

WEEKLY  ON-SITE    REPAIR TIME        DEPOT     REPAIR TIME       FACTORY   REPAIR TIME       DISCARD   REMOVE TIME
          1  1   .33246688E+00          2  1   .71745946E+01         4  0  0.                     5  1   .29855542E-01
          1  1   .79613446E+00          2  1   .13865833E+02         4  0  0.                     5  1   .64661953E-01
```

SITE	ON-SITE INV COSTS	SUPP EQUIP COSTS	TRANSPORT COSTS	OFF LINE REP COSTS	OFF SITE COSTS	TOTAL SITE COSTS
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00
4	655.16	0.00	574.86	2889.49	5334.53	9454.03
5	655.16	0.00	574.86	2889.49	5334.53	9454.03
6	655.16	0.00	574.86	2889.49	5334.53	9454.03
7	1310.31	0.00	1291.46	5778.98	6525.61	14906.37
8	1965.47	0.00	2008.07	8668.47	7722.04	20364.04
9	2620.62	0.00	2567.18	11557.96	9216.88	25962.64
10	2620.62	0.00	2567.18	11557.96	9216.88	25962.64
11	2620.62	0.00	2567.18	11557.96	9216.88	25962.64

Figure 5
ACCLOGTROM RUN CONTROL

INITIAL AND COMPUTED VALUES

TEST EQUIPMENT CODE = 1 TEST EQUIPMENT SET FOR MOD ULES REQUI RING NO TEST EQPT

PART NUMBER	LEAF NUMBER	SPARES INIT	SPARES ADJ	SPARES MIN	LOGISTICS DELAY TIME (HR.)	LOAD FACTOR	EXPECTED ANNUAL FAILURES	EXPECTED ANNUAL REPAIR TIME (HR.)	DEPOT SPARES PROTECTION
PSK MD-921/G	1	0	1	0	.15560500E+03	.17770091E-02	.10003920E+00	.38014896E+01	.95000000
SM-A-724784	2	0	1	0	.15560500E+03	.98453570E-02	.55538400E+00	.21104592E+02	.95000000
SM-D-739483	3	0	0	0	.15560500E+03	.39461428E-01	.72215360E+01	.84418368E+02	.95000000
SM-F-753361-1	4	0	1	0	.15560500E+03	.98653570E-02	.55538400E+00	.21104592E+02	.95000000
SM-F-753361-3	5	0	0	0	.15560500E+03	.98653570E-02	.55538400E+00	.21104592E+02	.95000000
1525509	6	0	1	0	.15560500E+03	.17770091E-02	.10003920E+00	.38014896E+01	.95000000
1525511-102	7	0	1	0	.15560500E+03	.17770091E-02	.10003920E+00	.38014896E+01	.95000000
1525530-100	8	0	1	0	.15560500E+03	.46308048E-02	.26069760E+00	.99065088E+01	.95000000
1525531-100	9	0	1	0	.15560500E+03	.75872998E-02	.42713760E+00	.16231229E+02	.95000000
1525532-100	10	0	1	0	.15560500E+03	.42573528E-02	.23967360E+00	.91075968E+01	.95000000
1525805-100	11	0	1	0	.15560500E+03	.17770091E-02	.10003920E+00	.38014896E+01	.95000000
1548419	12	0	1	0	.77700000E+03	.89355000E-03	.10074000E-01	0.	.95000000
1549581	13	0	1	0	.15560500E+03	.17770091E-02	.10003920E+00	.38014896E+01	.95000000
360066-1	14	0	0	0	.15560500E+03	.31121000E-04	.17520000E-02	.66576000E-01	.95000000
360120-1	15	0	2	0	.15560500E+03	.48231326E-01	.27152496E+01	.10317948E+03	.95000000
360146-1	16	0	1	0	.77700000E+03	.88733400E-02	.10003920E+00	0.	.95000000
360163-1	17	0	1	0	.15560500E+03	.17770091E-02	.10003920E+00	.38014896E+01	.95000000
360234-042	18	0	1	0	.15560500E+03	.17770091E-02	.10003920E+00	.38014896E+01	.95000000
53C1-82901	19	0	1	0	.15560500E+03	.17770091E-02	.10003920E+00	.38014896E+01	.95000000
5314-045	20	0	1	0	.77700000E+03	.14840700E-01	.16731600E+00	0.	.95000000
5314-069	21	0	1	0	.77700000E+03	.12432000E-02	.14016000E-01	0.	.95000000
723398-22	22	0	0	0	.15560500E+03	.88694850E-04	.49932000E-02	.18974160E+00	.95000000
723899-854	23	0	1	0	.77700000E+03	.17746680E-01	.20007840E+00	0.	.95000000
996652-1	24	0	1	0	.77700000E+03	.88733400E-02	.10003920E+00	0.	.95000000
996669-4	25	0	0	0	.77700000E+03	.77700000E-05	.87600000E-04	0.	.95000000
						TEST EQUIPMENT TOTAL	.89291556E+01	.31682520E+03	

Figure 6

INITIAL VALUES

ACCLOGTRON PART DATA AND ON-SITE SPARES BY PART NUMBER

TEST EQUIPMENT CODE = 1 TEST EQUIPMENT SET FOR MODULES REQUIRING NO TEST EQPT

PART NUMBER	LEAF NUMBER	CRIT CODE	PART COST	PART DENSITY	ON SITE SPARES	FAILURE RATE (10-6)	REMOVE AND REPLACE TIME	REPAIR TIME (HOURS)	WASH OUT RATE	REPAIR LOCATION	DOWNTIME PER FAILURE (HOURS)	SITE PROTECTION
PSK MO-921/G	1	C	10000	1	0	11.4200	2.00000	40.00000	.05	DEPOT	157.6050	0.00000000
5M-A-724784	2	C	30000	1	0	63.4000	4.00000	40.00000	.05	DEPOT	159.6050	0.00000000
5M-D-739483	3	C	10000	2	0	126.8000	.00200	40.00000	.05	DEPOT	155.6070	.00000000
5M-F-753361-1	4	C	50000	1	0	63.4000	4.00000	40.00000	.05	DEPOT	159.6050	0.00000000
5M-F-753361-3	5	C	50000	1	0	63.4000	4.00000	40.00000	.05	DEPOT	159.6050	0.00000000
1525509	6	C	390	1	1	11.4200	1.53100	40.00000	.05	DEPOT	1.8070	.99822614
1525511-102	7	C	4572	1	0	11.4200	1.53100	40.00000	.05	DEPOT	157.1360	.00000000
1525530-100	8	C	995	2	1	14.8800	1.53100	40.00000	.05	DEPOT	2.2483	.99539054
1525531-100	9	C	1048	4	1	12.1900	1.53100	40.00000	.05	DEPOT	2.7027	.99246983
1525532-100	10	C	1153	2	1	13.6800	1.53100	40.00000	.05	DEPOT	2.1907	.99576070
1525805-100	11	C	1858	1	1	11.4200	1.54500	40.00000	.05	DEPOT	1.8210	.99822614
1548419	12	C	47	1	1	1.1500	1.54500	16.00000	1.00	DISCARD	2.2387	.99910725
1549581	13	C	250	1	1	11.4200	1.00000	40.00000	.05	DEPOT	1.2766	.99822614
360066-1	14	C	927	2	0	.1000	2.28400	40.00000	.05	DEPOT	157.8890	.00000000
360120-1	15	C	21695	4	1	77.4900	4.54700	40.00000	.05	DEPOT	11.7067	.95398790
360146-1	16	C	40000	1	0	11.4200	4.00000	40.00000	1.00	DISCARD	781.0000	0.00000000
360163-1	17	C	2000	1	0	11.4200	2.00000	40.00000	.05	DEPOT	157.6050	0.00000000
360234-042	18	C	3500	1	0	11.4200	2.00000	40.00000	.05	DEPOT	157.6050	0.00000000
53C1-82901	19	C	8750	1	0	11.4200	1.54500	40.00000	.05	DEPOT	157.1500	.00000000
5314-045	20	C	118	1	1	19.1000	4.66400	24.00000	1.00	DISCARD	16.0266	.98537633
5314-069	21	C	110	1	1	1.6000	4.66400	24.00000	1.00	DISCARD	5.6288	.99875834
723398-22	22	C	1003	1	0	.5700	1.54500	40.00000	.05	DEPOT	157.1500	.00000000
723899-854	23	C	438	2	1	11.4200	2.00000	40.00000	1.00	DISCARD	15.5487	.98256277
996652-1	24	C	87	1	1	11.4200	1.53100	16.00000	1.00	DISCARD	8.3649	.99120470
996669-4	25	C	495	1	0	.0100	1.54500	40.00000	1.00	DISCARD	778.5450	.00000000

Figure 7

MINIMUM ON-SITE SPARES AND LRU DATA

SEA74T03 USACC LOGISTICS TRADE-OFF MODEL NET = 46 PAGE 1

ACCLOGTROM COST CALCULATIONS BY TEST EQUIPMENT GROUP

TEST EQUIPMENT CODE = 1 TEST EQUIPMENT SET FOR MODULES REQUIRING NO TEST EQPT

SITE	ON-SITE INV COST	SETS	SUPP EQUIP COSTS	TRANSPORT COSTS	OFF LINE REP COST	OFF SITE COSTS	TOTAL SITE COSTS
1	0.00	0	0.00	0.00	0.00	0.00	0.00
2	0.00	0	0.00	0.00	0.00	0.00	0.00
3	0.00	0	0.00	0.00	0.00	0.00	0.00
4	234.96	0	0.00	474.19	2122.06	3280.35	6111.57
5	234.96	0	0.00	474.19	2122.06	3280.35	6111.57
6	234.96	0	0.00	474.19	2122.06	3280.35	6111.57
7	469.93	0	0.00	1065.30	4244.12	4266.04	10045.39
8	704.89	0	0.00	1656.41	6366.19	5257.07	13984.55
9	939.85	0	0.00	2117.60	8488.25	6546.50	18092.21
10	939.85	0	0.00	2117.60	8488.25	6546.50	18092.21
11	939.85	0	0.00	2117.60	8488.25	6546.50	18092.21
12	939.85	0	0.00	2117.60	8488.25	6546.50	18092.21
13	939.85	0	0.00	2117.60	8488.25	6546.50	18092.21
14	1174.81	0	0.00	2591.79	10610.31	7920.56	22297.48

NO. OF TEST SETS OFF SITE = 1

TEST EQUIP. COST OFF SITE = 0.00

Figure 8

LIFE CYCLE COST REPORT

SEA74T05 USACC LOGISTICS TRADE-OFF MODEL NET = 46 PAGE 1

ACCLOGTROM ON-SITE SPARES STOCKAGE LIST

PART NUMBER	NOMENCLATURE	NUMBER OF SPARES
PSK MO-921/G	MODEM AND RACK	0
SM-A-724784	LIQUID COOLER HEAT EXCHANGER	0
SM-D-739483	PARAMETRIC AMPLIFIER	0
SM-F-753361-1	NON-MODAL FREQUENCY CONVERSION SUBSYSTEM	0
1525509	ANT. FEED ASSEMBLY	1
1525511-102	FUNCTION SELECT CARD	0
1525530-100	AMPLIFIER CARD	1
1525531-100	TRIGGER CARD	1
1525532-100	REFERENCE AND GATING CARD	1
1525805-100	COMPARATOR	1
1548419	ARC DETECTOR ASSEMBLY	1
1549581	MOTORIZED HANDCRANK	1
360066-1	PHASE SHIFTERS	0
360120-1	TRANSMISSION	1
360146-1	BALL SCREW ACTUATOR	0
360163-1	PORTABLE CONTROLLER	0
360234-042	HYDRAULIC CYLINDER	0
53C1-82901	53C ORDERWIRE	0
5314-045	CIRCULATING FAN/MOTOR	1
5314-069	HEATER	1
723398-22	DUMMY LOAD	0
723899-854	AZIMUTH SHOCK ABSORBERS	1
996652-1	30 DB ATTENUATOR	1
996669-4	WAVEGUIDE WINDOW	0
361054-11	VACUUM PUMP	1
1525653-100	RECEIVER DECODER	0
1525804-100	RF OSCILLATOR	0
1525810-100	FREQUENCY DIVIDER	0
1525900-100	BEACON SIGNAL DECODER	0
SM-F-717529	RADIO FREQUENCY AMP.	1
1525088-100	RF NOISE GENERATOR	0
1525090-100	FREQUENCY CONVERTER FUNCTION	0
1525096-100	+28V DC POWER SUPPLY	1
1525104-100	POWER METER ASSEMBLY A1, A2, A3	1
1525149-100	FREQUENCY CONVERTER	0
1525610-101	COMPARATOR	0
1525611-101	ELECT. FREQUENCY CONVERTER	0
1525612-101	BEACON ACQUISITION	0
1525613-101	RECEIVER GAIN EQUALIZER	0
1525614-101	SERVO DRIVE	0
1525615-101	IF AMPLIFIER	0
1525649-102	ELECT. FREQUENCY CONTROL	0
1525650-101	ACQUISITION FILTER	0
1525658-100	ELECTRICAL CONNECTOR ASSEMBLY	0
1525768-101	MAGNET POWER SUPPLY	0
1525920-100	HARMONIC GENERATOR DRIVER	0
1525921-100	MODULATOR CONTROL	1
1525992	SLIP CLUTCH	1
1526263-100	FAULT CARDS A1-A6	1
1526275-100	RELAY INTERLOCK CARD	0

ON-SITE SPARES STOCKAGE LIST

Figure 9

STOCK AVAILABILITY STUDY

Mr. J. M. Hodges
Mr. R. J. Caccamise

US Army Electronics Command

The Systems Analysis Office was tasked earlier this year to undertake a study of secondary item management. The objective of this study was to identify means of improving the management of secondary items. Specifically the "fill rate" of secondary items, termed the stock availability, was to be investigated and recommendations made for improvement.

Stock Availability is a technique used to measure supply effectiveness. It shows the percentage of requisitions for stocked items only that were filled. It is computed by dividing the number of requisitions for stocked items filled during the first pass by the number of requisitions for stocked items received. The AMC stock availability goal is 85% for each commodity command. The parameter is computed monthly through Military Supply Transportation Evaluation Procedure (MILSTEP) reports. Another technique used to measure supply effectiveness, also reported through MILSTEP, is "days wait". This is defined as the number of days that elapse between the receipt of a requisition at the Inventory Control Point (ICP) and the transmittal of the materiel release order to the depot. Both of the above measures are concerned with how well the legitimate demands of consumers are met by the supply system. Due in part to the fact that a goal has been set for stock availability, particular attention is paid to that parameter by managers. The calculation for this parameter is straightforward and the choice of input data is well defined. A weakness of stock availability is that equal weight is given each requisition regardless of the number of items demanded on each requisition.

Accurate computation of quantitative requirements is crucial to maintaining an acceptable stock availability. Individual item managers are assigned a given number of items by category for requirements computation. Varying degrees of management intensity are given items. The degree of emphasis is based primarily on dollar value with higher dollar value items receiving greater emphasis. Other governing considerations are:

(1) Criticality - Items critical to weapon system operational readiness require greater management emphasis.

(2) Special characteristics - Items having technical, hazardous, or sensitive characteristics require greater management intensity.

(3) Requisition frequency - Fast moving items require greater emphasis than items having fewer demands in the same time period.

The following are the degrees of management intensity assigned items:

(1) Very High Management Intensity - This category entails intensive review and analysis of requirements determination and day-to-day management to include updating demand and requirements data as changes occur.

(2) High Management Intensity - This category entails review of requirements determination on at least a quarterly basis and maximum use of computers with output subject to close manual review and validation.

(3) Medium Management Intensity - This category entails review of requirements determination at semi-annual intervals and maximum use of computers with output being manually received on a periodic basis.

(4) Low Management Intensity - This category entails review of requirements at least annually and maximum use of computers with output not normally subject to manual review.

In computation of requirements a Requirements Objective (RO) is computed for each item. The RO is the maximum quantity of an item maintained on hand and on order above the due out quantity. This objective consists of the following elements:

(1) Safety level quantity - This is the quantity of materiel that is required to be on hand to preclude minor interruption of normal replenishment caused by unpredictable fluctuations in demand. The model used at present does not consider unusually high demands. Negative safety levels are not used.

(2) Foreign Military Sales Order (FMSO) - FMSO is an approved order placed by a foreign country for in-storage maintenance support of specific equipment and other logistical services or assistance to be furnished by the United States within the terms of current Supply Support Agreements.

(3) Procurement leadtime requirement (PROLTR) - PROLTR is that quantity of an item that represents the forecast demand quantity for the period beginning when the procurement work directive is generated and ending when a significant quantity is actually received. Therefore, the PROLTR is equal to the total demand quantity that is expected to occur during the procurement leadtime (PROLT). The PROLT consists of the following:

(a) Administrative leadtime (ALT) is the average time from the date the procurement work directive is generated to the date when the contract is let.

(b) Procurement leadtime (PLT) is the average time from the date of the contract to the date of receipt of the first significant contract delivery. A significant delivery consists of a quantity equal to or greater than one third of the total procurement work directive quantity or procure-subline value, as applicable. The PLT is computed by using the last representative procurement action (PLT portion); or by using the PLT value in the signed contract; or if representative procurement actions are not available within the last 18 months, by using representative PLT's for similar items. Contractor estimates are not used.

(4) Procurement Cycle Requirement (PROCYR) - PROCYR is that quantity of an item the represents the forecast demand quantity between procurement actions and is based on the Economic Order Quantity (EOQ*). There-

* EOQ is computed by a model which minimized the total cost. The model considers such things as holding cost, shortage cost, order cost, item cost, etc.

fore, the PROCYR is equal to the total demand quantity that is expected to occur during the procurement cycle (PROCY).

(5) Protectable War Reserve Materiel Objective (PWRMO) - At the beginning of the semi-annual stratification period the PWRMO will be equal to the total war reserve stocks on hand and on order at the end of the previous stratification.

The quantity of dues-out or back orders, while not strictly a part ofthe RO, influences procurement quantities directly. Dues-out represent an obligation to issue materiel as soon as replenishment stocks are received. In this sense they can be treated as negative inventory and must be reflected in any comparison of RO with stock on hand and on order.

Figure 1 shows the important stratifications of the RO. The reorder point (ROP) is that point where stock replenishment action should be taken to maintain the calculated RO and avoid future stockouts. The ROP, as shown in Figure 1, is established by summing all levels except the PROCYR. ROP's are established for all items in conjunction with the EOQ computations.

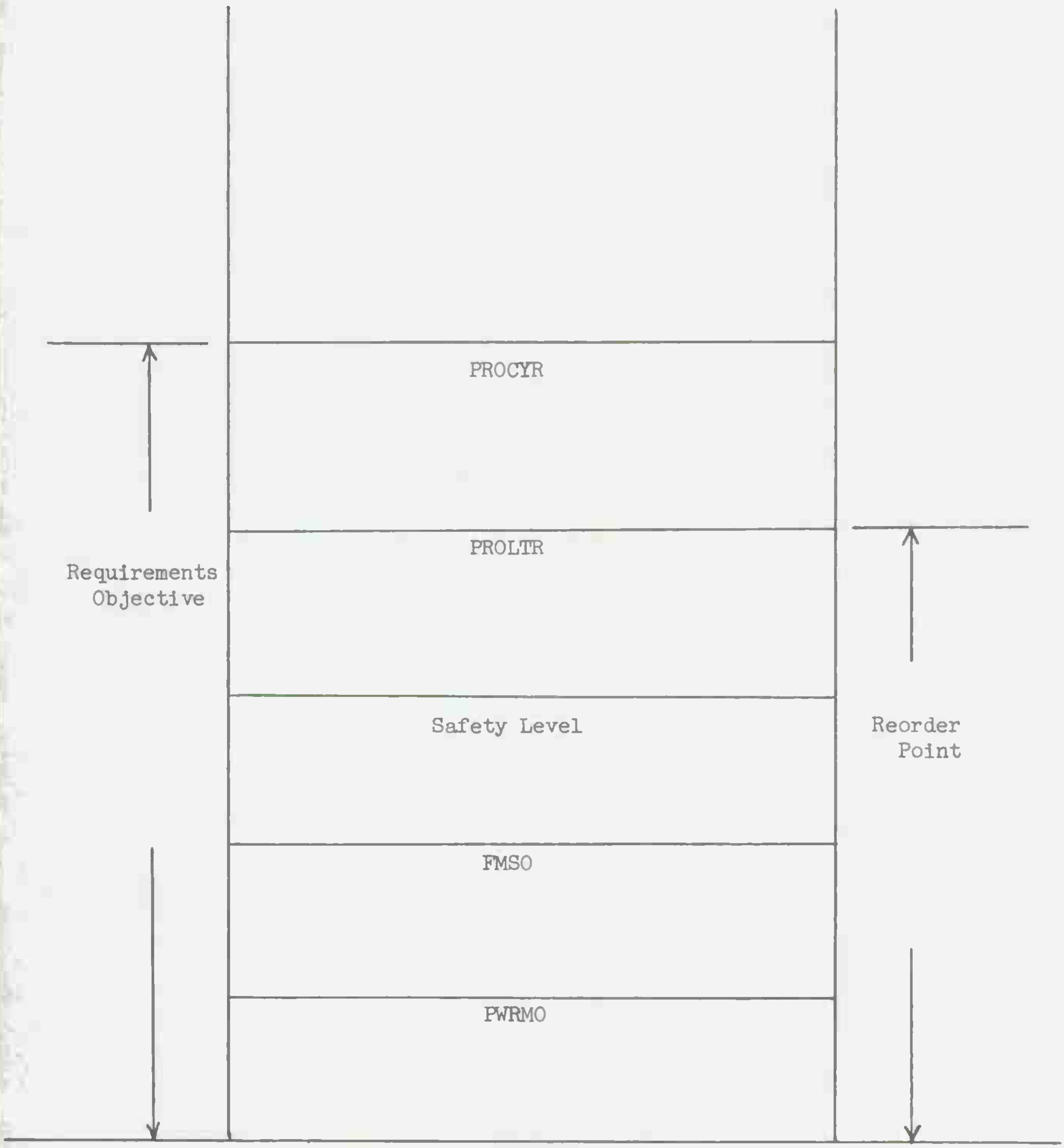
The safety level is necessary stratification of the RO since for the vast majority of secondary items, demand is neither constant nor highly predictable. The safety level is based only on a consideration of variations in demand over procurement leadtime. However, the safety level also represents a hedge to minimize the effects of poor forecasts, unforeseen demands, errors in reported asset data, variation in leadtimes, and similar requirements that might otherwise cause a stockout. The safety level provides a predetermined level of protection against stockouts due to demand fluctuation if the demand pattern is known. For example, if the distribution is normal, a safety level equal to two standard deviations of demand over leadtime will provide a 97.5% level of protection.

Safety levels are intended to protect against shortages resulting from random variation in item demand. Theyare not intended to protect against definite trends in average demand rates. Average monthly demands are normally computed by averaging historical demand received during the previous 24 months to the date of the requirements determination process. However, shorter periods of data are used if the 24-month demand base is not representative of the existing situation because of unusual activity that is significant to several months nearest to the current date, or items haven't been in the system for 24 months.

Figure 2 presents a hypothetical general inventory model with inventory level versus time. Both demand rates and leadtimes vary and the model illustrates how an unfilled requisition may result from excessive leadtime. Accurate forecasting of leadtimes is very important to maintaining acceptable stock availability.

Since the study was to be comprehensive and include the roles of all pertinent activities, effort was begun by interviewing key personnel in various activities to gain an understanding of potential problems in

Figure 1 - REQUIREMENT LEVELS



secondary item management. Discussions were also held with personnel from the USAMC Inventory Research Office who design analytical techniques for inventory control. As a result of these discussions, the following concepts were identified as fruitful areas of study for improvements in stock availability and hence supply effectiveness:

(1) Large communication "push packages" are developed which generate a large number of demands for secondary items. The generation of these demands will impact stock availability if only those secondary items which are not on back order status are included. For example, if thisiis the case and the number of demands generated by "push packages" has been increasing for a period of time, then managers should expect the stock availability to increase accordingly during this period, other factors being equal.

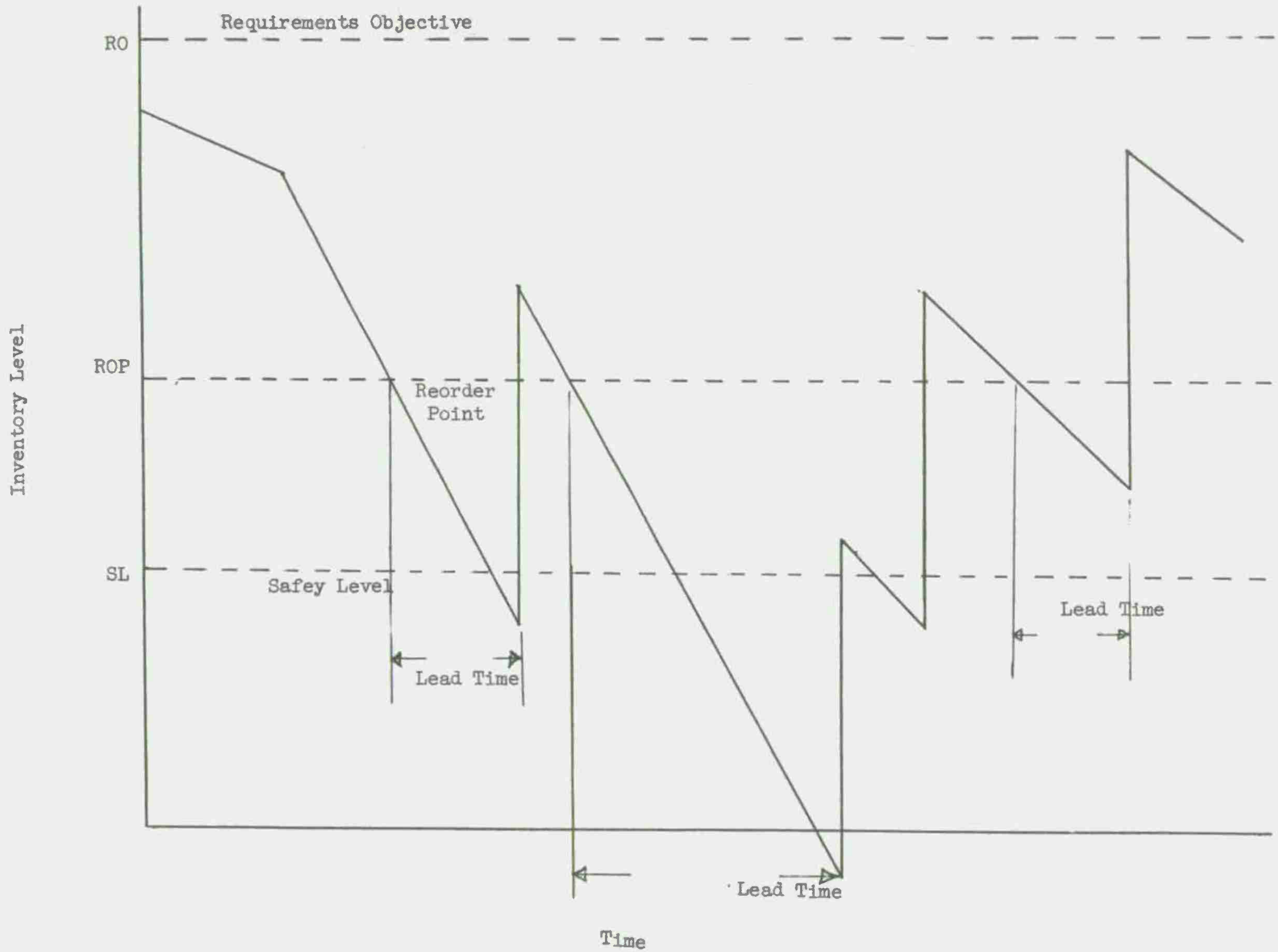
(2) Accuracy of demand forecast impacts stock availability. This is clear if the observation is made from reference to Figure 2 that a prolonged demand rate exceeding expectations can cause back orders.

(3) Demand variability assumptions which determine safety levels impact stock availability. If demand variability is underestimated then the resulting safety level does not provide the level of protection required and a greater than expected number of stockouts occur. This condition would adversely affect stock availability. Likewise, an overestimated demand variability would cause overstockage.

(4) A comparison of forecasted ALT's with actual ALT's could identify means of improving supply effectiveness. This is true since, as noted before, underestimated leadtime forecasts can cause back orders.

(5) Comparison of forecasted PLT's with actual PLT's could also identify means of improving supply effectiveness for the same reason as above. Forecasted PLT is thought to be a particularly important area of consideration since there is reason to believe that production leadtimes for the electronics industry have been increasing forthe past several years. A report by the Air Force Systems Command entitled "Increased Material and Component Lead Time Study", dated 14 December 1973, shows that from January 1973 to November 1973 material and component leadtimes increased significantly. The increases are due to a complex web of factors which includes dynamic market conditions of increasing demands and high industrial operation levels creating backlogs, price increases, and priority allocations.

FIGURE 2 - INVENTORY LEVEL VERSUS TIME



SUBJECT: Fort Leavenworth Installation Budget Model
(A Directed Research Project)

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CONCEPTUAL BACKGROUND

1. Introduction

This research project had as its genesis a requirement stated by the USACGSC Department of Command that there existed a need for development of a methodology for scientific management of the fiscal aspects of base operations activities at installation level. This methodology, which would utilize quantitative management techniques and the capability of the computer, would be designed to assist the installation commander and comptroller in determining base operations funding level requirements on a more scientific basis than that presently used. The methodology would be embodied in an econometric input/output model that would serve two functions: (1) determine funding required; and (2) allocate funds when shortfalls were experienced between requirements and actual allowances. The model would permit acceleration of the budget preparation cycle at installation level and make time that is now spent in manual computations available for detailed managerial analysis of fund usage and requirements. The basic hypotheses on which this research is predicated are:

a. That there exists an identifiable and measurable output in each base operations activity.

b. That these outputs are related to the dollars put into that activity.

c. That these relationships, as well as the relationship among the base operations activities can be expressed by an econometric model.

The key element of the methodology is the development of a mathematical relationship between the dollar inputs to each base operations activity and the outputs of the activity--either quantified performance data or demand satisfaction.

The first approach requires that a cost estimating relationship be developed between performance or activity level, e.g., requisitions processed, jobs completed, records maintained, and the dollars required as input to support that level of activity.

The second approach requires the identification of factor(s) which bear a statistically significant relationship to dollars consumed or inputed to base operations activities. These factors need not necessarily be directly related to the outputs of the activity analyzed. However, the factor should exhibit a high degree of correlation with the dollars spent in the particular base operations activity. This factor could well be something either endogenous or exogenous to the installation, e.g., military population of the installation or size of the Army budget.

Ideally, the predictor should be an endogenous factor that is expressed in the installation mission, e.g., the size of the regular class at CGSC, or, is a performance factor of the activity as expressed in AR 37-100-XX. The difficulty with relying on performance factors is that these are, in reality, functions of demand for activity output. Thus, in the case of the resale commissary operation, the performance factor is dollars of sales. In actuality, dollars of sales are a function of the population served by the commissary, i.e., the number of military families and/or sponsors and dependents in the area served by the store. Similar examples can be found in other areas of base operations activities.

If a constancy in the relationship between the population generating the demand for activity and the dollars required to operate the activity exist, the population would then serve as the statistically significant predictor of dollar inputs. The added advantage of this approach is that figures for the population to be served (personnel, equipment, real estate) are normally provided the installation commander with his annual budget guidance. This would then enable use of the factors in the model to predict what fund requirements will be. Additional utility would be provided by the constancy of these relationships in that they could be applied to all similar installations and thus provide a useful tool to both installation and higher level commanders. This is in contrast to most of the AR 37-100-XX performance factors which are installation peculiar and are more in the nature of historical records of activity, available only after the fact and are, when predicted, done so on the basis of the population anticipated.

Both of the approaches have as a scientific basis the methodology of econometrics, which is concerned with the use of the theories of economics, statistics and mathematics to forecast the behavior of economic systems. Econometric models of systems as complex as that of the entire economy of the U.S. are used daily to assist the government in formulating fiscal and monetary policy as well as by businessmen in making a variety of crucial business decisions. Although these models are extremely complex and constructed in a variety of ways, they have in common the use of demand data as predictors of economic activity in much the same fashion as posited above.

Within DOD, econometrics has been given the name economic analysis. This type analysis is used in weapons cost analysis, DA budget preparation and in the management of a variety of industrial-type operations. Its use in the field of base operations management is still virtually uncharted.

2. Demand Determination

As alluded to above, it would appear that if the population generating demand could be distinctly characterized by inclusion of a sufficient number of variables, and serve as a predictor of required fund input, a generalized model can be developed which would be valid for any installation. This is the same type approach taken in business where demographic factors are used to develop statistical relationships in econometric models. A simple business example may better illustrate the point. A grocery store owner is faced with the decision of predicting his gross sales for the following year. In the absence of an econometric model, he would, much in the same fashion as a post activity director, assume that next year's sales will be approximately the same as this year's. He would thus plan no expansion and prepare for the same level of activity. If nothing changed in the community he serves, he would be fairly accurate in his prediction. If, however, a large apartment building suddenly appeared in the area served by his store, his sales would expand significantly; and conversely, if several hundred family residences in the area were removed by urban renewal, his sales would contract significantly. In both cases, his failure to consider the population he is serving would cause his prediction to be in error.

There are, of course, factors other than number of families that would impact on his sales. The size of each family, as well as the income of the families, would also have significant effect. Thus, were he to use econometrics to solve his sales forecasting problem he would, as a minimum, attempt to establish a relationship using multiple regression analysis between his sales as a dependent variable and the number of families in the area served, the average size of the family and the average family income as independent variables. In all probability, his use of this data would enable him to make much better forecasts as to his sales level than would a mere assumption that next year will be the same as this year.

This is the same sort of theoretical reasoning that underlies the approach taken in this paper. If the installation commander can either be given, or in some fashion deduce the demand he must satisfy for base services, he can, given historically developed CER's or statistical predictors, make a fairly accurate estimate of the funding level that will be required to support his base operations activities.

If this basic hypothesis can be accepted, the results would be significant in terms of effective management both at installation and higher headquarters levels. The impact of population changes, either equipment or personnel, on funding levels could be quickly ascertained and appropriate budgetary changes made.

3. Allocation of Funds

Unfortunately forecasting fund requirements is but one aspect of the fiscal management problem at installation level. A related problem is that of resolving the differences between requirement for funds and the actual funding levels authorized. Very few managers ever receive the level of funding they feel is necessary to accomplish their mission. The heart of the manager's problem is the apportionment of the shortfall between requirements and resources.

This problem is the crux of the installation comptroller's problem. At present, resolution is made by a trial and error manual method of either applying across the board cuts to all activities or simply not funding those activities which have the lowest level of priority in the eyes of the commander. Neither of these options is satisfactory. The former method ignores the fact that, based on demand, some activities can absorb cuts without degrading service while others simply cannot. The latter generates a pattern of deferral of activity that often permits a degradation of an activity to a point where either the item is no longer economically repairable or the funds originally requested are totally insufficient to do the job even when they become available. As an example, deferral of a maintenance project for a year will result in higher costs in the subsequent year due to factors of inflation as well as additional aging.

In attempting to resolve this problem, several approaches recommend themselves as being feasible. The obvious method of redressing shortfalls in funds would be the one already mentioned, application of an across the board percentage cut to all activities regardless of the demand the activity is required to support. This would represent no real improvement over present methods of accomplishing the same thing except that an econometric model could quickly determine the amount of unsatisfied demand that would be generated in each account. The manager could then, on the basis of this quantified impact, attempt to obtain additional funding. Were this not possible he could, without assistance of the model, subjectively apply additional cuts in certain activities thereby generating additional funds to apply to those with the most significant unfilled demand. This is essentially the process that is followed now and thus the model would not really assist in facilitating resolution of shortfall problems.

The second approach that is deemed feasible is to, in some fashion, incorporate a "commander's utility index" into the model, that would prescribe in quantified terms the priority the particular commander assigns to the various installation activities. When a shortfall situation arose the model would make cuts from the amount forecasted on the basis of anticipated demand, by reducing funds first for the lowest priority activity by a dollar amount that would be necessary to support the demand the commander is willing to see remain unfilled. This would, of necessity, be an interative process, requiring some feedback mechanism that would inform the commander when he had satisfied the total shortfall.

A variant of this process would be a methodology that would preincorporate the utility index. What would then be required is a statement to the model of the dollars available. The model would then, utilizing this index, fund those activities with the highest utility first, and those with lesser utility in descending order, until the available funds were exhausted. Each of these utility approaches would provide a budget that reflects the commander's desires on the optimal utilization of the funds given him on the basis of his preferences and priorities. This would in fact be a most ideal situation were it technically feasible.

What makes it an extremely difficult approach is the necessity for quantification of relative utility for some 40 installation activities that are supported by base operations funds. This would require, as an example, a commander to state his preference for satisfying demand for things as diverse as headquarters operations, a chapel program, wheeled vehicle maintenance, and garbage collection, in some quantified fashion. Compounding this problem would be the fact that installation budgeting is a bureaucratic process that incorporates not only the desires of the commander himself, but a host of other lesser managers whose utility index for various activities would most certainly be different. A change in personality anywhere within the decisionmaking bureaucracy would invalidate the current index and require development of an almost completely new model incorporating the preferences of the new personality. Although it is felt this would be the most ideal method of handling the allocative process its complexity removes it from the realm of possibility.

The last possibility and the one which is deemed to be the most feasible is the development of patterns of relationships among the various activities that would reflect the impact dollar shortfalls would have in all areas. The model would thus incorporate basically two relationships: one between demand determinants or cost predictors and dollar requirements for each account or activity and a second showing how, on the basis of both demand and internal correlation, one dollar of funds would be optimally distributed. This would be in the nature of an incremental distribution model which would show how an increase or decrease in funds would be distributed between activities. Operationally the model would take the shortfall between forecasted and allocated funds and distribute the shortfall decrementally throughout the system. Once the distribution is complete the model could then show the amount of unfilled demand in each activity. The value of this type result is somewhat limited since it provides the decisionmaker with a somewhat "take it or leave it" situation. Therefore, it would appear that an additional feature of the model must be a device that permits introduction of utility in terms of a level of demand that must be filled by high priority activities. This could be done either by means of a minimum demand floor or a dollar floor that when reached would isolate the particular activity from the decrementing process. The process would continue until the total shortfalls had been distributed. This feature could also be useful in the generation of the forecast by permitting the establishment of a ceiling on either dollar level or demand level that would reflect the maximum amount of resources the commander desired to allocate to a particular activity.

This last approach appears to be the most feasible one both in terms of development and in solving the allocative portion of the budgeting process at installation level. A model of this nature would of course automate a portion of the budget preparation, but more importantly it would permit development of an array of budget options that would give, in quantified terms, the results of any number of budget decisions made by the commander. This would be done quickly and permit analysis of the varying impacts of these decisions.

4. Summary

In summary, the research project addresses two basic concepts. The forecasting portion of the model is developed by finding statistically valid predictors of fund requirements using multiple regression analysis. The predictors are the set or sub-sets of the populations served by the installation.

The allocative portion of the model is developed by devising a method of incrementally increasing or decreasing the amount of funds forecasted on the basis of internal relationships between the various activities.

The totality of the effort produced a model that accepts a commander's guidance either in terms of dollar inputs or desired outputs and produces an installation budget option. Because of the speed with which the model operates, the commander will be able to vary this guidance and receive a new budget option that shows the impact of his decision. Through this iterative process, the commander will eventually generate a budget option that will optimize his conception of resource allocation or maximize outputs he deems essential to his proper mission accomplishment. A corollary development will be the generation of time in which those responsible for budget preparation will be able to effectively analyze the use of funds—time that is presently spent in manual computation of a single budget option.

DESCRIPTION OF THE MODEL

1. Introduction

The BUDGET model is a computerized analogy of the fund allocating process used at installation level. It is designed to allocate funds within a financial management structure based on multiple forecasts of a detailed expense history.

a. Scope. The BUDGET model is designed for application at the installation level. It contains the necessary framework for representing the Army base operations accounts in terms of main accounts (.BO, .CO, etc.) and sub-accounts (.B1, .B2, etc.). Within each account direct and reimbursable funds are represented in four expense categories each. These expense categories correspond to major grouping of elements of expense. The model uses the expense history within this structure to forecast expenses for some future year and then allocates funds within the structure based on constraints imposed by budget guidance.

b. Purpose. The BUDGET model was developed as a tool to assist the installation comptroller in determining his annual budget. This is currently accomplished through a manual process in which account representatives present their proposed requirements and justification for funds. Given these proposals, the installation comptroller (and/or commander) arbitrate competing proposals consistent with available funds. The magnitude of the computational effort and the relative short time interval allowed for preparing a budget precludes detailed analysis of alternative budgeting schemes. The BUDGET model was designed to overcome these weaknesses. It automates the computational process and provides the means for rapidly generating alternative budgets based on different strategies for using the funds. This releases the budget analysts from the manual work of computations and allows them to dedicate their effort toward analyzing from a management rather than an accounting perspective.

2. Approach

The BUDGET model performs three general functions--bookkeeping, forecasting and allocation.

a. Bookkeeping. The bookkeeping functions array historical expense data and installation variables in a 14-year annual file. The files are designed to hold up to 14 years of historical data. When the files become full, future annual updates cause the oldest year in the file to be deleted. This feature recognizes the fact that when data becomes too old it loses its utility in a forecasting system. On the other hand, the system requires sufficient historical data to achieve statistical confidence. The 14-year term is an arbitrary resolution of this trade-off. The files are maintained on a permanent tape file which can be updated or corrected with the utility routines that are part of the model. Presently, the model uses only six years of historical data starting with 1969. Changes in the budgeting system in 1969 render prior data incompatible with the later data.

b. Forecasting. This function is performed using the Bio-medical stepwise multiple linear regression routine (BMD02R). The model contains a fixed set of up to 30 independent variables. A set of nine independent variables (one is always an annual inflation factor) are selected for each account by the analyst. Independent variables are either measurements of levels of activity, activity demand generators (population, land area, civilian employees, etc.), statistically significant fund level predictors or historical expenses of a dependency account. Given that there are N years of historical data, the regression routine selects N-2, but not more than nine, variables which provide the highest level of correlation to produce a forecasting equation for each individual expense category of each individual account. Estimates of each independent variable for the forecasted year are then fed into the forecasting equations to produce the forecasts.

c. Allocation. The allocation function provides the means of adjusting forecasted expense levels to correspond with the total fund authorization and to correspond with any restrictions that may be placed on individual accounts. The procedure assumes that forecasted amounts will not necessarily equal the total authorization. The differential (either plus or minus) must therefore be either added to or subtracted from subordinate accounts. The adjustment factors are a function of the standard error of estimate for each applicable subordinate account as derived from the multiple linear regression on that account.

(1) The standard error of estimate for an account is a measure of the natural variability of the account's history. Assuming that the relevant variables that explain the fluctuation in expenses have been identified, any unresolved fluctuations are random and unexplained by the relationship between dependent and independent variables. For purposes of the BUDGET model this variation is assumed to reflect the elasticity of the account. In other words, it is the degree to which the account can expand or contract about its mean level. When an account is underfunded one year its representatives will argue more adamantly for additional funds the next year. Conversely, if it's overfunded its representatives will be hard pressed to justify additional funds. The standard error of estimate measures this trend. It is assumed that one standard error of difference from the forecasted mean (expressed in dollars) for account A represents the same degree of depravation (or excess) within that account as one standard error in account B would represent, even though the two errors may be vastly different.

(2) The objective function of the allocation routine is to allocate dollars to the various accounts such that all accounts are operating at the same degree of depravation or excess--the same number of standard errors of the estimate from the forecasted value. This is accomplished

throughout the accounting structure except where a constraint (ceiling or floor) terminates the allocation to a specific account.

3. System Variables

Three sets of variables are required to prepare the model for execution. These data establish the accounting structure and provide the basis for changing priorities and constraints on the allocation of money.

a. Hierarchy of Accounts (KCOD). This array defines the structure of the accounts. Each individual account is assigned a code number (three digits) external to the model. Code numbers are arranged in the KCOD array such that main accounts (B, C, G, etc.) appear on the first row. Sub-accounts (B1, B2, B3, etc.) appear below their respective main account in column. Provisions are made for 10 main accounts each having up to eight sub-accounts and a dummy account. The dummy accounts provide two functions. In some cases, the dummy account can be used to check the arithmetic consistency of the data, when not used as a miscellaneous account. In general terms, the KCOD array serves as a numerical representation of the lettered base operations account format.

b. Monetary Constraints (CONST). The CONST array provides the means for establishing floors and ceilings on direct expenses. These can be applied at any level in the hierarchy of accounts (i.e., expense category, sub-account, main account, or total Z account). At any level a floor or a ceiling can be applied to a given direct expense category. When these are established (they are not required) allocations are appropriately constrained. Constraints may be applied, for example, on accounts where expense levels are required by law or where anticipated expenses are known with a higher level of accuracy than the model could be expected to predict.

c. Regression Variables (IPRAM). The multiple linear regression routine of the model functions with nine independent variables. A default is established in the model such that the first eight variables of the XIDAT array will be used as the independent variables of the regression along with a ninth term that accounts for inflation. The inflation term is the natural logarithm of N, where N is the nth year in the historical files counting from the oldest year with N=1. The analyst may (and should) select variables that are likely to be good estimators of each specific account. This is done by specifying the variables in IPRAM, thereby overriding the default. Historical data from either XIDAT or DDAT can be used for this purpose.

(1) It is generally assumed that the XIDAT variables will be selected; however, provisions have been made to use expense data from DDAT as regression variables. This is done in recognition of the fact that some accounts are "driven" by expenditures in other accounts.

(2) There is no objective criterion for selecting one variable as opposed to another. This is purely a function of the analyst's intuition

about the dynamics of the account. The objective is to achieve the highest possible level of correlation. This can only be done by a trial and error process.

(3) The IPRAM array also provides for limited transgeneration of the regression variables. They can be entered individually and/or summed or they can be entered as the natural logarithm of the individual value or of the sum of a set of values.

4. Operation of the Model

The program is written in FORTRAN IV. A general system flowchart is shown at figure 1. The program flowchart and listing are located in the Department of Command (DCOM), USACGSC.

a. Tapes. The model operates from two or three tapes depending on the mode of operation. The program tape is OIDPL. The data base is referred to as TAPE50 for the purposes of input to the model for execution. The data from TAPE50 can be altered internal to the program for execution without altering the tape. If a new data base is to be established, both OIDPL and TAPE50 are required as input, but the new data base is output on TAPE60. TAPE60 then becomes TAPE50 for subsequent input. A new data base should be created only for permanent data changes.

b. System Control Cards. System control cards for the Fort Leavenworth CDC6500 computer are required for the two modes of operation. The tape unit numbers are subject to change and, therefore, are not published. They may be obtained from DCOM at CGSC. Update cards are used only for program changes and are not normally required. However, the 789 multi-punch cards are always required.

c. Run Options. The program has eight run options that can be executed independently or in sequence. These provide considerable flexibility in the use of the model. The run options are identified by the value IROPT.

(1) IROPT=1. This is an input option used to update the data base for a given year which is already in the file. This option branches to a part of the program that finds the address of an historical year (entered on the IROPT card in the MYEAR field). Those data which are entered following this IROPT card are superimposed on data that currently exist in the file.

(2) IROPT=2. This option is used to replace the oldest year in the file with the data for a recently completed fiscal year. The old data are not zeroed out; thus, a complete new set of data for the new year must be entered. If not, some of the old data will remain in the file.

(3) IROPT=3. This option reads in the data files from tape. In the normal execution this option is run first to establish the file so that data update can be accomplished. The only case where it would not be run

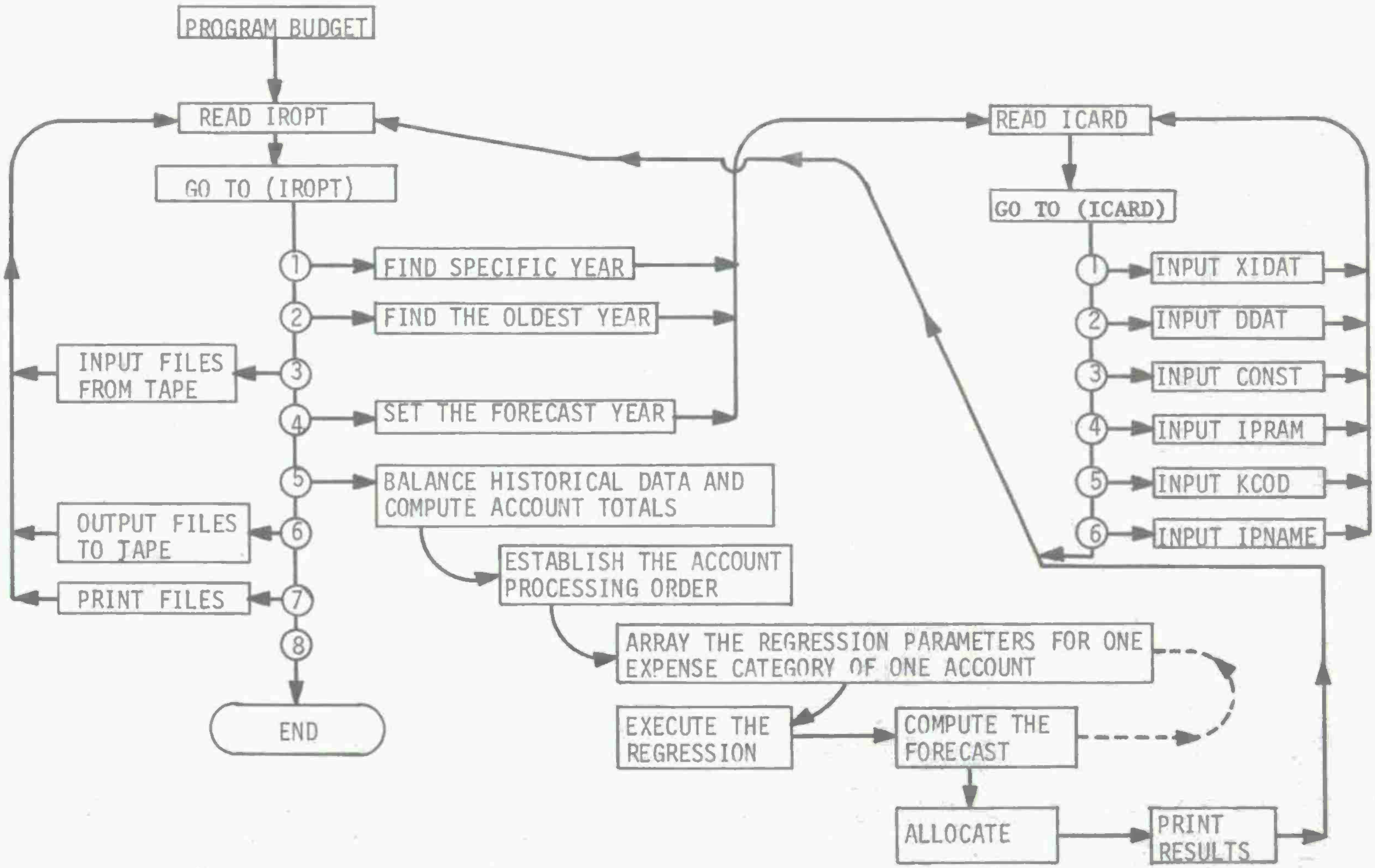

FIGURE 1. BUDGET MODEL SYSTEM FLOW CHART

first is when a complete set of data is being run from a card deck. TAPE50 must be requested for this option.

(4) IROPT=4. This option is used to input complete data (or update data) for the forecast year. It places all subsequent data in the forecast year file. Under this option DDAT data will not be entered as it would be illogical to have expense data for the forecast year. The fiscal year must be entered in the MYEAR field (i.e., 76, 77, etc.).

(5) IROPT=5. This option causes the forecast and allocation routines of the program to be executed. It is used after all of the data update options have been entered. The operations executed under this option are discussed in paragraph 4e, below.

(6) IROPT=6. This option creates a new data tape and may only be used with mode 2 control cards. It would normally be used after the data update options and prior to an execution option. Along with this option a save tape (TAPE60=SAVE) must be specified for kkkk unless a specific tape number has already been allocated. DO NOT ATTEMPT TO REWRITE ONTO TAPE50.

(7) IROPT=7. This option prints all of the data in the data base. If an option 5 is to be run, option 7 should follow it allowing the allocations for the forecast year to be included in the output. If it is run prior to an option 5, the data shown for the forecast year will be "garbage."

(8) IROPT=8. This option terminates the execution. The program does not have an automatic cutoff point; thus, any sequence of run options can be executed. Successive runs, for example, can be made with different constraints without interrupting the job. Option 8 simply provides for normal termination.

d. Bookkeeping. Some of the bookkeeping functions of the model have already been discussed above. The only data base files that involve other than simple data input is the DDAT file. This file is constructed such that arithmetic errors in the input can be readily identified.

(1) Input data are entered for each main account and its eight sub-accounts. The total BASEOPS account and the individual dummy accounts are zeroed out. Then the data is correct and ready for execution. The total BASEOPS account (Z account) can be checked with external data to ensure correctness.

(2) Within each account there are 12 expense categories, as discussed above. Only six of these 12 categories are input to the model; the remainder are calculated from the input.

e. Forecasting. Run option 5 (see figure 1) initiates the forecasting and allocation routines. The procedures from this point follow the steps outlined below.

STEP 1. Complete the DDAT array as discussed in d, above.

STEP 2. The program provides for the use of DDAT cost data as independent parameters in the multiple linear regression analysis. Because of a relationship that will be discussed later, it is essential that any cost data used in this manner must have been forecasted prior to its use. Consequently, simple sequential processing cannot be used. If, for example, cost data from account #51 (51 is the code for acct. .K1) is to be used in the regression for account 20, then 51 must be processed through the regression and forecasting steps before account 20. A large number of such "dependencies" may result from the analyst's selection of regression parameters. Subroutine ORDER corrects for these problems by establishing a processing order (array KORD) in which the dependency accounts are placed in the necessary sequence. The possibility exists that an unresolvable dependency may be created by the analyst. This contingency will be reported in the output and will have to be corrected by changes to the IPRAM array, in a subsequent run.

STEP 3. Following the account processing order, the model takes each expense category 5 through 12, one category at a time, and proceeds through the regression and forecasting steps described below. After one expense category has been processed, the program returns to this step and starts the next expense category.

STEP 4. Subroutine FIX prepares the array of variables to be used in the regression analysis. This is done using the array REG. The array IPRAM defines which data sets are to be used for eight of the regression variables. Each set (consisting of the historical data points) is fed into array REG along with the inflation variables and the dependent variable data set. When completed, REG contains all of the historical independent data for each parameter plus the estimated independent data for the forecast year. If a data set from DDAT is used, it must contain the forecast for the target year. This arrangement allows the forecasts to be computed immediately upon the completion of the regression and the return of the regression coefficients. This explains why the processing order must be rearranged as described in step 2. During this step some limited transgeneration of the data can be accomplished. Variables may be added together to form a composite variable or they may be entered in logrithmic form.

STEP 5. At this point the multiple linear regression is performed on the data that has been entered into the REG array. For this purpose the stepwise multiple linear regression program (BMD02R) of the Bio-medical series has been adapted to the model. The normal input and output functions of BMD02R have been either bypassed or removed and replaced with functions that directly accept the REG array for input and returns two arrays, COEF and PCOR, plus the value COEFX. COEF contains the regression coefficients of those independent variables, in the equation the standard error of the estimate, and the multiple-R term. COEFX is the regression constant.

NOTE: The BMD02R program is included in the model in its entirety, except for certain statements that have been removed. Since this is a standard routine, no attempt will be made to document it here.

STEP 6. In this step subroutine FORCAST computes the forecasted value for the given expense category in the target year. This is accomplished by summing the constant term, COEFX, plus the products of the regression coefficients (COEF) times the respective values estimated for the independent variables in the target year. The results of the regression and the forecast are then printed out.

STEP 7. The program at this point recycles through STEP 3 until all accounts and their direct and reimbursable expense categories have been forecasted.

f. Allocating. After the forecasts are complete the program proceeds to allocate funds. The logic of the model is based on the assumption that in an unconstrained fiscal environment the forecasted values would be the best estimates of expenses in the target year. In a constrained environment, however, the sum of the forecasts would not necessarily correspond with the total authorization. This problem can be resolved by making a percentage cut (or increase) across the board. This approach is rather arbitrary in that it ignores the unique problems within the various accounts and it does not allow for the influence of fiscal priorities. The BUDGET model employs a completely different approach. The standard error of the estimate is used as a measure of an account's adaptability to fiscal variations. The error, therefore, becomes the basis for making cuts or increases. In a general sense, each account is adjusted either up or down such that all accounts within a specific segment of the account hierarchy are allocated funds at the same number of standard errors from the forecasted levels. Expense categories within accounts are similarly allocated. Command priorities are superimposed on this process in the form of constraints on the funding of specific accounts. The allocation process occurs on four levels:

Level 1. At this level total installation direct funding is allocated to the main accounts (from Z to .BO, .CO, etc.). The total direct dollars forecasted for all main accounts (i.e., expense category 9) are accumulated and compared for the total authorization. The difference (DELTA) is then allocated to the main accounts based on the size of the respective standard errors (ERR_i). The total authorization is determined either by the forecast or by the constraints placed on that value. The authorization for direct funds can be specified exactly by applying tight constraints, thus suppressing the forecast. The algorithm for accomplishing the allocation is illustrated below.

X = total authorization for direct funds
y_i = forecasted direct expenses of the main accounts
Y = the sum of y_i
DELTA = X - Y
Z = the sum of ERR_i: this is the amount of change caused by a one standard error adjustment

$$ADJ = DELTA / Z$$

The new allocation y^1_i is then computed by:

$$y^1_i = y_i + (ADJ * ERR_i)$$

The new y^1_i may violate one of its constraints, in which case it must be truncated at the constraint. This prevents an exact balancing between X and Y, and a new DELTA is generated. The new DELTA is reallocated by repeating the same procedure several times until the final DELTA becomes zero. An alternate stop on the refinement process occurs after the process is replicated several times. The actual DELTA remaining at the stop is included in the printout.

Level 2. At this level total direct dollars at the main accounts are allocated to the respective sub-accounts (from B0 to B1, B2, etc.). Using the total dollars previously allocated to the main account as X and forecasted values of the appropriate sub-accounts as y_i, the algorithm described above accomplishes the allocation to the sub-accounts.

Level 3. At this level total direct dollars are allocated within each sub-account to the direct expense categories. Expense category 9 becomes X and expense categories 10, 11, and 12 become the y_i, within a given sub-account. The algorithm is again applied to determine the allocations.

Level 4. At this level reimbursable expenses are allocated. Since reimbursements are not truly allocated funds, the concept of allocation becomes one of balancing forecasted values. This occurs within sub-accounts only. Expense category 5 becomes X and categories 6, 7, and 8 become the y_i. The algorithm is applied in the same manner as described above. The main accounts and the total Z account are not treated at this level.

g. Recapitulation. After the allocations have been completed some inconsistencies remain. The refinement controls leave some money unallocated, expense categories in the sub-accounts do not necessarily correspond with the values in the main accounts, and the total expenses (categories 1, 2, 3, and 4) have not been computed. At this point the program begins at the lowest level in the account hierarchy and accumulates from bottom to top. The forecasts for the main accounts and the total Z account (direct expenses) have had their impact on the allocation process, have been printed out and are now ignored in computing final totals. The final allocation totals for these higher level accounts are now computed by accumulating the sub-accounts. A total of the direct and reimbursable expenses for each account are computed at this time also.

h. Output. The model provides three types of output and can be readily modified to generate output in any required format.

(1) Input data listing. Run option 7 generates a listing by subroutine PRNOUT of all input data. When executed after a Run option 5 it

also incorporates the completed allocations for the forecast year so that they can be compared with the historical data. This listing contains in order:

(a) The KCOD array showing the existing hierarchy of accounts.

(b) The XIDAT array showing the values by year for each of the independent variables.

(c) The DDAT array showing each of the expense categories (1 through 12 from left to right) preceded by the account code and the year identifier for each account from top to bottom. The last line for each account code shows the allocations for the forecast year.

(d) The constraint array with default values included where appropriate. Each row shows from left to right the account number and four sets of two numbers corresponding to the ceiling and floor respectively for the four categories of direct expenses (9, 10, 11, and 12).

(e) The IPRAM array. Each row shows an account number and eight sets of three numbers from left to right corresponding to the three data points for each of the eight regression variables as defined in IPRAM.

(2) Regression result listing. Each time that regression is performed on an expense category, the results are listed by subroutine FORCAS in the following format.

(a) The first line shows from left to right:

1. The account code.

2. The expense category.

3. The constant term of the regression equation in dollars.

4. The forecasted value in dollars.

5. The standard error of estimate (deviation) in dollars.

6. The cor lation term from BMD02R (MULTIPLE-R).

(b) The second .ine shows from left to right:

1. The r ame of the first variable in the IPRAM list.

2. Its regression coefficient (zero, if not in the equation).

3. The F-value for entry into the equation (zero, if this variable is in the equation). F-value will not appear here until there are 11 years of data in the file.

4. The first of the three lines in the IPRAM array for this account.

(c) Subsequent lines follow the same format as line two for successive IPRAM values of that account. The IPRAM array is completed at line three.

(3) Allocation results listing. Following the regression results, subroutine PRNOUT generates a summary of the forecasts and allocations. Each page in this section contains data pertaining to a main account and its several sub-accounts. Each account has a two line entry. The first line shows the account number followed by the amount (in whole dollars) allocated to each of the 12 expense categories of that account (1 through 12 from left to right). The second line in a set shows the amount of money (in dollars) forecasted for those expense categories. The accounts are listed in order from top to bottom on each page:

(a) Sub-accounts.

(b) The dummy account.

(c) The main account.

The last page shows the allocations and forecasts for the total base operations (Z) account followed by a recapitulation of the allocations by main account.

OTHER APPLICATIONS

1. General

In addition to the primary purpose of developing an annual budget, the BUDGET model has inherent capabilities which are applicable as a management tool in other areas. In this context, the model can be adapted to solving operational questions of installation management with speed and efficiency where manual procedures might be too expensive to allow thorough analysis. Some examples are described below.

2. Long Range Forecast

The forecast year in the model need not be the next chronological year. If estimates of the independent variables (XIDAT) for some "out" year are available, the model will generate a budget for that year. Given that the historical file is complete to the present year, then the forecast year could be identified on the run option as that five years in future. This along with the 30 independent variables are all that is necessary to complete the budget for that future year. Caution must be exercised in extending this capability too far into the future. The model is based on the premise that expense history is consistent from one year to the next. It cannot anticipate disruptions to that consistency such as a war, depression, or fundamental changes in the budgetary system. Such disruptions will render any long range forecast invalid. Subject to this limitation a complete five-year budget could be developed at the cost of one man-day plus five minutes of computer time.

3. Changes in Level of Activity

Changes in levels of activity can be analyzed in two ways depending on form in which such changes are proposed.

a. If changes in level of activity are directed in terms of manpower or real property, then the proposed activity levels are simply entered in the XIDAT array for the forecast year and the appropriate budget is generated. A similar run can be made without these changes and the two can be compared to identify budgetary impact of the proposed changes.

b. If changes in level of activity are directed in terms of dollar constraints, these constraints can be entered into the CONST array. Again, the impact will show up in comparison to an unconstrained run. An alternate approach could be taken in the case of a reduction of base operations authorizations. By selectively reducing various independent variables, in an attempt to generate forecasts that equate to the reduced authorizations, the overall impact of a proposed budget cut could be developed in terms of activities that would have to be reduced. This is basically a trial and error approach, but it can be done rather quickly. Its primary advantage is that it allows alternate activity level reduction strategies to be war-gamed in a search for the least detrimental strategy.

4. Use By Other Installations

a. The budget for a second installation might be produced using the historical expense data for the first installation and the forecast year estimates of activity levels (independent variables) and constraints for the second installation. The use of this technique can be valid only if the two installations are basically similar. For example, a budget for Carlisle Barracks could possibly be produced using Fort Leavenworth data. If the second installation were too dissimilar, say Fort Knox, the model would not produce a viable budget. As of this report this technique has not been thoroughly tested, but the concept is worthy of future study.

b. The BUDGET model is designed for application at any installation employing the base operations account system. Such application in most cases (subject to a, above) require the development of an historical data base for that installation. Done manually this will require two or three man months worth of effort for the initial application and about one man week for each successive year. An area of productive study could be directed toward interfacing the BUDGET model with the BASEOPS system directly. Budget is compatible with the Prior Year Report format and could be interfaced for direct input from the Prior Year Report tape. This would reduce the preparation time and eliminate arithmetic errors caused by manual transfer of data.

CONCLUSIONS

1. Listing of Conclusions

a. Econometric modeling techniques provide a valid methodology for installation fiscal management.

b. There exist factors, readily available to the installation commander, that when used in multiple regression analysis, provide statistically valid predictors of base operations funding levels.

c. The model developed in this project is usable at Fort Leavenworth to assist in allocating funds to major base operations activities. The interactive feature of the model permits the production, through the use of fund floor and ceiling constraints, of a variety of installation base operations budget options.

d. The research was not able to support the hypothesis of relationships between activity outputs or demand generating populations and dollar funding levels.

e. The model, although developed primarily for use in base operations management at Fort Leavenworth, has universal application in solving fiscal predictive and allocative problems.

2. Discussion of Conclusions

This research project had as its ultimate objective the development of an econometric model that would facilitate the management of base operations funds at installation level. It would appear that this objective has, in fact, been achieved.

The model developed the Fort Leavenworth FY 75 budget based on prior year expense data. When compared with the FY 75 COB, a forecast developed by activity and comptroller analysts, a striking similarity exists. There are variances between the two ranging from 2 to 35%. These errors rather than being testimony of the inappropriateness of econometric techinques appear to be directly attributable to the inability of the team to gather all desired data elements and a reaffirmation that the subjective judgment of a manager cannot be totally replicated by a mathematical model.

In analyzing the results, it must be remembered that the COB is a subjective prediction whereas the model is an objective device developed from actual historic expenditures as found in the prior year reports. While these discussions are somewhat cursory, several general conclusions emerge that indicate areas that bear further scrutiny and investigation.

In terms of the stated hypotheses, the first two concerning the identity of activity outputs and their relationship to dollar inputs to the activity must be tentatively rejected. This rejection is supported by an examination of the regression equations developed for each of the accounts. Except in very few cases, there does not appear to be a relationship between variables that can intuitively be considered activity outputs, as evidenced by their inclusion in the regression equations, and the dollar forecasts computed. It is felt that further manipulation of the data in the form of how it is aggregated or arrayed is necessary before a final judgment can be made. This is particularly true of those accounts dealing with real property and equipment maintenance and operation. There undoubtedly exist other factors, such as climactic conditions and equipment densities that dictate expenditure levels, that have not been included in the independent variables used. Only after these have been exhaustively examined can a final acceptance or rejection of these hypotheses be made.

The nature of the model and its operation also contribute to this rejection while at the same time validating one of the other basic concepts, that of the existence of statistically valid predictors of funding levels. The model has a choice of nine independent variables, from a possible list of 30, that it can use in the regression equation. Through the use of analysis of variance, it selects those variables with "F" ratios that are significant at the 99% confidence level. Thus, the model emphasizes statistical validity rather than probable measure of activity output in selecting independent variables for inclusion in the regression equation. This rationale is also followed even when variables are included in the nine possible choices that are intuitively appealing as output measures.

When the above option is overridden in the model and either measures of output or demand generating population variables are forced into the equations, the forecasts and allocations change slightly. This lack of a significant change could be indicative of one of several things. First, it could prove that a relationship, between population as a demand generator, and dollars to operate an activity to satisfy that demand, can be postulated. Or in a normative view, it could lead to formation of a hypothesis that the large unexplained variation in costs is indicative of a lack of efficiency in fund utilization. In order to further investigate this area, it is necessary that several installations be similarly analyzed. If the degree of unexplained variation were significantly different at each installation, the latter hypothesis would be supported. If the degree of unexplained variation remained approximately the same for several installations, the concept of a relationship between population and dollar inputs to activities could be totally rejected.

For the present, however, it can be concluded that there are factors, readily available to the installation commander, that can be used to provide statistically valid predictions of fund requirements in base operations accounts.

Concomitantly this leads to acceptance of the third hypothesis which deals with the construction of an econometric model that can relate those factors and the dollar inputs to each base operations activity. Additionally, this model is capable of producing budget options that are reflective of fiscal constraints and guidance imposed by higher headquarters as well as installation generated constraints on fund usage.

The methodology developed to perform this allocative function is considered one of the unique aspects of the model. In employing the standard error of the estimate as a distributive parameter the model solves one of the major problems of budgeting--allocation of fund shortfall. As discussed in the general concept there are several possible alternative methods of solving this problem. Attempts to quantify management utility for various functions (as an expression of priority) and incorporate them in the model were attempted; however, these proved to be both technically and practically unfeasible. Use of the random variation in each account level recognizes that funding level is essentially dependent on total variation, with the minimum acceptable level being that portion which is explained. The unexplained variation, on the other hand, is reflective of the variability in funding levels with which the account has historically been able to exist.

The other facet of the model's allocative function, which enables a commander to state priorities, is the ability of the model to accept constraints on account dollar levels either as floors to be met or ceilings not to be exceeded. This, in essence, provides a function to override the standard error of the estimate's distributive parameter. This device is felt to be superior to any actual incorporation of utility since it has universal applicability and therefore need not be changed to reflect the bureaucratic realities of budgeting that occur when personalities or priorities change. These changes can simply be addressed in the form of constraints rather than in computation of some quantified form of utility.

The structure of the model as well as the rapidity with which it produces a budget option can provide the installation commander with a unique capability. By interacting with the model through the presentation of various constraints for one or more accounts, the commander can quickly ascertain the impact these managerial decisions have on the installation budget. He can thus prepare, with minimum effort, an array of budgets, each embodying different managerial decisions. This generation of options is a quantum improvement over the present situation in which the commander is given relatively little in the way of budget options.

The limitation of the options generated lies in their presentation in terms of dollar inputs only, and not in terms of output restrictions. Were this research able to find relationships between activity outputs and dollar inputs, the commander could ascertain the dollar impact of his budget decisions and also have a measure of output constriction that would occur as a result. Unfortunately this option is not yet available.

As presently structured, the model has a variety of uses. It can provide forecasts and allocate funds for any installation provided data is available at the given installation. The structure and mechanics of the model are such that its functioning is not restricted to just base operations. It can accept 14 data points for up to 99 different account classifications. These dependent data can be analyzed, using multiple regression techniques, against up to 30 independent variables, N-2 of which (the number of data points minus two up to a total of nine variables) can be incorporated into any regression equation. Thus, the model might be used at Headquarters, TRADOC for base operations management, or at Headquarters, FORSCOM for mission funding management.

As can be readily seen, the possibilities for fiscal analysis and management presented by expansion of this basic research are many. What is significant for the present, however, is that the validity of econometric methodology in installation fiscal management has been conclusively proven. In pragmatic terms, the Army now has a tool which has the potential to assist the commander in the development of his base operations budget. Preliminary review also indicates that the model has potential to assist in budget execution.

TITLE: Automated Supply Workload/Funding System

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INTRODUCTION

The Automated Supply Workload/Funding System (ASW/FS) is an interactive man/ADP system involving the forecasting, requirements estimation, fund planning, fund authorization, and data collection aspects of the US Army Major Item Data Agency (MIDAs) workloading mission for depot supply operations. An overview of ASW/FS functions is shown in Figure 1. Forecasting activities provide MIDA with aggregate level workload forecasts for supply functions of shipping, receiving, and set assembly. Depots submit unit man-hour and cost standards to MIDA. The ASW/FS analyzes the aggregate forecasts and bid standards and exceptions suspect submissions. Gross requirements for account-level workload, manpower and funds are estimated and summarized for management analysis. Constraints are imposed on the gross requirements to develop quantities which can be planned and authorized for funding.

The data exceptioning functions in Figure 1 involves testing and correcting incoming data as it is processed by the automated system. The productivity/variance block identifies a feedback and analysis function concerned with quantifying variances. Contributions of forecast inaccuracies and depot productivity to total man-hour variance are estimated. A productivity index is produced to reflect efficiency of manpower utilization.

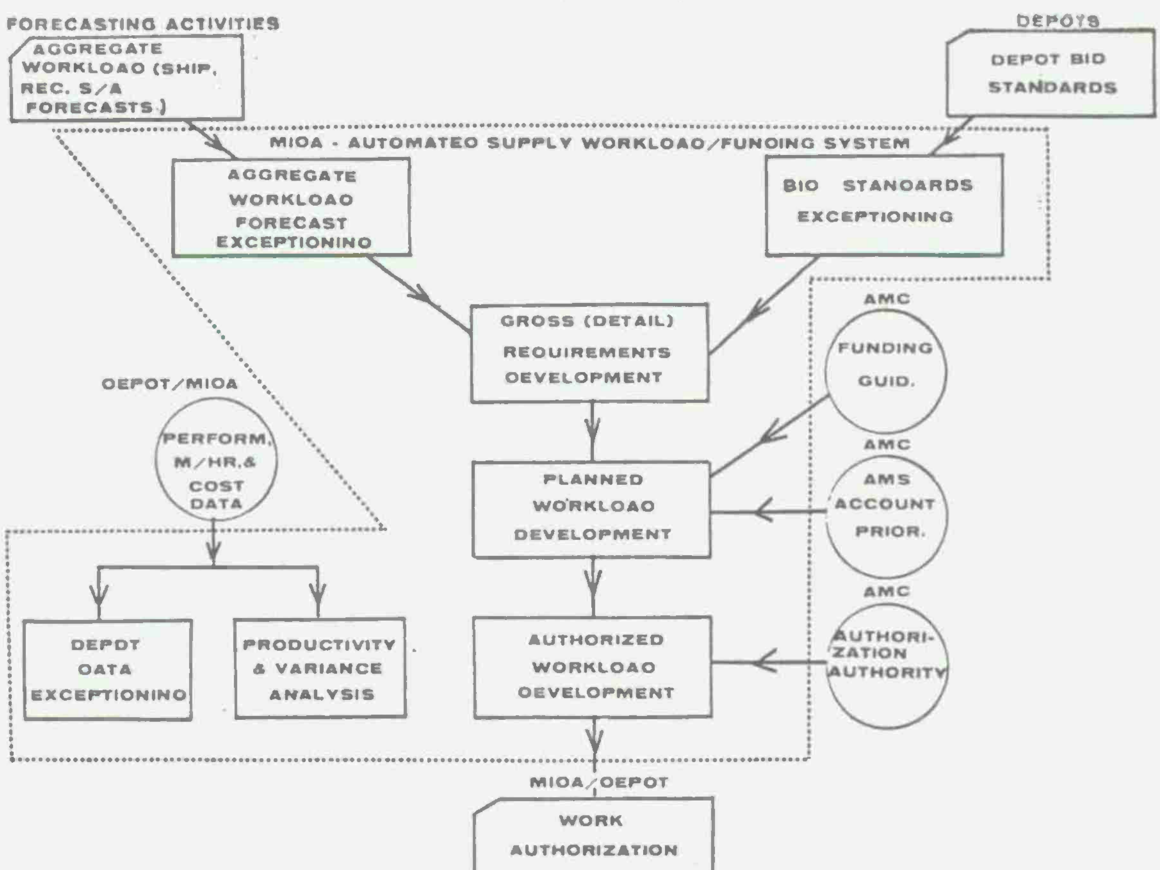

Fig. 1. Automated Supply Workload/Funding System Overview

FORECASTING AGGREGATE LEVEL WORKLOAD

Activity forecasts for shipping, receiving, and set assembly are the basis for generation and justification of depot manpower, funds, and storage space requirements. Forecasts are submitted to MIDA at dates specified by AMCR 740-16. The ASW/FS will produce exponentially smoothed forecasts and confidence limits which will be forwarded to forecasting activities prior to forecast submission dates to MIDA. These forecasts and confidence limits are reference points for use in forecast preparation. The same forecast limits will be used to exception and monitor forecasts when later submitted to MIDA.

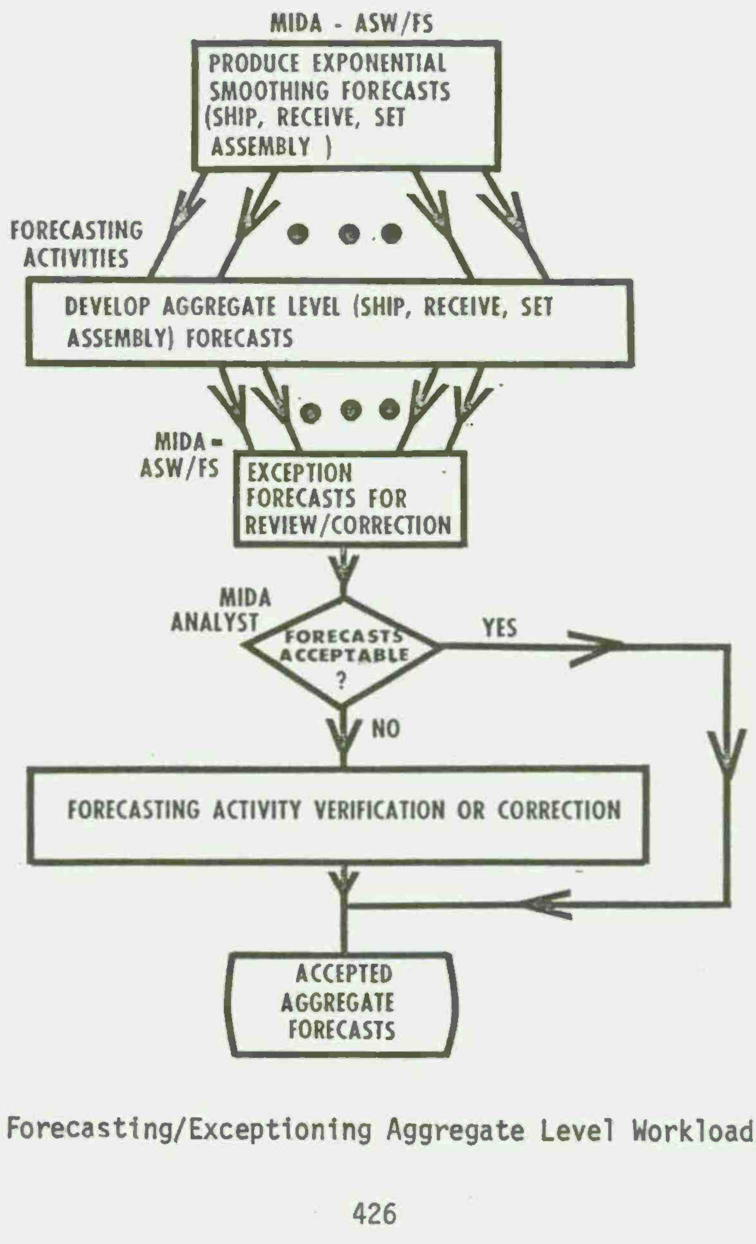

Fig. 2. Forecasting/Exceptioning Aggregate Level Workload

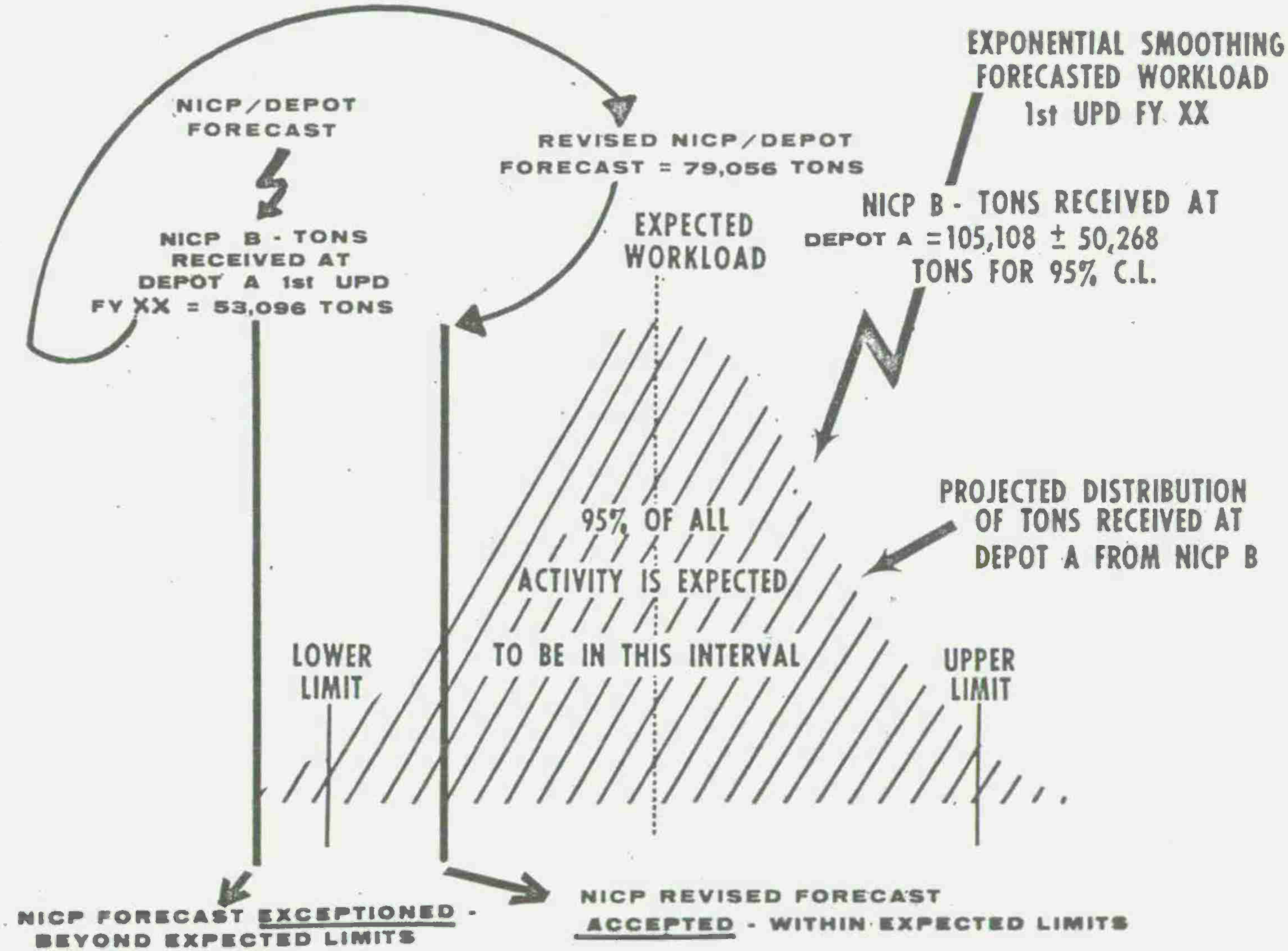

Fig. 3. Aggregate Workload Exception Criteria

GROSS REQUIREMENTS (DETAILED WORKLOAD) DEVELOPMENT

The aggregate forecasts for shipping, receiving, and set assembly functions are used to derive detail level man-hour, workload, and cost requirements at the Army Management Structure (AMS) reporting level. Figure 4 illustrates the relationship between aggregate and detail workload and the techniques used in the ASW/FS to translate aggregate into detailed requirements.

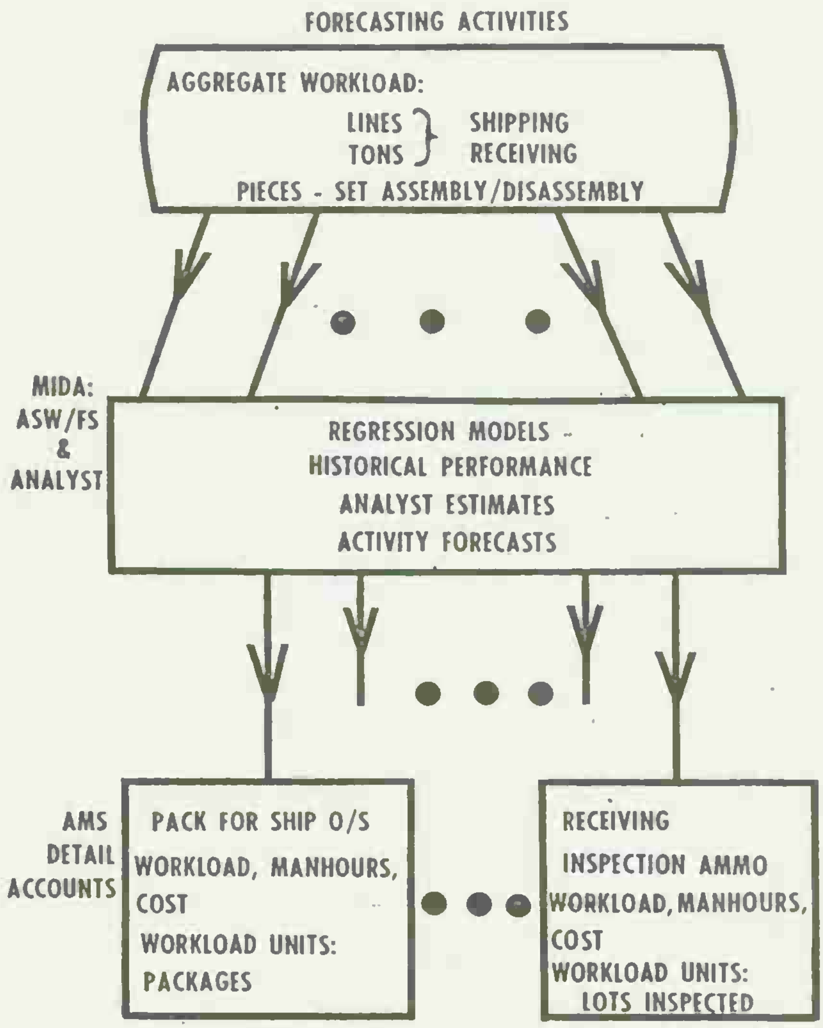

Fig. 4. Derivation of Detail Requirements from Aggregate Forecasts

The regression techniques are a key method used to derive the detailed AMS level gross requirements. The form of the regression models is shown in Figure 5. To eliminate manually coding regression coefficients for ASW/FS files, a series of programs were written to automatically access the historical data base, perform multiple step-wise regression, test each resulting detail level equation, and load acceptable equations to ASW/FS files. Output reports identify detail accounts for which the MIDA supply analyst must provide supplemental or complete information to complete the computational capabilities of the system.

FORM 1: DEPOT TOTAL AGGREGATE PERFORMANCE AS INDEP VARIABLES

$$\begin{Bmatrix} MH \\ WKLD \end{Bmatrix} = F \left\{ (LR,\ LS,\ TR,\ TS)_{\text{TOTALS ALL FORECASTING ACTIVITIES}} \right\}$$

EX: AMS 123000 BIN ISSUE

$$MH = 200 + .005\ LS + .001\ TS$$

FORM 2: FORECASTING ACTIVITY AGGREGATE PERFORMANCE AS INDEP VARIABLES

A. SHIP/RECEIVE

$$\begin{Bmatrix} MH \\ WKLD \end{Bmatrix} = F \left\{ (LR,\ LS,\ TR,\ TS)_{\text{FC ACTIVITY}} \right\}$$

EX: AMS 122000 BULK ISSUE

$$MH = 818 + .18\ LS_{TAC} - 1.10\ TS_{TAC} - 02\ LR_{EC} + .04\ LS_{EC}$$

B. SET ASSEMBLY/DISASSEMBLY

$$\begin{Bmatrix} MH \\ WKLD \end{Bmatrix} = F \left\{ (PIECES)_{\text{FC ACTIVITY}} \right\}$$

EX: AMS 135400 SET ASSY/DISASSY, O/S

$$MH = 300 + .00005 \times PIECES_{TAC} + .00001\ PIECES_{EC}$$

Fig. 5. ASW/FS - Regression Equation Forms and Examples

The ASW/FS interfaces a file of AMC approved aggregate forecasts with files containing regression coefficients and "pointers" to link forecasts with the correct coefficients. Computations of workload, man-hours, and cost at the detailed AMS levels require only that regression equations be evaluated at forecast values. The automatically-computed requirements are tested against requisite historical confidence limits. If outside the limits, requirements are exceptioned for review by MIDA supply analysts. Each outlying requirement is automatically replaced with its historical average. The MIDA analyst reviews exceptioned requirements and may change the historical average requirements to some other values, or to the originally-computed values, as desired.

DEPOT BID STANDARDS EXCEPTIONING

After detailed AMS level workload, man-hour, and cost requirements are estimated in the ASW/FS, a depot-version of the resources required to perform the forecasted workload is computed. Unit man-hour and cost "bid" standards, submitted by each depot, are multiplied by the detail AMS workload estimate. If the depot and MIDA man-hour and cost estimates differ by more than a specified tolerance, the bid standard for the AMS account is exceptioned. The exception process is illustrated in Figure 6. Exceptioned standards require negotiation between MIDA and the depot. Negotiated man-hour and cost requirements must be entered into ASW/FS files if compromises result in agreement of other than the MIDA projected resources.

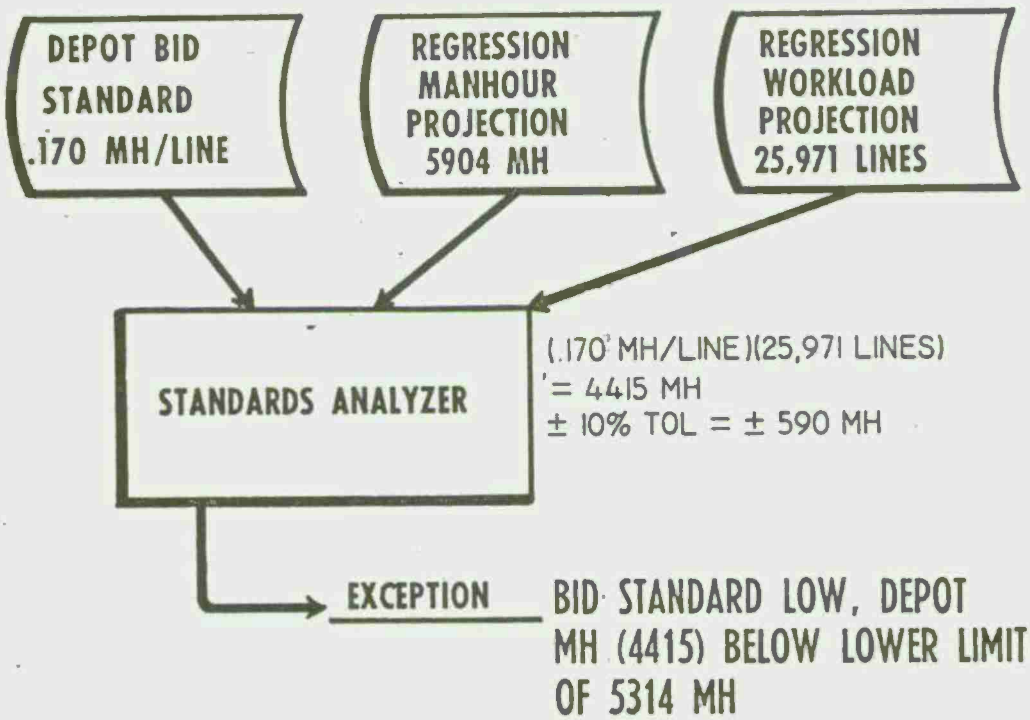

Fig. 6. Example Analysis of Depot Supply Bid Standards

GROSS REQUIREMENTS SUMMARIZATIONS

Gross requirements are summarized in various ways for management use. Depot man-hour and cost estimates, together with the standards used in the computations are displayed with the MIDA estimates. The summaries display estimated resource requirements to perform the projected workload. Since the workload estimates are unconstrained, the requirements represent a "gross" requirement, without consideration of monetary or practical limitations.

PLANNED WORKLOAD DEVELOPMENT

After management approves the gross requirements, monetary and other constraints can be applied to develop a funded plan for the budgetary period of concern. The supply analyst gets a last opportunity in the ASW/FS to refine the requirements for productivity, standards negotiations, or for other reasons. Planned workload is developed by applying budgetary limitations, assigned priorities, and other constraints to the gross requirements, then allocating the available funds.

All non-monetary constraints must be first converted into either a dollar limitation or a minimum percentage of the gross dollar requirement to be funded before starting priority allocations. Minimum funding can be specified at either the detail AMS account or priority level (or both) within the total dollar limitation. Specified constraints result in funds being taken "off-the-top" before the priority allocation, as illustrated in Figure 7. After all detail AMS and priority constraints are satisfied, the planned workload algorithm defaults to a priority allocation, in which funds are allocated to highest priority requirements, next highest, etc., until available funds are exhausted. The planned workload and manhours corresponding to allocated funds are computed from the unit cost and labor rates established during the gross requirements computations.

The yearly gross and planned requirements are summarized in the Schedule B, a standard worksheet used by supply analysts to display requirements for budget backup and coordination. The ASW/FS automates Schedule B development. The ASW/FS Schedule B will provide detail and required summaries at subsequent levels of consolidation including a grand consolidation for all depots.

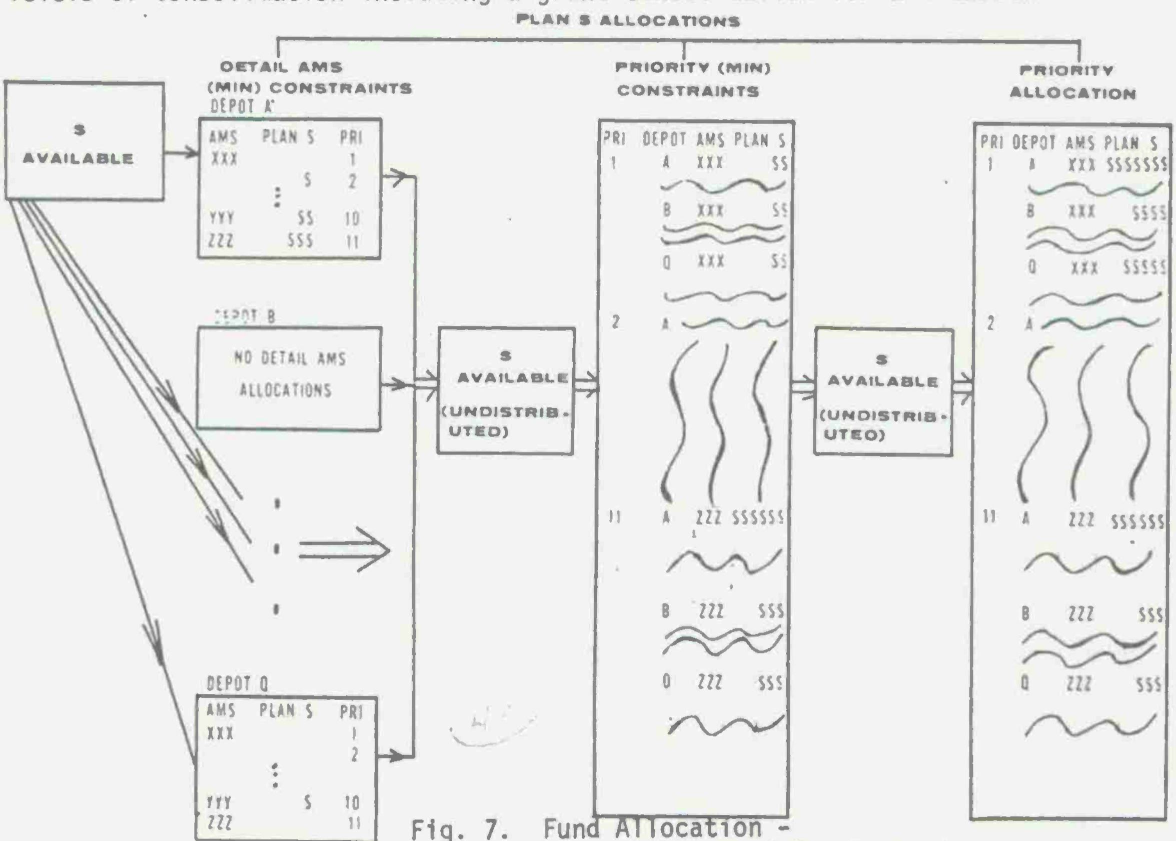

Fig. 7. Fund Allocation - Planned Workload Development

WORK AUTHORIZATION

Work Authorization's (WA's) are issued by MIDA to the depots. When the depot accepts a funded work authorization, funds are obligated and the depot will be reimbursed for costs incurred up to the obligated amount. Work authorizations are transmitted from MIDA to the depot as punched cards via AUTODIN. Cards to create WA's are presently manually created. When the ASW/FS becomes operational, these WA cards will be produced automatically.

Authorized workload, manhour and fund quantities will be computed based on an approved funding plan and an authorized expenditure limit. The ASW/FS authorization algorithm simply authorizes a proportion of the planned expenditure for each detail AMS account. The proportion is the ratio of authorization limit to the grand total planned expenditure for all detail AMS accounts at all depots. Authorized workload and manhour quantities are derived from the authorized funds for detail AMS accounts based on unit cost and labor rates. Several related AMS accounts comprise functional levels at which WA's are issued. Detail AMS quantities are summed to the appropriate WA levels. Numeric gross, planned and authorized data, combined with input accounting and identification data, provide sufficient information to produce WA cards.

PRODUCTIVITY AND VARIANCE ANALYSIS

A productivity and variance analysis report is produced by the ASW/FS to enable post-planning evaluation when depot cost and performance data becomes available. This report partitions total manhour variance into an element attributable to forecast and a second element attributable to depot productivity. The basic computations used are:

(1) Total Manhour Variance = Projected Manhours - Actual Manhours

(2) Forecast Variance = Projected Manhours - Earned Manhours

(3) Productivity Variance = Earned Manhours - Actual Manhours

(4) Total Manhour Variance = Forecast Variance + Productivity Variance

(5) Productivity Index = $\frac{\text{Earned Manhours}}{\text{Actual Manhours}}$

Equation (4) is the result of adding equations (2) and (3), thus the partition is verified. Projected manhours are the manhour estimates obtained at planning time by evaluating the regression equations at the aggregate level forecast values (i.e., the gross manhour requirement). Earned manhours are obtained by evaluating the regression equations with actual aggregate workload data. Assuming the regression model error to be much smaller than the forecast or productivity variance, then the differences between the models evaluated at the forecast and at the actual aggregate workload are attributable to the forecast errors. Similarly, the differences between manhours obtained by evaluating the models at the actual aggregate workloads (earned manhours) and actual manhours are attributable to depot productivity. The productivity index provides a measure of how efficiently a depot is utilizing manpower resources relative to a historically-based standard.

Due to lack of regressions for some accounts, the productivity/variance report will not cover all AMS accounts. Statistics will be accumulated to indicate the percent of the total program which has been sampled in producing the report. At the depot level, the different manhour quantities (programmed, projected, actual, and earned) are "priced-out" at an approved labor rate input by a MIDA supply analyst. The total, forecast, and productivity variances are similarly "priced-out" to provide an indication of the cost of forecast errors and depot productivity variances.

DATA BASE MAINTENANCE

Almost every facet of the ASW/FS is dependent upon maintenance of a reasonably accurate and complete data base. To maintain the data base, aggregate level workload data is tested with exponential smoothing confidence limits. Detail AMS data are tested with confidence limits derived from regression equations. Logical tests requiring non-zero entries for correlated data (e.g., non-zero manhour data requires cost to be positive) are made regardless of range test results. Data falling outside specified limits or failing logical tests are exceptioned for review and correction by the MIDA supply analyst.

The procedure for data base maintenance is a two-step sequential process. Aggregate level workload data are first exceptioned by exponential smoothing confidence limits and corrected. The aggregate shipping, receiving, and set assembly data becomes independent variables in the regression models. Thus, the aggregate exceptions must be cleared prior to evaluating the detail workload, manhour and cost data. The regression models are then evaluated with corrected aggregate data and confidence limits computed. Detail AMS data are then exceptioned for review and correction by the MIDA supply analysts. The approach is one of disciplined data base management by exception and of timely maintenance.

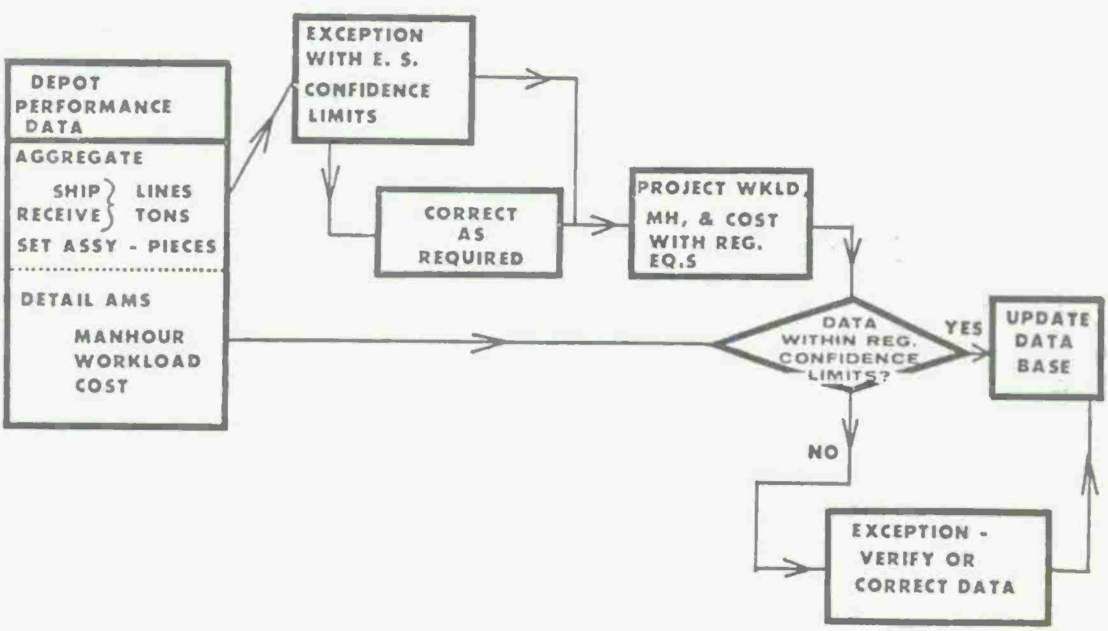

Fig. 8. Maintenance of ASW/FS Data Base

BENEFITS

Some benefits expected when the ASW/FS becomes operational are displayed in Figure 9. Exceptioning the aggregate workload forecasts will result in more accurate forecasts and, consequently, a sounder foundation for justification of depot manpower, funds, and storage space requirements. Exceptioning depot bid standards should result in a better distribution of funds to detail accounts and improved depot bid standards. The ASW/FS will function with second through fifth year aggregate forecasts and produce gross requirements so the capability will exist to produce an automated five-year plan for supply operations. Productivity and variance reports will enable the effects of forecast error and depot productivity to be evaluated. Automating the supply workload/funding function will sharply cut the turn-around time for producing depot supply requirements and reduce human-induced computational errors. With implementation of the ASW/FS, MIDA will perform the workloading mission both more effectively and more responsively.

BENEFITS

- IMPROVED AGGREGATE FORECASTS
- BETTER DISTRIBUTION OF FUNDS TO DETAIL ACCOUNTS
- IMPROVED DEPOT BID STANDARDS
- AUTOMATED 5-YR SUPPLY PLAN
- PRODUCTIVITY/VARIANCE ANALYSIS
- SHORTER FORECAST -TO - WA TURN-AROUND

Fig. 9. ASW/FS Benefits

A SYSTEM FOR THE QUANTITATIVE EVALUATION OF MENU PREFERENCES

by

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The concept that preferences may depend upon time was brought out in a series of papers by Balintfy and his colleagues.[1,2,3] Their approach to the problem of time-preference relations was to develop quantitative models that predicted the change in preference with time. Their scale was a 0 to 1 scale, with ratio properties, in contrast to the more commonly used hedonic scale of food preferences used by Peryam and Pilgrim.[4] The hedonic scale has been widely used in military food preference surveys and is well known in both preference assessment of food names (through surveys), and in the sensory evaluation of specific food products.

There are two elements to overall menu preference evaluation covered in this presentation. The first is the time-preference relationship for individual food items; the second is the proportionate weighting of meal components (or menu class weights) in the rating of a complete meal.

It would be appropriate here to define the terminology that will be employed. A food item is the actual product that is served, i.e., Beef Stew, Buttered Peas and Carrots, and Strawberry Shortcake. The term meal component is used in defining how food items are combined to make up a meal within a menu. The five meal components that are discussed here are: entree, starch, vegetable, salad and dessert. The term menu implies an ordered sequence of complete meals over a predetermined number of days; a cyclic menu is one that returns to Day 1 of the planned menu after the last menu-day and repeats itself indefinitely.

The first step in developing the model was the derivation of the time-preference relationships for food items. The approach used in this effort is the classic regression analysis technique wherein empirical data is collected and plotted, the data suggests appropriate functional relationships which are then best-fitted to the empirical data. The square of the correlation coefficient is used to determine which functional relationship can best represent the relationship between the dependent and independent variables. If the relationship is well established, the selected functional relationship can then be used to determine the value of the dependent variable given the values of the independent variables.

DATA COLLECTION METHOD

The standard 9-point hedonic scale employed with food preference surveys has been used as the measuring tool to elicit food preference attitudes.[5,6] This scale was used in this study to gather data on the time dependency of food preferences and the weighting of meal components within a standard menu framework.

A survey questionnaire was developed to measure a respondent's stated preference for a given food item, under the assumption that the time since he had last eaten the food was three months, one month, two weeks, one week, three days, and yesterday, respectively. For each time interval the respondent was asked to assign a hedonic scale rating for the desirability of the food to him.

The survey consisted of 144 food items from five meal components (entrees, starches, vegetables, salads and desserts) and was given to a group of U. S. Marines. From the group of 251 respondents, a subset of 173 completed questionnaires were selected.

ANALYSIS OF DATA AND FUNCTIONAL RELATIONSHIPS

Logarithmic functions are often useful to relate rating-scale values (hedonic) to a physical variable such as time. A plot was made of time since last serving vs. mean hedonic rating for a selected group of 15 food items. The plot is semi-logarithmic and is presented in Figure 1. Virtually all the functions in Figure 1 fail to conform to a linear function and show substantial curvilinearity. The 144 foods tend to fit one of two major patterns:

1) linear increase in preference for times up to one month, after which the preference stays almost constant, failing to increase by any substantial amount at three months, or

2) curvilinear changes in preference throughout the entire time period with preference increasing at a decreasing rate as time increases.

The analysis of empirical data strongly suggested that over all foods considered, the time-preference relationship for each food item is best described by the logarithmic quadratic function:

$$P(T) = K_1 + K_2 \left[\log (T)\right] + K_3 \left[\log (T)\right]^2. \qquad (1)$$

The quadratic function was best-fitted using standard regression techniques to the empirical data for each food item. With the 144 foods surveyed, comparisons could be made among food items in the same meal component group as well as across groups.

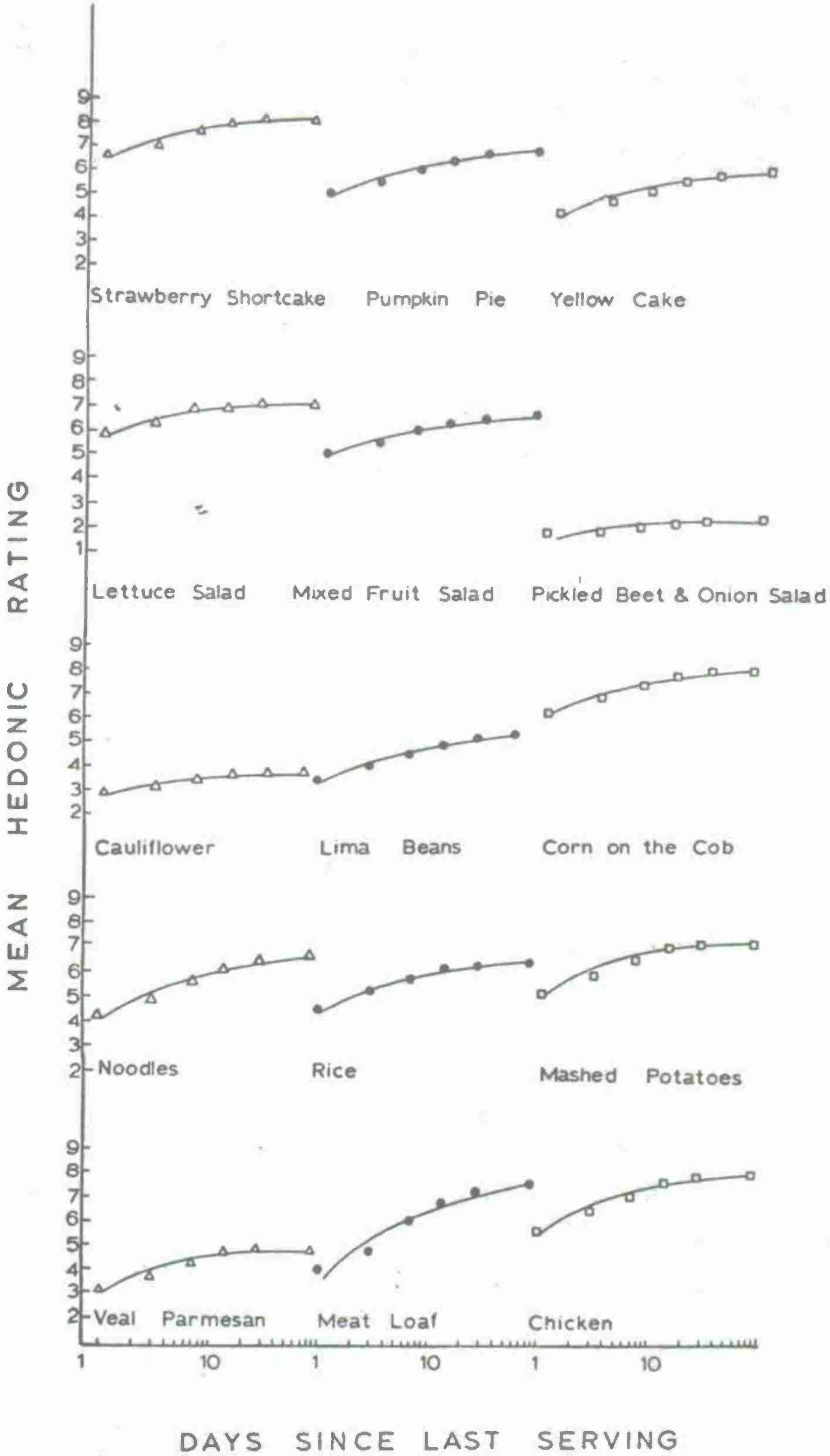

Figure 1: Plot of 15 Food Items - Hedonic Ratings VS. Days Since Last Serving.

Figure 2 presents a histogram of the 144 values for K_2, the coefficient for the linear portion of the time-preference log equation. The mean slopes and standard deviations (s.d.) for the five groups are as follows:

Entrees (n = 71): mean slope = 1.97, s.d. = 0.45

Starches (n = 17): mean slope = 1.93, s.d. = 0.31

Vegetables (n = 26): mean slope = 1.35, s.d. = 0.37

Salads (n = 14): mean slope = 1.12, s.d. = 0.32

Desserts (n = 16): mean slope = 1.53, s.d. = 0.25

The F statistic for the analysis of variance on these values for K_2 was highly significant (F = 22.97, degrees of freedom = 4,139). This significant F statistic says there exists a difference between meal component groups. The ranking of mean slopes are: entrees, starches, desserts, vegetables and desserts. In contrast, in terms of variability of K_2 (i.e., the standard deviation) desserts show the least variable slopes and entrees the most variable. The wide variety of entree items compared to the limited selection of dessert items may be the cause for this difference in variability.

By taking advantage of the representative sample of time-preference slopes obtained from the survey data, other data sources can be used to extend the results to a wider range of food items. It may be possible to define "equivalence-classes" of food items, which are nothing more than groups of foods. The items in each group are assumed to conform to similar time-preference slopes, although each item may have its own unique maximum preference value. By rearranging the time-preference functions, one can decompose the functions into two parts. One part involves the slopes (K_2 and K_3) and the other involves the maximum preference for the food item (P_{max}). The value for P_{max} is obtained from large-scale food preference surveys of items, in which only one preference value was collected for each item. The decrementing model of time-preference can be stated as:

$$P(T) = P_{max} + K_2 \left[\log (T/84)\right] + K_3 \left[(\log T)^2 - (\log 84)^2\right] \qquad (2)$$

The proportional preference, P(T) can now be obtained by computing the difference between the food item's maximum preference, obtained through conventional food preference surveys, and a quantity related to the time since the item was last served, T.

MEAL COMPONENT WEIGHTS AND TOTAL MEAL PREFERENCE

The second element in the menu preference evaluation model concerns the meal component weights for the five classes under study: entrees, starches, vegetables, salads and desserts. Many possible rules exist

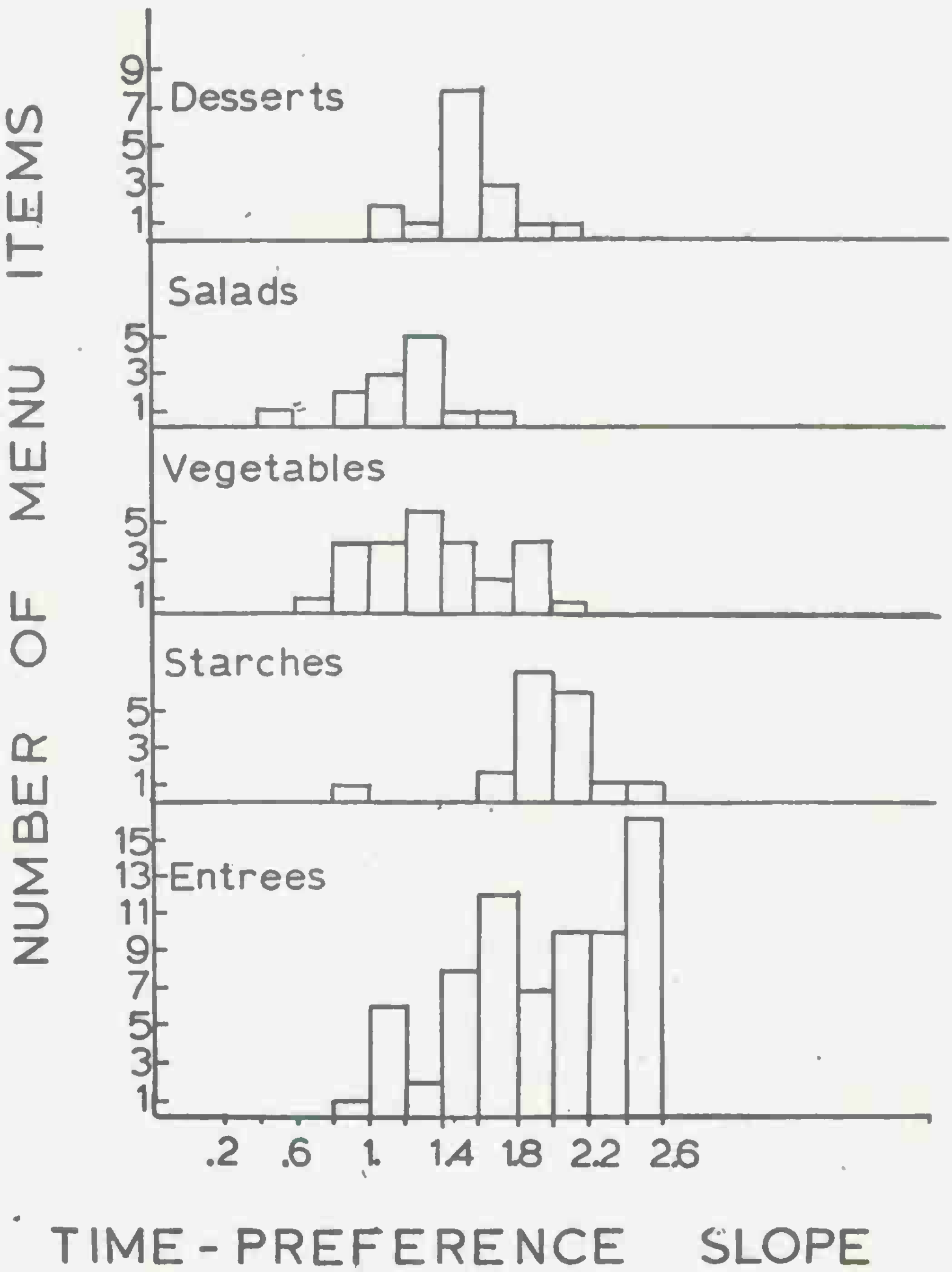

Figure 2: Histogram Of Average Time - Preference Slopes (K_2) For Five Ba
Meal Components For A Sample Of 144 Food Items.

whereby an individual can evaluate a menu for its overall preference or acceptability.

The objective of this effort was to develop a model which would permit predicting overall meal hedonic values given the stated customer hedonic values for the major meal components. In our previous work,[7] a simple model was utilized which involved adding food item values and averaging these values to derive the meal hedonic value. This model did not provide the required accuracy in predicting meal hedonic values when empirical data (i.e., stated meal hedonic values vs. stated food item values) were analyzed. Further analysis of these data has lead to the development of a linear additive model which provides different weighting factors for each of the major meal components (i.e., entree, starch, vegetable, salad and dessert).

The approach used was to collect empirical data on hedonic values for food items and entire meal hedonic values from the same customers. The data was then fitted to a multilinear function of food item hedonic values to obtain the coefficients or weighting factors for each meal component which would best predict the empirical meal hedonic values. The square of the multiple correlation was then used to determine whether the multilinear model could be used to predict meal hedonic values given food item hedonic values.

THE BASIC MEAL PREFERENCE MODEL

The basic model used provides a single number as an index of total meal preference; the additive model of acceptability is:

$$P_{meal} = W_1 P_e + W_2 P_{st} + W_3 P_v + W_4 P_{sa} + W_5 P_d + W_6 \quad (3)$$

where P_e - hedonic rating for the entree item, P_{st} - starch rating, P_v - vegetable rating, P_{sa} - salad rating, and P_d - dessert rating and W_1 to W_5 represent the relative importance factors of the corresponding meal components for the entire meal. The value W_6 is the residual preference value for a meal, and can be set $W_6 = 0$ for the analysis discussed here.

The meal preference for this model is the linear sum of the weighted food item preferences. Low weights (W_1, . . . W_5) signify that the meal component carries little weight. The individual food item preference has less effect on the respondent's overall judgement of the meal than the preference for items in meal component groups with high weights.

In part 2 of the survey discussed earlier, the respondent rated 136 different meals, each comprising an entree, a starch, a vegetable, a salad, and a dessert, taken from the list of 144 food items. For each meal presented, the respondent rated the overall acceptability, again with the 9-point hedonic scale. Using the multiple linear regression technique equation (3) was solved to yield the coefficients for the additive function for total preference. The regression was run with the intercept point, W_6 free to seek its' own value and with W_6 forced to zero. The multiple correlation coefficient squared with W_6 in the equation was $R^2 = 0.71$ indicating that 71% of the variance was accounted for by the model. For the case with W_6 forced to zero equation (3) can be restated as:

$$P_{meal} \times N = 2.34\ P_e + 0.74\ P_{st} + 0.58\ P_v + 0.35\ P_{sa} + 0.76\ P_d \quad (4)$$

where N = 5, the number of meal components in the equation.

The exceptionally high weight given to entree preferences as compared to starches and desserts, indicates that entrees account for almost half of the preference rating of a meal. Thus, the results suggest that it is most productive to concentrate upon providing optimally acceptable entrees when maximum acceptability is desired, and to place proportionately less effort on providing varied vegetables and salads, since the latter two meal components carry very little weight in overall preference determinations.

To determine the distribution of weights for the 173 individuals, a total of 173 linear regressions were run, with the 136 meal evaluations made by each individual entered separately into a single regression computation. Figure 3 presents the histogram of the distribution of the five meal component weights. Entrees are characterized by a larger scatter of individual weights, ranging towards the high values while the other meal components are clustered around lower importance values.

AN APPLICATION OF THE COMPLETE MODEL

With the two required elements formulated the preference evaluation model for predicting overall preference of a meal can be stated as:

$$P_{meal} \times N = 2.34\ P(T)_e + 0.74\ P(T)_{st} + 0.58\ P(T)_v + 0.35\ P(T)_{sa} + 0.76\ P(T)_d \quad (5)$$

where $P(T)_e \ldots P(T)_d$ are the time dependent preference values for the items offered. By using this model one can calculate the meal preference values given the individual food item preference values and the elapsed time between servings for each item.

The preference evaluation of a cyclic menu involves the rating of individual meals within the menu and tracking the serving intervals for all the items for the entire menu cycle. The meal preference model (5) along with the coefficients for each food item were programmed into a computer to aid in this computational process. For the menu under analysis the computer program calculated the elapsed time prior to each serving occurrence, T, generated the time dependent preference value, P(T) for each item in a meal, and combined the items with the appropriate meal

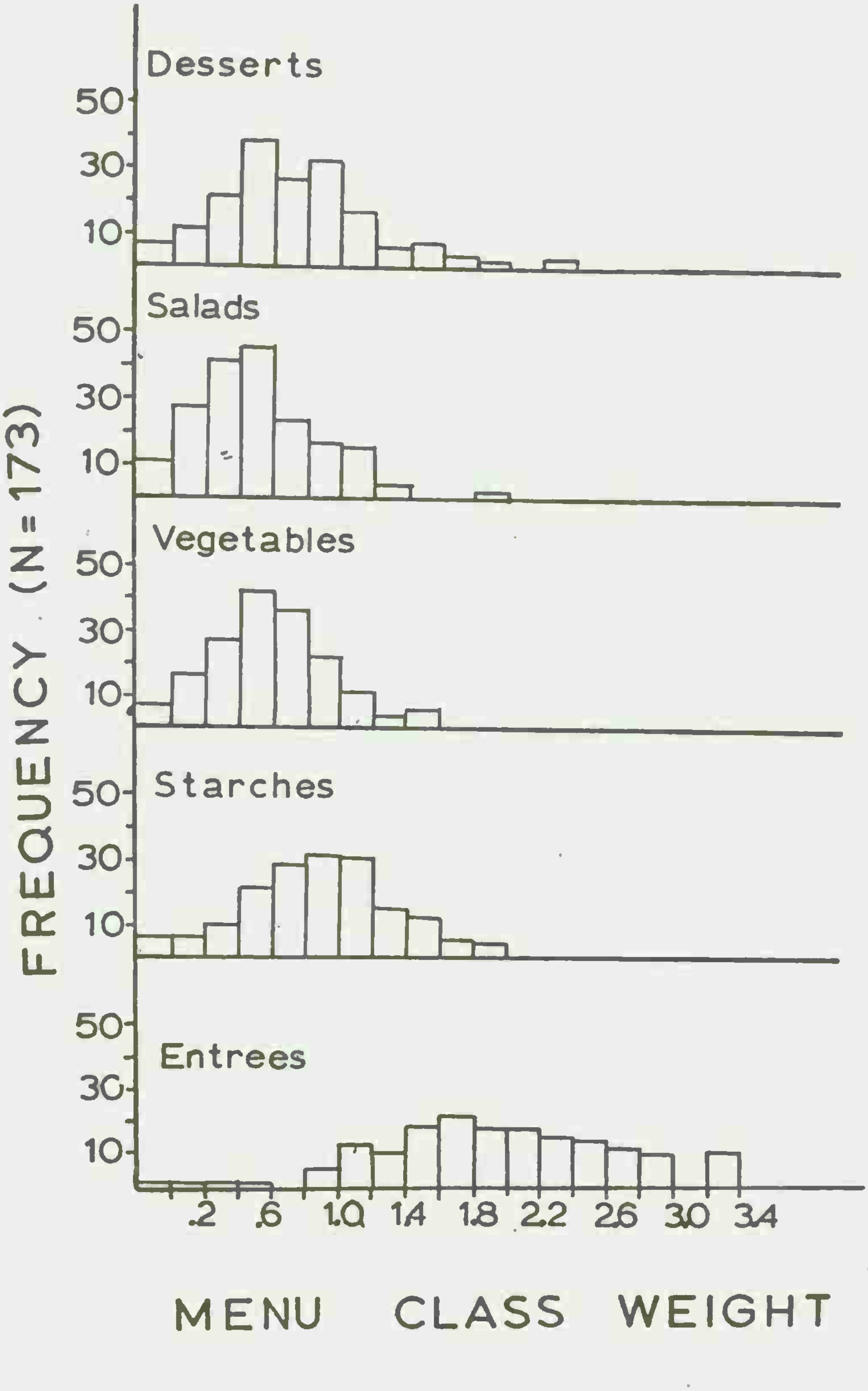

Figure 3: Histogram Of Menu Class (Meal Component) Weights For Five Basic Meal Components For A Sample of 173 Respondents.

component weights. Several menus currently in use in the military were analyzed using the preference evaluation model as adapted to the computer. A sample of one day's calculations is shown in Figure 4.

CONCLUSIONS AND CONSIDERATIONS FOR FURTHER RESEARCH

A quantitative method for evaluating the overall preference of menus has been developed. From survey data, time-preference functions were constructed that indicated how the hedonic rating of a food item varied with the time since the food was last served. The function assumes a quadratic form with entrees tending to be most time sensitive, and salads and vegetables the least. The derivation of the meal component weights allowed for the combination of individual food item preference values in the evaluation of entire meals. The overall system appears to offer a logical, realistic and integrated approach to reflecting time factors and relative importances of the various meal components in the evaluation of cyclic menus.

The Problem of Choice and Aggregation

Much of food preference surveying, whether for individual items, or for complete meals, concerns the average respondent. Often, the average respondent does not adequately represent the diverse groups that make up the average. This problem becomes more acute in evaluating selective menus for overall preference. The standard cyclic menus under analysis typically contain two entrees, two starches, two vegetables, etc., at each meal. If the individual has the option of choosing only one of the entrees then the chosen entree, and only that entree, should decline in preference immediately after the meal. The problem is whether individual behavior can be modeled in a more precise way to reflect the actual food selections made in a selective cyclic menu situation.

Expanded Data Base and Equivalence Classes

With only 144 food items surveyed there were a large number of translations made to relate these data to the more than 600 recipes in the Armed Forces Recipe System. As a minimum, additional food items as well as varied menus should be surveyed to reduce any incorrect assumptions incurred when making translations. With an expanded data base, similar items can then be analyzed to determine if equivalence classes really do exist and what food items make up these equivalence classes (i.e., green salads may be grouped into one class, whereas poultry recipes may not be).

Menu Preference Optimization Model

One important use of these survey data and the models developed could be a menu optimization model with the time-preference, weighting factor equation (5) as the optimization function, and cost, nutrition and compatibility functions the constraints of the optimization system.

MENU	DAY/MEAL	RECIPE	SERV-G	INTERVAL	P(MAX)	K(1)	K(2)	K(3)	MENU CLASS WT	ITEM PREFERENCE
3	2	BARBECUED PORK LOIN	12.	DAYS	6.60	4.32	2.46	-.53	2.34	13.727
3	2	GINGER POT ROAST	7.	DAYS	6.67	4.35	2.14	-.48	2.34	13.561
3	2	RISSOLE POTATOES	11.	DAYS	7.08	6.29	1.87	-.46	.74	4.909
3	2	MASHED POTATOES	1.	DAYS	6.92	5.28	1.88	-.42	.74	3.595
3	2	CAULIFLOWER POLONAISE	7.	DAYS	4.08	2.80	.89	-.21	.58	2.173
3	2	BUTTERED MIXED VEGETABLES	2.	DAYS	5.96	4.03	1.55	-.34	.58	2.710
3	2	CREAMED ONIONS	8.	DAYS	4.32	3.40	1.22	-.26	.58	2.218
3	2	COLE SLAW	2.	DAYS	6.15	4.81	1.30	-.28	.35	1.768
3	2	TOSSED GREEN SALAD	2.	DAYS	6.95	6.05	.96	-.25	.35	2.203
3	2	LETTUCE AND TOMATO SALAD	2.	DAYS	6.53	6.09	1.28	-.29	.35	1.925
3	2	DEVIL@S FOOD CAKE	5.	DAYS	6.48	4.25	1.48	-.34	.76	4.377
3	2	FRUIT BARS	4.	DAYS	5.14	4.90	1.56	-.33	.76	3.177
3	2	ICE CREAM	1.	DAYS	7.27	7.18	1.22	-.31	.76	4.613
3	2	PEACH CRISP	9.	DAYS	5.63	4.90	1.56	-.33	.76	3.829

** ** *** OVERALL MEAL PREFERENCE VALUE IS 6.79 *** ** **

MENU	DAY/MEAL	RECIPE	SERV-G	INTERVAL	P(MAX)	K(1)	K(2)	K(3)	MENU CLASS WT	ITEM PREFERENCE
3	3	GRILLED MINUTE STEAK	8.	DAYS	6.80	6.19	2.13	-.49	2.34	14.133
3	3	SIMMERED KNOCKWURST	12.	DAYS	6.23	4.23	2.07	-.42	2.34	12.979
3	3	BAKED BEANS	12.	DAYS	6.03	4.06	2.02	-.50	.74	4.138
3	3	MASHED POTATOES	1.	DAYS	6.92	5.28	1.88	-.42	.74	3.595
3	3	STEWED TOMATOES	10.	DAYS	4.95	3.44	1.42	-.32	.58	2.611
3	3	BUTTERED ASPARAGUS	5.	DAYS	5.20	3.23	1.08	-.24	.58	2.696
3	3	BUTTERED SUCCOTASH	4.	DAYS	5.10	2.33	.90	-.21	.58	2.675
3	3	GARDEN VEGETABLE SALAD	2.	DAYS	5.07	4.30	1.30	-.28	.35	1.390
3	3	JELLIED FRUIT COCKTAIL SL	31.	DAYS	5.57	4.33	1.31	-.26	.35	1.886
3	3	MACARONI SALAD	9.	DAYS	6.43	3.90	1.67	-.36	.35	2.035
3	3	BUTTERSCOTCH BROWNIES	12.	DAYS	5.36	4.90	1.56	-.33	.76	3.708
3	3	APRICOT PIE	28.	DAYS	4.77	2.69	1.10	-.24	.76	3.520
3	3	YELLOW CAKE	24.	DAYS	5.61	4.90	1.56	-.33	.76	4.069

** ** *** OVERALL MEAL PREFERENCE VALUE IS 6.23 *** ** **

Figure 4: Sample Output From Menu Preference Evaluation Computer Program.

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A STUDY OF REPLACEMENT POLICIES FOR VEHICLES BASED ON REPAIR COST LIMIT

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INTRODUCTION

1. Some time ago our group was asked to compare different ways of replacing and maintaining a fleet of vehicles. The desirability of minimizing cost under a constrained budget is obvious, and within an organization as large as DND there ought to be a substantial savings by monitoring large fleets of less expensive items, such as vehicles, in an optimal or close to optimal fashion.

REPLACEMENT PROBLEM - DIFFERENT POLICIES

2. Having a fleet of vehicles, we are always facing the question of whether to replace all vehicles in the fleet at the same time or to replace each vehicle individually. This question is being examined in this study. Specifically, we were asked to perform a comparison of four different replacement policies.

a. Present policy within the Department of National Defence of Canada (DND);

b. Present policy within the other Government Departments in Canada (Treasury Board Guidelines);

c. Optimum group replacement; and

d. Optimum repair limit - replacement.

3. The present policy within DND specifies certain repair limits for commercial pattern vehicles. The repair limits are established as a percentage of acquisition cost plus some overhead. This percentage is a function of both age and mileage. When a vehicle requires a repair, the estimated cost of the repair is compared to a predetermined repair expenditure limit. If this is exceeded, the vehicle is scheduled for replacement. However, a few additional factors are also taken into account. If a vehicle's repair history indicates an excessively high maintenance cost, or if the vehicle has lengthy periods of unserviceability due to non-availability of spare parts, it

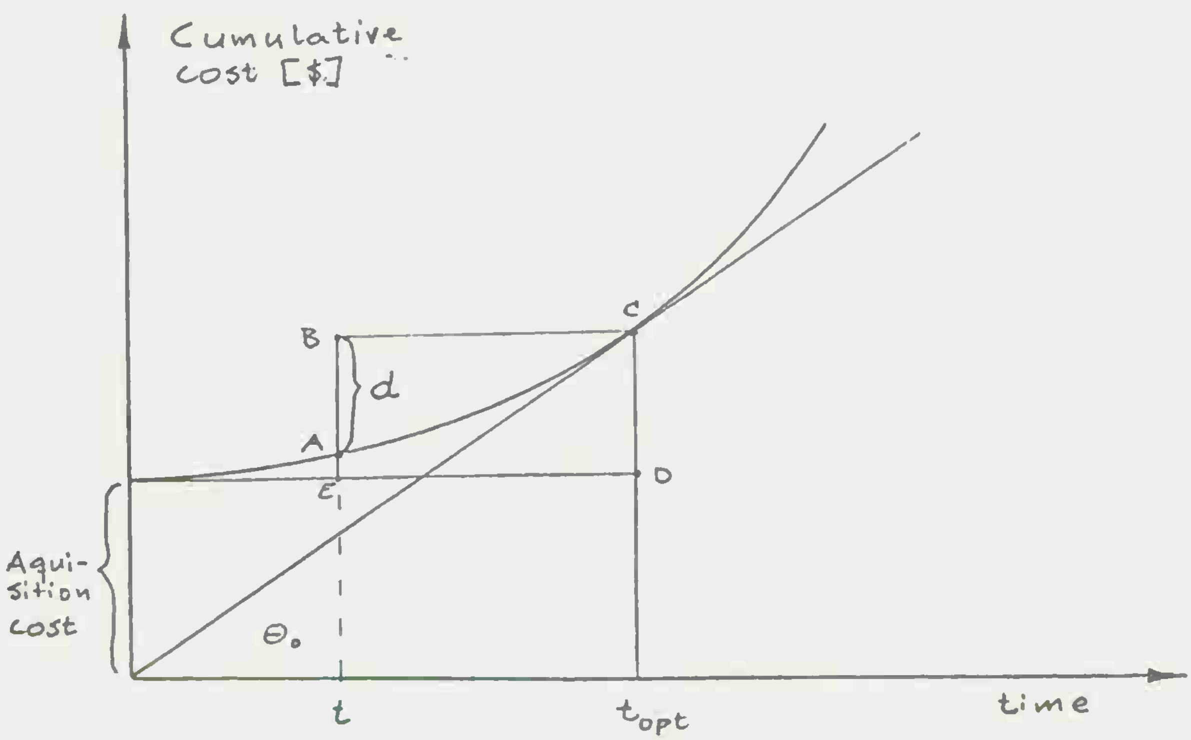
may be replaced. On the other hand, if funds for procurement are low, the disposal action may be deferred. We do not know the rationale on which the DND repair limits were calculated.

4. Treasury Board has established guidelines for disposal of vehicles by other departments within the Government of Canada. These guidelines advise the departments to dispose of a vehicle when it reaches a certain age or mileage limit, whichever occurs first. However, in addition, the departments may use repair limits which have been established for this purpose. These repair limits are a function of age and mileage.

5. Optimum group replacement is a system not presently being used for commercial pattern vehicles within the Canadian Government. The idea behind it is to replace the fleet at a period yielding the minimum average cost per unit time.

6. Optimum repair limit - replacement is a policy similar to the present DND policy; but with different repair limits.

7. The idea behind the repair limit concept is to choose to repair if the future expected cost plus the cost of the repair, per time unit, does not exceed the average cost per time unit.



8. Consider a vehicle at point A on the cumulative cost curve, requiring a repair costing r_t. The expected future cost due to repairs, d, up to time t will be the distance AB. The total expected future costs per time unit will then be

$$\theta = \frac{r_t + d}{t}$$

9. The repair limit $r_0(t)$ is the maximum repair cost we can have before it becomes economical to replace. This occurs when $(r_t+d)/t$ is equal to the minimum cost per time (θ_0).

i.e.

$$\theta_0 = \frac{r_0(t)+d}{t}$$

or

$$r_0(t) = \theta_0 t - d$$

HOWARD'S FORMULATION OF THE REPAIR LIMIT REPLACEMENT PROBLEM

10. When managing a vehicle fleet under a maintenance policy, a steady state will always be reached in some finite time, i.e., the fleet will reach a point when the distribution of the vehicles over its total mileage span (or age span) will not change with time. An underlying assumption of the model being used is that the optimal steady state solution is applicable to the fleet.

11. The problem was first formulated as a Markov decision process by Howard (2). In our case, the "states" are mileage intervals and the decision variable is the repair limit in each state. Given a fixed repair limit for a state we can define a transition matrix P where p_{ij} is the probability of going to state j, given that the system is in state i. Clearly, for our case $p_{ij} = 0$ except for j=1 and j=i+1, since a vehicle can only be repaired or replaced. We can also define a cost matrix R, where r_{ij} is the cost incurred over the transition $i \rightarrow j$. We define a policy as a set of repair limits, one repair limit for each state. The objective, then, is to find a policy which minimizes the expected cost to maintain a fleet of vehicles.

12. We can start by defining $v_i(n)$ as the total expected cost that the system will incur, given that it starts in state i and proceeds through n transitions. A recurrence relation immediately presents itself. When the system makes a transition from i to j, it will cost r_{ij} plus the expected cost of starting in state j and proceeding through n-1 transitions.

i.e.

$$v_i(n) = \sum_{j=1}^{N} p_{ij}(r_{ij}+v_j(n-1)) \qquad (1)$$

We now let

$$q_i = \sum_{j=1}^{N} p_{ij}r_{ij} \qquad (2)$$

which can be interpreted as the expected immediate return from the next transition.

13. Then, when the system reaches the steady state, the average gain, g, per stage will be:

$$g = \sum_{i=1}^{N} \pi_i q_i$$

Where π is the steady state vector distribution of vehicles over the total mileage span. Because this process is ergodic, the cost to maintain is constant over time (steady state) and the same no matter which state (i) we started in. We then have, for large n:

$$v_i(n)-v_j(n-1) = g \qquad \text{for all i and j}$$

Hence,

$$v_i(n) = ng+v_i \qquad (3)$$

where v_i is the relative value due to the fact that we now are starting from state i. Substituting (2) and (3) into the recurrence relation, we get:

$$v_i+g = q_i+\sum_{j=1}^{N} p_{ij}v_j \qquad (4)$$

Now for a given set of repair limits (policy A) we can solve the system of simultaneous equations:

$$v_i^A+g^A = q_i^A + \sum_{j=1}^{N} p_{ij}^A v_j^A$$

14. This is a set of N equations in N+1 unknowns. We can arbitrarily put one of the v_i's to zero and solve for the other relative values as well as g^A.

15. The first step is known as the value determination step. The second step in this problem will be to try to find new repair limits that will improve our steady state gain.

16. This can be done by finding the maximum over all the different repair limits of the right hand side of (4):

$$\max_{\text{(all repair limits)}} \{q_i + \sum_{j=1}^{N} p_{ij}v_j\}$$

17. This new improved right hand side of (4) is then introduced and we then go back to step 1 and iterate in this way until we have found the optimum gain. Howard has shown that the process terminates in a finite number of iterations provided the repair limits take integral values.

18. However, the most disadvantageous feature of this routine is the solution of the N simultaneous equations. By using expressions giving bounds on the optimal gain, developed by Odoni (6), the solution of the simultaneous equations is avoided.

19. It has been proven that for a given policy, the steady state gain for the present policy and the gain for the optimum policy is bounded.

below by: $\min \text{(all i)} \{v_i(n+1) - v_i(n)\}$

above by: $\max \text{(all i)} \{v_i(n+1) - v_i(n)\}$

A better estimate of the gain can be found simply by taking the mid-value of these bounds. Then, we can use this improved steady state gain to find improved values at stage n by subtracting this g^{Improved} from the new values at stage n-1. This brings us back to the beginning of the iteration cycle. We exit from this loop when the difference in the bounds is less than a specified value.

THE COMPUTER PROGRAM

20. Our thanks go to Major Mahon of the REME Data Centre, Woolwich, England, who was kind enough to provide us with a computer program to calculate repair limits based on the above algorithm.

ESTABLISHING A DATA BASE

21. The data needed for evaluating different replacement policies take the following elements into account:

a. Capital cost;

b. Depreciation;

c. Operation cost;

d. Maintenance cost;

e. Inflation; and

f. Discounts due to bulk buys.

CAPITAL COST AND INFLATION

22. Two factors which may influence the decision of when to replace an old vehicle with a new one are the interest on capital obtained if a new buy is postponed and the inflation in the cost of the vehicle over the same time period. It was felt that these two factors would counterbalance each other and hence would not need to be included in the analysis.

DEPRECIATION

23. Depreciation for this fleet was established from National Market Reports Truck Blue Book of resale values. The figures were corrected for the inflation effect.

OPERATION COST

24. Operating cost includes oil, gas, tires, and batteries. This was shown to have no significant change with age. This implies that it could be excluded, as expected, from a replacement decision.

MAINTENANCE COST

25. The decision to replace a vehicle need not be affected by those costs which do not change over time. The maintenance costs were divided between corrective and preventive maintenance to determine if either of these could be eliminated from the cost influencing a replacement decision. To obtain data, a fleet of station wagons within DND was selected as a test fleet. Data were obtained through the existing maintenance information system (LOMMIS) within DND. This provided reliable data for the last two year period. Unfortunately, some of the data needed for our study were not directly obtainable from the LOMMIS data base. Consequently, it was necessary to collect data manually at the CF bases from the LOMMIS reporting forms (CF 1020). Because of the obvious difficulty in following such a procedure, a preliminary sample was taken as a basis for stratified sampling of the remaining necessary amount of data. Age groups were used as strata. This procedure enabled us to obtain better confidence in the results with only a small sample.

26. By application of stepwise linear regression to the obtained sample, it was shown that the best linear model for predicting the corrective maintenance cost was to use mileage alone as the independent variable. Further, the data enabled us to conclude that the preventive maintenance costs did not significantly increase with age or mileage.

27. The corrective cost is a statistical variable, depending on both the number of repair visits over a given interval and the cost of each single repair. Within each mileage group of

5000 miles, the histograms for both the cost of a single repair and the number of repair visits were established.

28. Based on the assumption that the basic type of the distributions do not change over the mileage intervals, the data were "normalized" by taking away the effect of increasing cost due to increased mileage. The distributions could then be cumulated into one before a theoretical Weibull distribution was fitted. The problem of small amounts of data within some intervals was thus evaded. In Figure 5 the histogram is shown, as well as the fitted distribution. Although there were sufficient data for the χ^2 test to reveal a significant difference between the empirical and theoretical distribution, the departures were too small to affect the cost calculations, and accordingly the theoretical distribution was used. By going the opposite way, "denormalizing" the data, the only thing that changes is the scaling parameter in the Weibull distribution. The coefficient of variation was kept constant at 1.25. This was supported by the data where a weighted regression on the coefficient of variation gave the best linear representation as a constant at 1.3.

29. The data for the number of individual repairs were fitted to a Neyman Type A distribution. The mean number of repair visits increases strongly in the beginning and then levels off at 2.8 (visits per 5000 miles). In this case, the coefficient of variation also appeared to be a constant of 0.938. Two histograms are shown with the theoretical distributions in Figures 1 and 2.

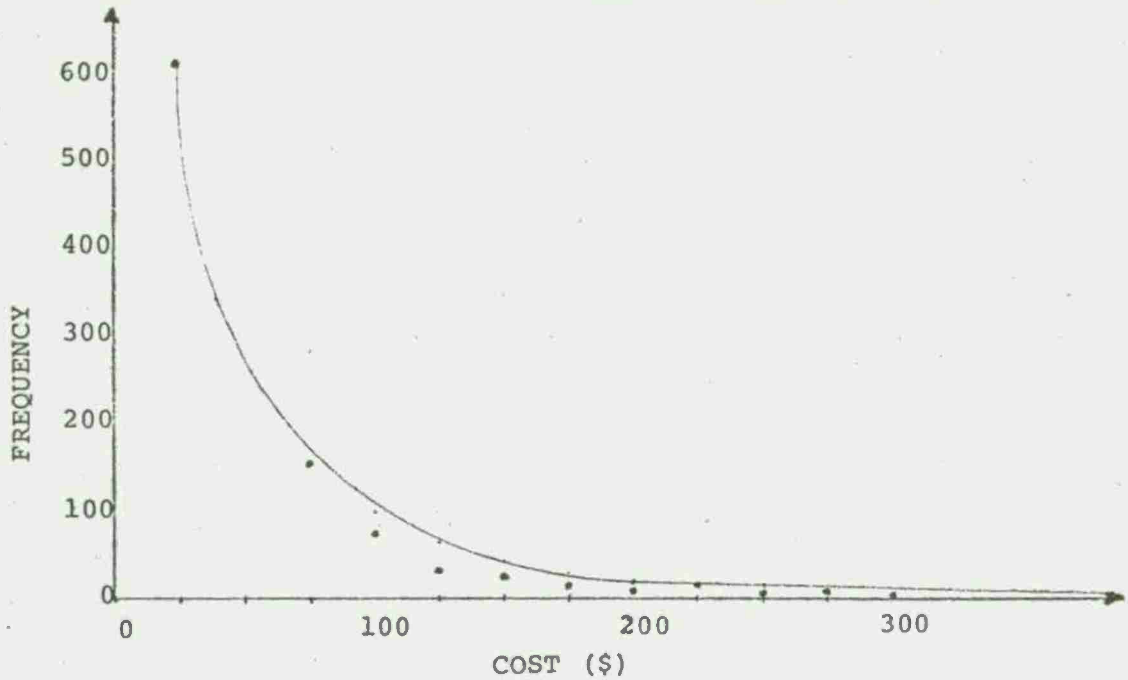
DISCOUNTS DUE TO BULK BUYS

30. Available data within the Government of Canada indicates 10%-15% discounts on buys of less than ten vehicles, and 20%-30% on buys of more than ten vehicles. This is of importance when evaluating a group replacement policy. However, it will be shown that bulk discounts can also be realized under a repair limit policy.

OUTPUT OF COMPUTER PROGRAM

31. The program gives us output tables with parametric description of the data input for the two basic distributions. It gives the optimum repair limit for all the different states (here mileage groups) and the cost that this policy incurs. The cost is split up into expenses for new vehicle buys and expenses for repairs. Information about the fleet's age and distribution in terms of mileage, and the probability of survival for each mileage interval is given as well. A sample printout is shown on the next page.

FIGURE 1: REPAIR COST. FIT ABOUT AT WEIBULL DISTRIBUTION



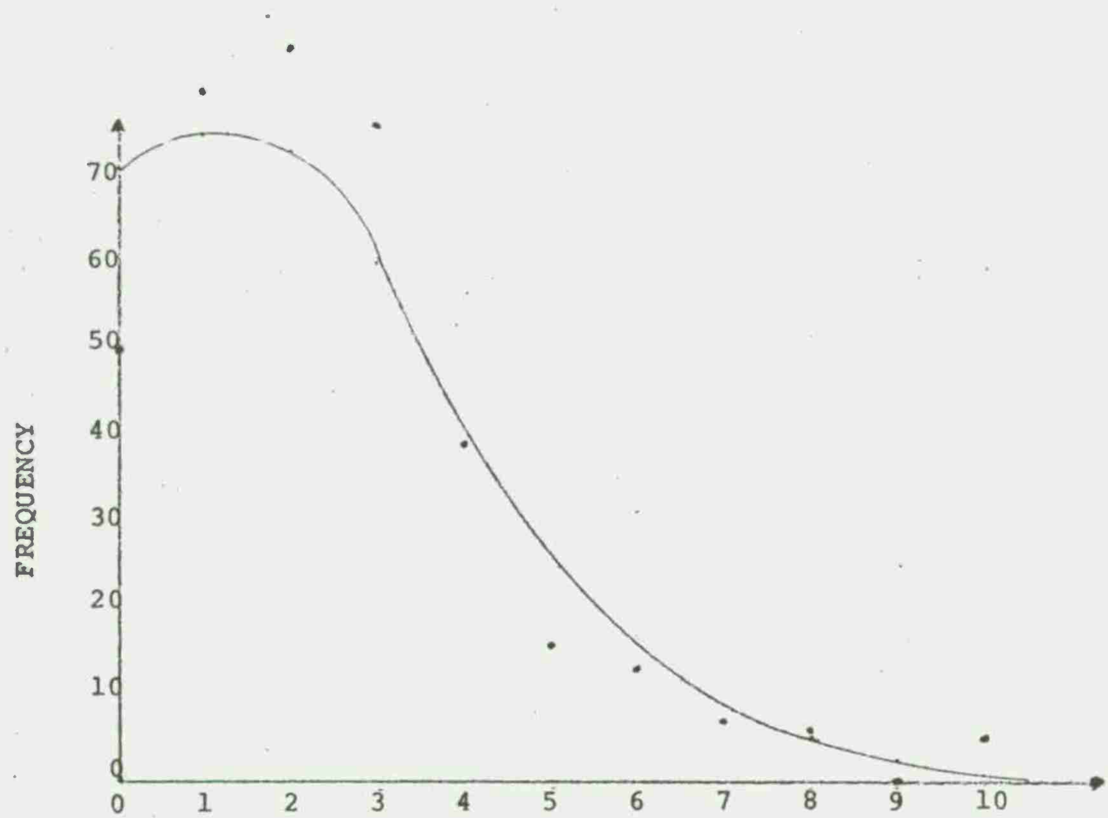


FIGURE 2: NUMBER OF REPAIR VISITS/5000 MILES.
FIT ABOUT A NEYMAN TYPE A DISTRIBUTION

REPAIR LIMITS CALCULATION OPTIMAZATION FULL RESALE

REPLACEMENT COST= 3200.00 GRID SIZE= 1.00 MAX MILEAGE INT= 20 MAX NO ITERATIONS= 999 EXIT= .1

PARAMETERS STATISTICAL PERIODS 1 TO 2 DATE OF EXTRACTION 9/10/74

COMPOUND POISSON				WEIBULL (LOCATION= 0)						
MEAN	STD DEV. .	THETA	LAMBDA	MEAN	STD DEV	SLOPE	SCALE	W/ITS	PERC LAB	NET COST
.93	.87	.200	4.628	47.13	58.60	.810	41.977	11	44.00	369.28
1.36	1.28	.200	6.805	48.90	60.79	.810	43.550	11	44.00	497.11
1.63	1.53	.433	3.763	50.66	62.99	.810	45.124	11	44.00	624.94
1.83	1.72	.612	2.993	52.43	65.18	.810	46.698	11	44.00	752.77
2.00	1.88	.761	2.630	54.20	67.38	.810	48.271	11	44.00	880.61
2.15	2.01	.889	2.415	55.96	69.57	.810	49.845	11	44.00	1008.44
2.28	2.14	1.003	2.269	57.73	71.77	.810	51.419	11	44.00	1136.27
2.39	2.25	1.106	2.164	59.50	73.96	.810	52.992	11	44.00	1264.10
2.50	2.35	1.201	2.083	61.26	76.16	.810	54.566	11	44.00	1391.93
2.60	2.44	1.288	2.018	63.03	78.35	.810	56.140	11	44.00	1519.76
2.69	2.53	1.370	1.966	64.80	80.55	.810	57.713	11	44.00	1647.60
2.78	2.61	1.447	1.922	66.57	82.74	.810	59.287	11	44.00	1775.43
2.80	2.63	1.464	1.913	68.33	84.94	.810	60.861	11	44.00	1903.26
2.80	2.63	1.464	1.913	70.10	87.13	.811	62.460	11	44.00	2031.09
2.80	2.63	1.464	1.913	71.87	89.33	.811	64.035	11	44.00	2158.92
2.80	2.63	1.464	1.913	73.63	91.52	.811	65.609	11	44.00	2286.75
2.80	2.63	1.464	1.913	75.40	93.72	.811	67.183	11	44.00	2414.59
2.80	2.63	1.464	1.913	77.17	95.91	.811	68.758	11	44.00	2542.42
2.80	2.63	1.464	1.913	78.93	98.11	.811	70.332	11	44.00	2670.25
2.80	2.63	1.464	1.913	80.70	100.30	.811	71.906	11	44.00	2798.08

SOLUTION OPTIMAZATION NO OF ITERATIONS ON N 127
EXPECTED COST / 5000 MILES 256.03 FINAL ODONI BOUNDS (256.58 , 256.68)
EXPECTED LENGTH OF LIFE 34160.76 NO OF CALLS OF TRANS 1029

MILEAGE INTERVAL	REPAIR LIMIT	PR(SURVIV INT/GOT TO INT)	PR(SURVIV INT)	DISTRIBUTION OF MILEAGE
(0- 5000)	381.00	.998	.9976	(2500.0 , .14534)
(5000- 10000)	381.00	.996	.9935	(7500.0 , .14487)
(10000- 15000)	381.00	.994	.9877	(12500.0 , .14415)
(15000- 20000)	381.00	.992	.9801	(17500.0 , .14318)
(20000- 25000)	174.00	.892	.8742	(22500.0 , .13492)
(25000- 30000)	117.00	.763	.6666	(27500.0 , .11210)
(30000- 35000)	91.00	.653	.4354	(32500.0 , .00018)
(35000- 40000)	72.00	.560	.2440	(37500.0 , .04943)
(40000- 45000)	57.00	.481	.1174	(42500.0 , .02630)
(45000- 50000)	45.00	.426	.0500	(47500.0 , .01218)
(50000- 55000)	33.00	.359	.0179	(52500.0 , .00494)
(55000- 60000)	21.00	.300	.0055	(57500.0 , .00170)
(60000- 65000)	14.00	.279	.0015	(62500.0 , .00051)
(65000- 70000)	10.00	.204	.0004	(67500.0 , .00014)
(70000- 75000)	8.00	.264	.0001	(72500.0 , .00004)
(75000- 80000)	6.00	.256	.0000	(77500.0 , .00001)
(80000- 85000)	5.00	.253	.0000	(82500.0 , .00000)
(85000- 90000)	4.00	.249	.0000	(87500.0 , .00000)
(90000- 95000)	3.00	.238	.0000	(92500.0 , .00000)
(95000-100000)	1.00	.238	.0000	(97500.0 , .00000)

VARIANCE OF LENGTH OF LIFE 86161.00 PARTITIONING OF EXPECTED COST TOTAL 256.03
APPROX 95 PERC CI FOR LIFE (33700.14, 34999.37) NEW VEH BUYS 160.31
MEAN MILEAGE OF VEHICLE FLEET 19670.03 REPAIRS 90.32
MEDIAN MILEAGE OF VEHICLE FLEET 19999.40 LABOUR 39.74
PERC REP COST DUE TO LABOUR 44.00 SPARES 50.58

32. The information just described is of great value to maintenance and procurement managers. Further, the recommended policy minimizes costs in the long run. Because we have found a solution to the steady state problem, a finite time will elapse before the predicted optimum cost will be fully realized. The actual cost will be somewhere between the cost incurred by the current policy and the optimum one. However, budgeting and procurement people will mostly be interested in obtaining a forecast for how many vehicles are to be bought over a defined period. The expected number of discarded vehicles can be obtained by a simple manipulation of the probability of survival for any specific interval and the number of vehicles currently within this interval. A further consequence of this will be that the greatest advantage of group replacement (substantial discounts due to bulk procurement) will also be realized for this policy by utilizing this forecast to order in bulk ahead of time.

RESULTS

33. The computer program we have obtained has the capability of evaluating a given set of repair limits as well as calculating optimum repair limits. Consequently, it is a relatively straightforward problem to evaluate the different policies.

34. The DND repair limits are stated as a percentage of acquisition cost and are a function of both age and mileage. In the course of analysing the data, we found that mileage was a better independent variable for prediction of cost than age. A correlation coefficient of 0.65 on 2000 degrees of freedom tells us also that there is a very strong relation between age and mileage. These two results provide strong justification for transforming the DND repair limits into a function of miles alone using the average annual mileage of 11,400 miles/year. Using this procedure we were able to obtain a set of repair limits representing the DND policy and conforming with our model.

35. The Treasury Board repair limits were also stated as a percentage function of age and mileage and the same analysis was carried out as for the DND repair limits. Also there was the additional constraint that when a vehicle exceeded 50,000 miles it was to be discarded. This was implemented simply by setting the repair limits to equal to zero after this point.

36. The Treasury Board Guidelines are so defined that they do not lend themselves to a well-defined mathematical formulation. For this reason we decided to represent the worst case situation of repairing everything up to 60,000 miles and not repairing anything thereafter. This was done by having very high repair limits up to 60,000 miles and zero repair limits afterwards. By doing this, the cost of the actual policy will

be somewhere between the cost of this policy and the cost of the Treasury Board repair limit policy.

37. The Treasury Board repair limits and the DND repair limits are shown in Figure 3.

38. A sensitivity analysis was carried out on the parameters of the repair cost and repair visit distributions. These results are shown in Figures 4 and 5. In both cases, the means and variances were changed together so as to keep the coefficient of variation constant. This property was supported by the data on repair visits and assumed for the repair costs. The figures show that the four policies remain in the same order with respect to overall cost and that the repair visit mean is slightly more sensitive than the repair cost mean.

39. It was also found that the cost was extremely insensitive to changes in repair limits for mileages less than 20,000 or greater than 70,000. For example, a change in the first four repair limits from $400 to $2000 produced no change in the overall cost.

40. In the course of evaluating the various repair policies it was found that the relative savings were greatly influenced by the resale value realized. This fact, along with our lack of confidence in the resale values, makes it necessary to make all comparisons with respect to this parameter.

41. The calculations were first carried out using standard resale values from the National Market Reports Truck Blue Book (hereafter referred to as full resale values). Then, based on data received on actual resale values of DND vehicles, it was felt that the full resale values were too high. Consequently, a sensitivity analysis of resale values was carried out and a comparison of the policies was done over the full range. These resale values were also adjusted by the cost of the repair which caused the vehicle to be condemned (the partial mean above the repair limit). These results are shown in Figure 6.

42. For full resale values, the optimum repair limit policy yields a cost of $51.20 per 1000 miles while Treasury Board repair limits cost $53.60 per 1000 miles, DND repair limits cost $54.00 per 1000 miles, and Treasury Board Guidelines cost $54.80 per 1000 miles. This means that a fleet of 1000 vehicles operating 11,400 miles/year under an optimum repair limit policy will cost $27,500 less per year than the same fleet operating under the Treasury Board repair limit policy; $32,000 less than DND repair limits, and $41,000 less than Treasury Board Guidelines.

FIGURE 3: REPAIR LIMITS

MILEAGE INTERVAL	DND-REL'S	TB-REL'S	OPTIMUM
(0- 5000)	2450.00	1111.00	381.00
(5000- 10000)	1779.00	988.00	381.00
(10000- 15000)	1335.00	901.00	381.00
(15000- 20000)	1133.00	813.00	357.00
(20000- 25000)	989.00	707.00	174.00
(25000- 30000)	826.00	638.00	117.00
(30000- 35000)	796.00	551.00	91.00
(35000- 40000)	531.00	463.00	72.00
(40000- 45000)	422.00	375.00	57.00
(45000- 50000)	379.00	288.00	45.00
(50000- 55000)	230.00	200.00	33.00
(55000- 60000)	154.00	113.00	21.00
(60000- 65000)	80.00	0.00	14.00
(65000- 70000)	45.00	0.00	10.00
(70000- 75000)	26.00	0.00	8.00
(75000- 80000)	16.00	0.00	6.00
(80000- 85000)	6.00	0.00	5.00
(85000- 90000)	6.00	0.00	4.00
(90000- 95000)	3.00	0.00	3.00
(95000-100000)	0.00	0.00	1.00

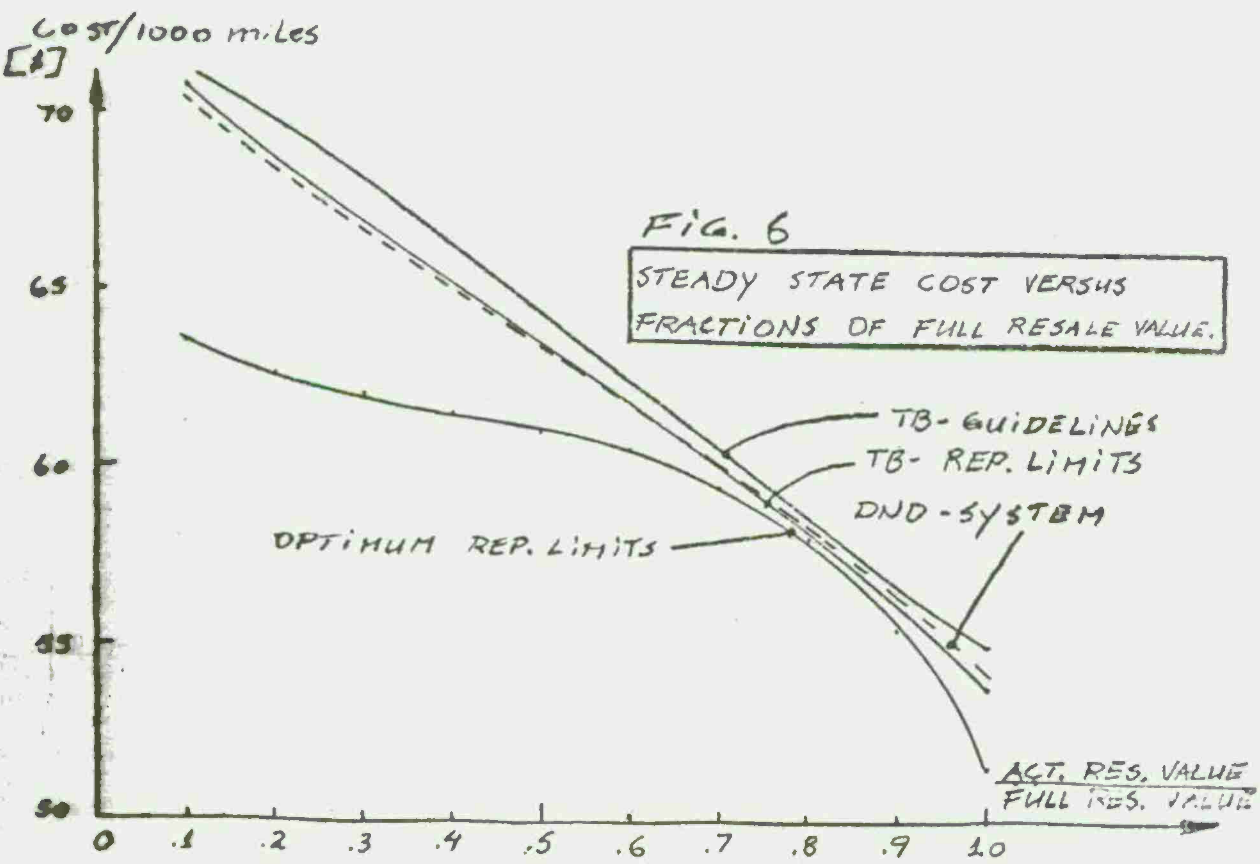
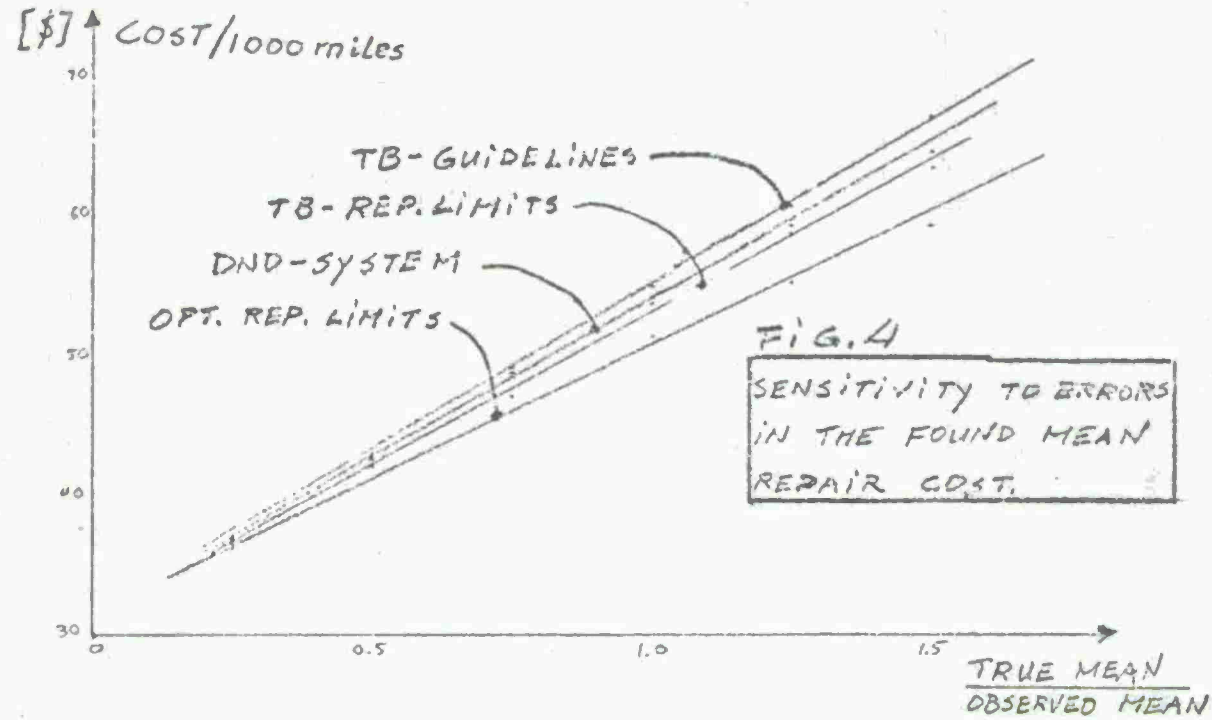
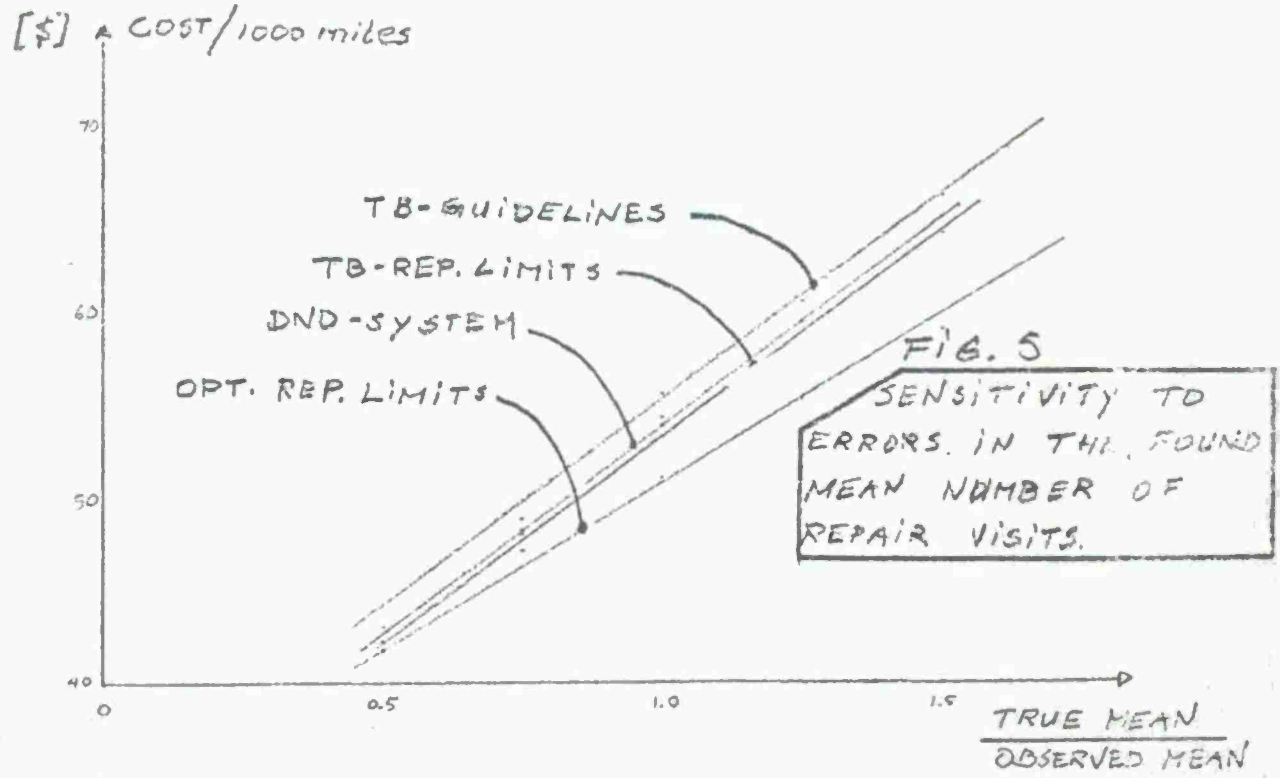


FIG. 6

STEADY STATE COST VERSUS FRACTIONS OF FULL RESALE VALUE.


[$] COST/1000 miles
70
60
50
40
30
0
0.5
1.0
1.5
TB-GUIDELINES
TB-REP. LIMITS
DND-SYSTEM
OPT. REP. LIMITS
FIG. 4
SENSITIVITY TO ERRORS IN THE FOUND MEAN REPAIR COST.
TRUE MEAN / OBSERVED MEAN


[$] COST/1000 miles
70
60
50
40
0
0.5
1.0
1.5
TB-GUIDELINES
TB-REP. LIMITS
DND-SYSTEM
OPT. REP. LIMITS
FIG. 5
SENSITIVITY TO ERRORS IN THE FOUND MEAN NUMBER OF REPAIR VISITS.
TRUE MEAN / OBSERVED MEAN

43. The data obtained for DND resale values indicate that we may actually be getting between 0.4 and 0.5 of the full resale values. In this case the optimal repair limits would give an improvement of $50,000 per year. The corresponding savings for resale values at 0.8 of the full resale value is only $6,800.

44. These results show immediately that it is very important that detailed studies be carried out on resale values.

45. The data necessary for implementation of a repair limit replacement policy may be useful in other areas (i.e., manpower allocation, budgeting). The cost of gathering such data is substantial. If it is to be used solely for replacement policies, then a detailed study of this cost should be performed, in order to determine if it is cost effective. If the data must be collected for other purposes then it could also be used for determining an optimal replacement policy. Even in this case, however, there is still the cost of paperwork involved in changing the repair limits which may or may not be significant.

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USE OF COMPUTERIZED SUPPORT MODELING IN LOGISTIC SUPPORT ANALYSIS

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BACKGROUND: There has been growing concern within the Department of Defense (DOD) during recent years for the consequences of ignoring predicted cost of ownership for any given system while it is still in design. Cost considerations during design were traditionally restricted to research and development (R&D) acquisition costs. The realization that downstream cost of ownership can turn out to be many times the cost of acquisition, was the catalyst for new policy.

In July of 1971, a new DOD Directive 5000.1 entitled "Acquisition of Defense Systems" was distributed. Essentially the directive contains four new policies, one of which is the requirement to "consider logistics as a principal design parameter". Another is the translation of operating and support costs into "design to" requirements.

LOGISTIC SUPPORT ANALYSIS: In order to deal with problems of ownership as well as acquisition of a system, one must be able to bridge the gap between the inherent characteristics of the design and the environment in which the system will be operated and maintained. The process by which this can be accomplished is called logistic support analysis (LSA). It consists of first representing a system in its typical operational, maintenance, and logistics environment and then systematically studying the effects that the various design and support parameters have on system ownership costs, as well as availability of the system to accomplish its intended mission. The most cost effective trade-off options involving both design and support are identified and evaluated from a logistics point of view. By providing another perspective from which to observe the system acquisition process, the display of these LSA options can assist decision makers in choosing the most cost effective approaches to pursue.

LSA OBJECTIVES: In order to fully appreciate the role of LSA throughout the system acquisition cycle, it is necessary to identify the objectives of LSA during the various development phases. These objectives can be summarized as follows:

Advanced Development: (1) Identify and assess the impact of alternative design approaches on logistics support. (2) Evaluate alternative support concepts for the advanced development prototype. (3) Determine "design to" support cost parameters to be utilized as the basis for demonstrating actual achievement in subsequent development phases. (4) Identify trade-off options and rationale based on logistics considerations.

Engineering Development: (1) Affect baseline design configuration. (2) Determine optimal support policy alternatives based on ownership cost and operational availability. (3) Subsequent to baseline design freeze, assess impact of proposed design changes on maintenance support. (4) Assure the development of compatible logistics data products, such as technical manuals, provisioning documentation, test equipment, and maintenance manpower requirements.

Post Deployment: (1) Evaluate existing maintenance policies for fielded equipment. (2) Assess product improvement programs in terms of logistics support considerations.

COMPUTERIZED SUPPORT MODELING: The key to making logistics a principal design parameter is the performance of timely and comprehensive LSA's throughout the acquisition cycle in accordance with the objectives outlined above. Because of both system and logistics complexities, computerized support modeling has proven to be a valuable tool to assist in the performance of LSA's. Support modeling enables numerous design and support alternatives to be represented and examined in a rapid, accurate manner. Situations involving interaction of large amounts of intricate information can be easily handled by a computer model in a matter of minutes. In addition, a dynamic picture of the sensitivity of variations in design and support options can be dramatically displayed and identified with measures of confidence.

GENERALIZED ELECTRONICS MAINTENANCE MODEL: At the US Army Electronics Command (ECOM) a computerized support model has been developed in-house and is presently being utilized for the performance of LSA's during each of the above cited phases. The model is called GEMM which stands for Generalized Electronics Maintenance Model. GEMM is a computer program in FORTRAN IV. It is an analytic type mathematical model which represents the equipment, the logistics support system, and the operational and maintenance environment. The best way to briefly describe GEMM is to identify the types of input data required to run the model and the kinds of information that are outputs.

GEMM INPUT DATA: The GEMM input data can be classified into four categories: system hardware, mission, maintenance, and logistics data. System hardware data consists of equipment breakdown structure, quantitative reliability and maintainability parameters, and hardware costs. Description of system deployment including quantities, distribution patterns, and operating requirements comprise the mission profile data. Maintenance data encompass types of manpower, test equipment, and facilities required to repair the system, as well as training, technical manuals, and overhaul information. Logistics data consist of maintenance shop structure, including typical transportation times and distances between shops at the various levels of maintenance. Also included in this category are delay times, requisition times, stockage objective periods, order-ship times, turn-around times, shipping data, inventory management and other parameters describing the Army supply system.

GEMM OUTPUTS: The key GEMM outputs are life cycle support costs and operational availability. The life cycle support costs are divided into the following areas: (1) Stockage, including both initial provisioning and re-order stock. (2) Test equipment. (3) Maintenance personnel. (4) Training. (5) Transportation. (6) Publications. (7) Inventory Management. (8) Overhaul.

Other GEMM outputs include maintenance allocation, annual maintenance manhours, and stockage quantities, test equipment, and maintenance personnel requirements per shop at each maintenance level.

SENSITIVITY ANALYSIS: The most powerful attribute of GEMM is its sensitivity analysis capability. It provides a simple and easy method of varying selected input data parameters and observing the resulting impact on the outputs. The interaction of several variables can be considered simultaneously. The GEMM sensitivity analysis mechanism can be used to illustrate the effect that changes in both design and support variables have on life cycle support costs and operational availability of the system.

FIGURE OF MERIT: In the performance of an LSA, both system design and support concepts can be analyzed. A useful figure of merit to permit evaluation of these kinds of alternatives is the cost effectiveness ratio, which is defined as system operational availability divided by life cycle support cost.

$$\text{COST EFFECTIVENESS RATIO} = \frac{\text{OPERATIONAL AVAILABILITY}}{\text{LIFE CYCLE SUPPORT COST}}$$

Thus, the cost effectiveness ratio represents how much operational availability is bought for the amount of life cycle dollars spent. It should be noted that operational availability is a measure of system readiness including the effect of the operational, maintenance, and logistics environment. It provides an excellent insight into the design/support interactions that are taking place. Once the operational availability requirement is specified, an important question remains, namely: What is the lowest cost design support approach which can be taken in order to achieve that required level of availability?

AVAILABILITY OF DATA: One of the most critical facets of performing a meaningful LSA is the availability of thorough and accurate data upon which to base the analysis. The problem of data availability is different at each phase of the acquisition cycle.

During the advanced development phase, even the system configuration is a guess. Therefore, any statement about the best maintenance concept to employ really boils down to a guess about a guess. Fortunately, it is not quite as hopeless as it may first appear. With the aid of a comprehensive uncertainty analysis, it is possible to predict ranges within which parameters will fall with a stated level of probability. Various options can be identified along with their levels of confidence. This kind of thinking early in the development cycle can save much time and money in the long run by avoiding those paths which, even at this early stage, can be identified as **high risk approaches.** The best one can hope for during the advanced development phase are gross ballpark type estimates of the major design and support parameters. This is an area where even the use of computerized support modeling techniques can be very difficult due to the shortage of good, reliable data.

During engineering development, the data situation begins to change dramatically. More and more design and support data become increasingly largely predictive. At this point logistics impact must be made on the baseline design. As the design is firmed up, data become more precise as well as abundant. It is at this stage that computerized support modeling becomes an invaluable tool for the analysis of this large and complex mass of information. On the negative side is the fact that as we reach this point in time, when so much meaningful data are available, we find that little or nothing can be done about the system design. The real area of impact now lies in optimizing the maintenance support of the item and influencing design changes which may be considered as the engineering development phase progresses.

During the post deployment phase of the life cycle we again find serious data availability problems. This is due to the fact that it can be extremely difficult to gather meaningful data on equipment which is dispersed throughout the world. With large, fix plant type systems, the collection of data can be a reasonable task. The difficulty arises, however, with high density equipment utilized in many locations by numerous different users. Unfortunately, this is the rule rather than the exception. At the present time, attempts are being made to gather field data using sample data collection and analysis techniques.

LSA DURING ADVANCED DEVELOPMENT: In order to illustrate some of the analysis techniques which can be employed, two case studies will be examined. Case I deals with problems faced during advanced development and Case II is concerned with the engineering development phase.

The key role of LSA during advanced development is to quantitatively assess the impact of alternative design approaches on logistics. In this manner logistics considerations can be presented to management as trade-off factors which evaluate systems effectiveness in terms of operational availability and total cost of ownership. These factors can then be weighed against other criteria such as technical feasibility, risk, and scheduling constraints.

CASE I - ADVANCED DEVELOPMENT: The LSA task at hand is to evaluate three alternative design approaches. The key parameters of these approaches are outlined in Table 1. In order to facilitate their identification these approaches are labeled low-cost, mid-cost, and high-cost, based on their relative production unit costs which are twenty, fourty, and eighty thousand dollars, respectively. Theoretically, each of the design approaches will have an inherent availability (A_I = MTBF/MTBF + MTTR) of over 99%. The specified operational availability (A_o = MTBF/MTBF +MDT) for this example is 95%. Technical proposals promoting these design approaches might sound like the following:

The low-cost approach presents an end item which is relatively inexpensive because some reliability has been traded-off for low-cost and exceptional maintainability characteristics. This is to be accomplished by using inexpensive parts and a modular pluck out design which will experience a higher number of failures than a more expensive and more reliable item, the lower cost of each repair will more than compensate for this and lower total maintenance costs will result.

The mid-cost approach represents a more conservative design. Trade-offs between reliability, maintainability, and cost do not rely as heavily on maintainability and cheapness as in the low-cost approach. At the same time, total dependence has not been shifted to the reliability aspects to carry the design approach. All in all, this approach is a well balanced effort that is safely within the state-of-the-art to attain.

The high-cost approach stresses ultra-high reliable performance. The higher cost is due to the fact that only the highest quality and most carefully tested parts will be used. In addition, ease of maintenance is traded-off in favor of increasing reliability. This item pushes the state-of-the-art to the limit in order to achieve the most dependable, failure free equipment possible. Although the cost of each repair will be higher than the other two approaches, the exceptional reliability of this item will more than compensate by lowering the total life cycle support costs. After all, in the limit an item that never fails will cost nothing to fix.

The arguments are impressive for each of the three design approaches. It must be remembered that we are not interested in assessing the technical risks at this point, but rather in analyzing each based upon logistics impact only. Although each approach seems reasonable, unless we can quantify them in some manner, we are forced to rely on little more than "Kentucky Windage" to base our management decisions. In order to accomplish this quantification, the three approaches were modeled using the GEMM Program. Results of this analysis are shown in Table 2. The ownership costs shown in this table represent the amount of money that must be expended under each design approach in order to achieve the required operational availability of 95%.

The table shows that in support costs alone, the low-cost approach is $22.5 million less than the mid-cost approach and $46 million less than the high-cost design. When acquisition costs, including research, development, and production, are added to the support costs, the low-cost system is $42.5 million less than the mid-cost system and $86 million less than the high-cost approach. All of these figures are based on the equipment operating under identical mission conditions over the same equipment life span. Therefore, the desirable approach from a logistics point of view is the low-cost design.

The LSA should go beyond the mere display of these comparison data. The next step should be to identify critical parameters of each design approach in terms of logistics and to assess the relative impact of their variations. An attempt should be made to assign quantitative risk factors to these critical parameters for trade-off purposes. In addition, design-to-support cost parameters should be determined for each approach in order to provide a basis for evaluating the contractor's subsequent efforts and to assist in the tracking and control of the various logistics elements throughout development. Wherever possible these design-to-support cost criteria should be specified as requirements in the follow-on development and production contracts in a similar manner to the design-to-unit cost requirement.

LSA DURING ENGINEERING DEVELOPMENT: Logistics support analyses performed during the engineering development phase will naturally vary from system to system; however, as a general approach the following steps could be used as a guide: (1) Represent the baseline system design using available predictive data such as hardware breakdown structure, reliability and maintainability estimates, and unit production cost criterion. (2) Examine alternative maintenance policies based upon meeting the specified operational availability requirement for the lowest possible support cost. This step is identified as optimum repair level analysis (ORLA) by the Air Force and level of repair (LOR) analysis by the Navy. (3) Determine the most critical and sensitive parameters. Attempt to refine sensitive data and surface key design features which requires extra attention. (4) Investigate areas of high uncertainty in order to determine impact of variations within reasonably established intervals. (5) Analyze maintenance and logistics significant trade-off areas, such as use of standard versus special test equipment, throw-away versus repair, extent of modularization and packaging variations, and alternative maintenance float policies.

In order to get the most mileage out of the performance of LSA during engineering development, results of the initial analyses must be provided to the decision makers for consideration during design reviews; and to significantly affect the baseline design, a substantial portion of the LSA must be accomplished prior to the baseline design freeze. The LSA effort should not end at that point, but rather should be a continuous effort throughout engineering development. The analyses should be refined as more and better data become available. Engineering changes developed subsequent to the baseline design freeze should be evaluated and assessed in terms of impact on maintenance and logistics support.

CASE II - ENGINEERING DEVELOPMENT: We are now at the stage in development where the design approach has been chosen by the Government and the engineering development contract is awarded. In six months a design review will be held and the system baseline design will be frozen. The initial predictive design data, as it becomes available during this period, is to be analyzed from a logistics viewpoint in order to determine the optimum maintenance policy and in addition provide rationale for decisions to be made during the development of the baseline design. This example will focus on the former problem, that is to determine the best maintenance approach.

The first step is to represent the baseline design using the available predictive data. Figure 1 shows the equipment breakdown structure along with predictive reliability, maintainability, and cost information. The types of maintenance personnel and test equipment required for the support of the end item, components, and modules are then identified, in addition to other maintenance data. The operational availability constraint is 95% and this must be achieved within a defined Army logistics structure. The deployment consists of 1,000 end items distributed around the world with an average of 10 equipments at each organizational unit. The system will operate 12 hours per day every day throughout the year and the intended life expectancy is 12 years.

The object of the LSA is to determine the optimum method of utilizing the Army 4-level maintenance structure either in total or in part. These four levels of maintenance are identified as follows: Level 1: Organization (ORG) Unit, which could also be referred to as the site of the operating system. Level 2: Direct Support (DS) Unit, which is a higher level of maintenance responsible for supporting a given number of organizational units. In this example one DS shop must support four organizational units. Level 3: General Support (GS) Unit, which is the highest level of field maintenance and normally encompasses an entire theater or large portion thereof. This example uses two GS shops. One for the Pacific and one for Europe. Level 4: Depot, which is comparable to the repair capability of the hardware manufacturer. The example utilizes one depot located within the continental United States.

The technique employed to analyze this situation is to model the system, using the GEMM Program, and display the results of alternative feasible maintenance policies. Each policy is then further refined in terms of the proper amount of stockage required in order to achieve an operational availability of 95%.

Table 3 shows the best ten maintenance policies in order of the most cost effective. The measure of effectiveness is the support cost required over the life of the system to maintain an operational availability of 95%.

A great deal of information can be obtained by examining the results shown in Table 3. Policy number one reflects the optimum maintenance policy. It consists of evacuating the failed system or end item, to the DS unit where the faulty component is replaced. The component is then shipped to the GS unit where the faulty module is isolated, removed, repaired, and installed back into the component. This maintenance policy requires stockage of end items at the organizational level, components at the DS level, and piece parts at the GS level. Stockage of modules is not required since modules are both replaced and repaired at the same level (i.e., GS Unit).

In Table 3 location of stockage for each maintenance policy is indicated by a small circle around the letters E, C, M, and P, representing end item, components, modules, and parts, respectively. From the Table it can be seen that the repair of modules should be done at GS rather than Depot. In the first six policies module repair is performed at GS, and the seventh policy represents the most cost effective of the policies where modules are repaired at depot. Thus, from a support cost standpoint, the choice is quite clear. Modules should be repaired at GS.

Of critical importance to meeting the required operational availability is the proper choice of the lowest site replaceable unit, more commonly referred to as maintenance float or operational readiness float. In policy number one, the lowest site replaceable unit is the end item itself; therefore, end item maintenance float must be stocked. In policy number two, components are floated. Thus, when the system fails, under policy two the faulty component is replaced on site using a spare component from float stock. The faulty component is then evacuated to the GS level for repair.

In policy number three, end items are floated, as in policy one. However, the failed end item is evacuated all the way to the GS shop, level 3, for repair rather than the DS shop as in policy one. As can be seen by Table 3, policy three will cost $4.2 million more than policy one. This is due to the fact that even though end items are floated in both policies one and three, it takes a greater quantity of end item stock with policy three to achieve 95% operational availability. The reason for the increased end item stockage with policy three is the greater maintenance turn-around time required to send the failed end item to GS for repair and return it to stock on site. In policy one we are able to draw upon component stockage at DS to get our end item float back into site stockage more rapidly.

Under policy four, modules are the lowest site replaceable units. When the end item fails, the faulty module is replaced with a float module right at the ortanizational site and the faulty module is shipped to the GS Unit for repair and return to site stockage. It might intuitively be felt that because modules are cheaper than the end item or components, it should be the best policy to float modules on site. But as can be seen in Table 3, it costs $17.6 million more to stock modules on site than to stock end items.

A useful technique for identifying critical parameters is to examine the distribution of costs over the various support elements. Table 4 illustrates the support cost breakout for the optimum maintenance policy. More than sixty percent of the support cost dollars are for stockage. This includes both initial provisioning and re-order stockage throughout the system life. This is certainly cause for a closer look at stockage parameters, which involves the identification and examination of all variables which enter into the computation of stockages. The most critical ones should be determined and an attempt be made to ascertain their validity. If possible, alternate methods should be sought to reduce costs resulting from these parameters. If re-order stockage is excessively high because of the attrition rate of certain items, the nature of these losses should be investigated. Are they caused by equipment design or is the supply system at fault? And what can be done to improve the situation? The high cost of initial provisioning stockage could possibly be reduced by pooling site stockage from a number of organizational units and creating a common float stockage point such as at the DS Unit. This approach must then be weighed against the impact it will have on the system operational availability.

The next most expensive support item is overhaul cost. This element would likewise be cause for in-depth examination since millions of dollars could possibly be saved here. In addition to identifying areas which require additional in-depth examination, the display of support costs shown in Table 4 also point out areas which result in only a small fraction of the support costs. For example, it would be unwise to spend a great deal of money during engineering development in order to perform extensive transportation studies. The pay off of such an effort could only have a minimal impact on the overall support costs.

CONCLUSIONS: Much effort at ECOM is being focused on the performance of LSA since this process enables the consideration of logistics support as a principal design parameter. It is used for evaluating alternative design approaches and proposed engineering changes in terms of logistics in addition to optimizing support posture for a fixed design. LSA's are presently being performed in over two dozen programs at ECOM during advanced development, engineering development, and post deployment.

One valuable tool for the performance of LSA is computerized support modeling. It is of prime importance to stress the fact that modeling is just that, a tool. The heart of any LSA is the engineering effort, not the computer model. The man must accomplish the identification and analysis of the specific problems at hand, as well as translation of those problems into quantifiable factors which can be evaluated. At this point the computerized model can be applied to handle the tremendous volume of computations which are required in the course of the LSA. Finally, the engineering analysis of all this computer generated output data must be accomplished. This requires the man to analyze, interpret, and translate these results into objective options for management consideration.

The surface is just being scratched on techniques for performing LSA. Further work is being pursued to apply additional tools and techniques to assist in these analyses. Particular emphasis is being placed on the application of additional LSA techniques in the following areas: (1) Measurement of logistics effectiveness and translation of logistics support parameters into "design to" requirements. (2) Optimization of maintenance support policies. (3) Estimation and analysis of uncertainties due to limited availability of relevant data.

The aim of these efforts is to make the most useful and up to date technques for the performance of LSA readily available. The accomplishment of these LSA's will be directed toward the long overdue consideration of logistics early in the acquisition process by providing to decision makers the maximum number of quantifiable design and support options.