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TENTH ANNUAL

UNITED STATES ARMY

OPERATIONS RESEARCH SYMPOSIUM

THE NEXT DECADE

26-28 MAY 1971

PROCEEDINGS

Host

U. S. ARMY RESEARCH OFFICE-DURHAM

Sponsor

OFFICE of the CHIEF of RESEARCH & DEVELOPMENT

DEPARTMENT OF THE ARMY

PROCEEDINGS

of the

United States Army

OPERATIONS RESEARCH SYMPOSIUM

26-28 May 1971

Sponsored by

Office of the Chief of Research and Development

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Planned and managed by

U.S. Army Research Office-Durham

Durham, North Carolina

Institute of Systems Analysis

Combat Developments Command

U. S. ARMY OPERATIONS RESEARCH SYMPOSIUM

26-28 May 1971

FOREWORD

The Tenth Annual U. S. Army Operations Research Symposium was held on 26-28 May 1971. These symposia, normally held in the spring of each year, are sponsored by the Office of the Chief of Research and Development, and conducted by the U. S. Army Research Office-Durham.

This volume contains invited and contributed papers and major addresses. Some of the presentations at the symposium are not included here either because the paper was not formalized or the speaker chose not to have his remarks published.

The technical program for the symposium was planned and organized by Dr. Marion Bryson of the Institute for Systems Analysis, Combat Development Command, assisted by Dr. George Nicholson of the University of North Carolina. This Office is indebted to Dr. Bryson and Dr. Nicholson for their outstanding efforts on our behalf. We also appreciate the valuable assistance of those who organized and participated in the various sessions and panels of the symposium.

W. J. LYNCH
Colonel, GS
Commanding
U. S. Army Research Office-Durham

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Welcome

Colonel William J. Lynch

CO, U.S. Army Research Office-Durham

Welcome to the Army Research Office-Durham, and the Tenth U. S. Army Operations Research Symposium.

This is the largest attendance we have ever tried to accomodate and I hope we have not overreached ourselves. If you have a problem, a complaint, or suggestion, please let me know.

For the benefit of those present who are not acquainted with our mission and the reason for our location in the university environment, very briefly, our mission is four part:

(1) To conduct that part of the Army's basic research program in mathematics and the physical, engineering and environmental sciences which is accomplished through contracts and grants primarily with universities, and with some nonprofit, government and industrial laboratories. (At present we have just over 450 of these, generally funded at 20 to 30 thousand dollars a year.) Our annual budget for this purpose is about 14 1/2 million.

(2) Secondly, we provide a liaison function between the Army scientific community and the scientific community at large, principally through locating and arranging for the services of uniquely-qualified scientists to provide advice and assistance on R&D activities. This includes the ARO-D Army Laboratory Research Cooperative Program with which some of you are acquainted, where we secure for your laboratories highly qualified university scientists, generally for the three months' summer vacation period, to work on research tasks, and perhaps of greater importance, accomplish an interchange of knowledge, understanding, and insight with laboratory personnel. For these programs some 2 to 3 million dollars of customers' money usually flows through our hands annually.

(3) Our third responsibility is to provide a convenience contracting service to other governmental agencies as well as Army laboratories, and

(4) The fourth is to act as a catalyst or stimulant in the transfer of scientific information through conferences, symposia, military theme reviews, and ad hoc groups. To do this I have 71 people, plus three military besides me.

This symposium falls under the last broad function, and we are indeed happy to have you here, whether transferring, absorbing, stimulating, or just plain catalyzing.

One further remark. I know that many of you have heard various versions of the fact that Duke University has cancelled its contract with us, and that we will be moving. In fact, we have 29 contracts and three grants with Duke. Twenty-seven of these contracts are covered under a basic agreement, which Duke is cancelling as of 30 June. In order to assist in effecting an orderly transfer of these subordinate contracts, most of which are on behalf of various commands and laboratories for scientific services, they have been extended through this December, but without the cover of the basic agreement, meaning no new funds nor work.

A new contract has been proposed by Duke to extend through September, 1972, to provide for operation of their Coordination Office and certain other functions necessary to continuity of our operation during a changeover to a new contractor.

We do plan on moving from the campus, and have applied through channels to have GSA locate suitable accommodations for us in this area - hopefully at the Research Triangle Park, where we will be about equidistant from the three universities in this area. I wish to add that our relationships with Duke are amicable, and student dissidents have not forced Duke's decision.

We hope shortly to come to some decisions necessary prior to selection of a new contractor to take over from Duke. We will try to provide services as usual, with a minimum of glitches in the Scientific Services part of our work which has proven so valuable to the various Army commands and laboratories. We will do all that is possible to continue to provide the assistance our customers require.

I trust you will find this symposium well worth your while, and I thank you for coming. Now your General Chairman, the Director of Army Research, OCRD, Brigadier General George M. Snead, Jr.

Opening Remarks
Brigadier General George M. Snead, Jr.
Director of Army Research

I'm privileged to once again serve as your general chairman. I'm never sure whether its a nominative, selective or volunteer sort of a function, but I do enjoy it. I think I should give recognition now to the role that Colonel Lynch and his staff have played in arranging for the accomodations and the facilities for this large assemblage here. I am particularly aware of the smallness of the staff with which Colonel Lynch gets this done and I would again like to thank you Bill for all you and your staff has done to get us aboard and to make the arrangements as smooth as they are.

As for myself, I plan to sort of relax and enjoy your company.

I do feel I have a couple of responsibilities. One is to make the coffee breaks come out on time, and if you cooperate with me as well as you did last year, I anticipate that we will have no problem there. And finally, to participate with Dr. Nicholson in the critique at the end of the symposium, which, I've received confirmation, has been extremely valuable.

I really have no great message for you. I think many of you, like me, have operated in sort of a dual mode in which sometimes you're in the research or the operations research side of the business, and as such you become aware of what is called the "communications gap" across these two. If you're sensitive to this, I would suggest that this is not the place to be sensitive. Relax and enjoy the symposium.

As general chairman, it is now my distinct pleasure to introduce the sponsor of this Tenth Annual Operations Research Symposium and the Chief of Research Development, Lieutenant General William C. Gribble, Jr.

Introduction of Keynote Speaker
Lieutenant General William C. Gribble, Jr.
Chief of Research and Development

I'd like to add my welcome to the welcome words of Colonel Lynch and General Snead and announce that it is my distinct pleasure to have been invited to introduce to you this morning your keynote speaker who is a very distinguished gentlemen and a personal friend, General Jack Norton.

I don't intend to go into any great detail about General Norton's very distinguished and lengthy military service record, nor do I intend to reveal to you ahead of time the subject on which he proposes to deliver his message this morning. Rather, I see my role as introducing him as very analogous to that of a fan with a fan dancer, and that is to call attention to the subject without actually revealing it.

General Norton does bring to the platform a reputation as an interesting, fine speaker who is very forthright in the expression of his views. He also brings to the platform a distinguished record as both a manager and a leader who has occupied very senior positions within the Army. Therefore, I think that he is uniquely qualified to set the pace for the symposium, which is to take a critical look into the future.

These are challenging times and taking critical looks is fashionable outside the service and is essential inside the service, particularly to those of us who, within the military service or associated with the military establishment, have the responsibility for analysis or management in the allocation of ever-scarce resources. This symposium as a form for the exchange of your views will be an invaluable tool for those managers in key positions.

I'd like to, at this point, insert a word of commendation to Dr. Marion Bryson, who has been the chairman again this year, for the development of the very interesting agenda and program which you have before you. Dr. Bryson, as the technical director of the Systems Analysis Group of the Combat Developments Command, has, for several years, held this very important and key position with respect to the symposium. And thanks to him and his dedicated committee members, the symposium is continuing its unbroken record of ten year history of annual symposia.

After last years successful meetings on the subject of the application of simulation to decision-making, the program committee determined that it would be appropriate this year to pick a topic of looking into the future. You will see in the logic in the development of this years agenda and program, the underlying principle of introducing topics and stimulating discussions that could lead to the development of long range objectives for Army Operations Research.

Against this setting, then, the choice of General Norton as the keynote speaker was most deliberate. For many years he's carried the identity as one of the Army's most progressive leaders, and these many years go way back.

Within my recollection, as a cadet at West Point, General Norton was selected to be the First Captain of his class; it happened also to be General Chapman's and my class.

In the early days of World War II, General Norton became a pioneer in the application of a doctrine of airborne tactics in the concept of warfare. He later in his service served on the Howze Board and had the opportunity to demonstrate the success of air mobility concepts as a Commanding General of the First Calvary Division in Viet Nam in 1966 and 1967. He is one of the very few senior people in the Army who has the distintion of having served in very senior positions in all three of the Army's major subordinate commands. He's been the Assistant Commandant of the Infantry School at Fort Benning, the Commanding General of the Aviation Systems Command of AMC, and in his present capacity as Commanding General of the Combat Developments Command is responsibile for developing the future concepts and doctrine for the United States Army.

I deem it a distinct privilege and pleasure to introduce to you now, General John Norton, Commanding General, Combat Developments Command.

New Initiatives in ORSA*
Lieutenant General John Norton
CG, Combat Developments Command

General Gribble, thank you for a very gracious introduction -- and I want to thank all the people that arranged this symposium on Operations Research. Never in our time have your skills been more important to our country. In the Defense Department, and particularly in the Army, we must do everything we can to maximize the advantages of these skills. This is the reason I was delighted to be asked down here to speak to you.

I spoke to last year's Symposium, representing Project MASSTER, and in the months after that meeting my manpower authorization at MASSTER increased significantly. So you see that I would be a fool not to come back this year and represent Combat Developments Command!

Seriously, I do want you to understand what we are trying to do at CDC, and I know that many of you in this room are quite familiar with certain parts of our operations. My predecessor, General George Forsythe, who is now leading the Modern Volunteer Army Program, put a lot of energy and vigor into this motto --

Figure 1

--- which is "Vision to Victory." General Harry Kinnard came up with

*/ Keynote speech, United States Army Operations Research Symposium, Durham, N.C., 26 May 1971.

these words when he was at Combat Developments Command. The combination is a good one: Vision to Victory -- plus Vigor.

We have to have a lot of vigor, and we certainly have to have a lot of scientific approach. We need better ways of knowing not only that we are getting the right answers, but also that we are working on the right questions.

When the Civil War ended, we had the same kind of problems that we have now. We had cutbacks in the budget; we had reductions in the ranks. We had at least one Lt Colonel that was hard hit by the reductions. When the smoke cleared, he was a Lieutenant. He was sent to Tombstone, Arizona, to head up a small camp. In addition to his other duties there, he was made Postmaster. The Lieutenant got quite a shock when he found that three or four civilians there ahead of him, trying to run this little post office, had all been fired. None of them had been able to carry out the Army's instructions. It seems that all the mail coming through there had to be weighed very precisely, and the rules were pretty clear. The Lieutenant had to weigh packages in one-pound increments up to 40 pounds, and under this Cost Reduction Program, each post could have only four weights. One could use balance scales, but he couldn't use packages to weigh packages -- that would be holding up the mail. So he had to find out what four weights he needed to weigh these packages from 1 to 40 pounds. Pretty tough requirement, when you are 100 years away from a computer.

The Lieutenant, however, had taken a course in Systems Analysis in the OCS program. He solved this problem, got the right four weights, and Washington promoted him. Now I know that you are also qualified in this area, so you ought to be able to solve this problem, too. You are going to be under some strain, because when I'm through -- we will put out sheets of paper -- everybody will be required to put his solution down and we will turn these over to your bosses. Here is a slide that shows the Lieutenant's problem.

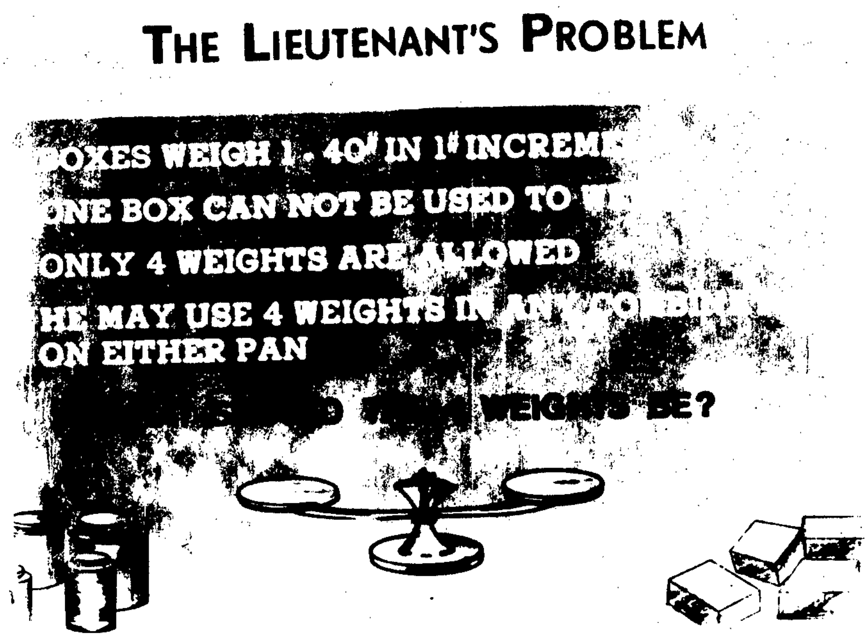


Figure 2

There is a more important point to be brought out here, as you look at this chart. I'm going to divide you into three kinds of people. The first group is not going to try to solve this problem; the members of that group are trying to look polite and attentive. There is another group that couldn't solve the problem if they stayed here all day; they are concentrating on appearing to be rapidly calculating the answer. The third group contains the man we are looking for. He knows that he is going into multi-processing; he can tell his human computer to track on that problem with his eyes; he can tell his ears to track on my speech -- and he will solve the problem without missing a word. That is the man we want in ORSA.

It is ten years now since the Whiz Kids came into Washington and achieved a reputation for great efficiency in using the tools of ORSA. I've gone back and looked at some of the things that were done -- and that were not done. I think it is worth a few minutes this morning to look at how we are really tracking on the techniques for applying ORSA. I am suggesting that the gap between our military requirements and our military solutions is opening faster than we are able to solve our problems. We must find new ways to expand our capabilities and increase our efficiency.

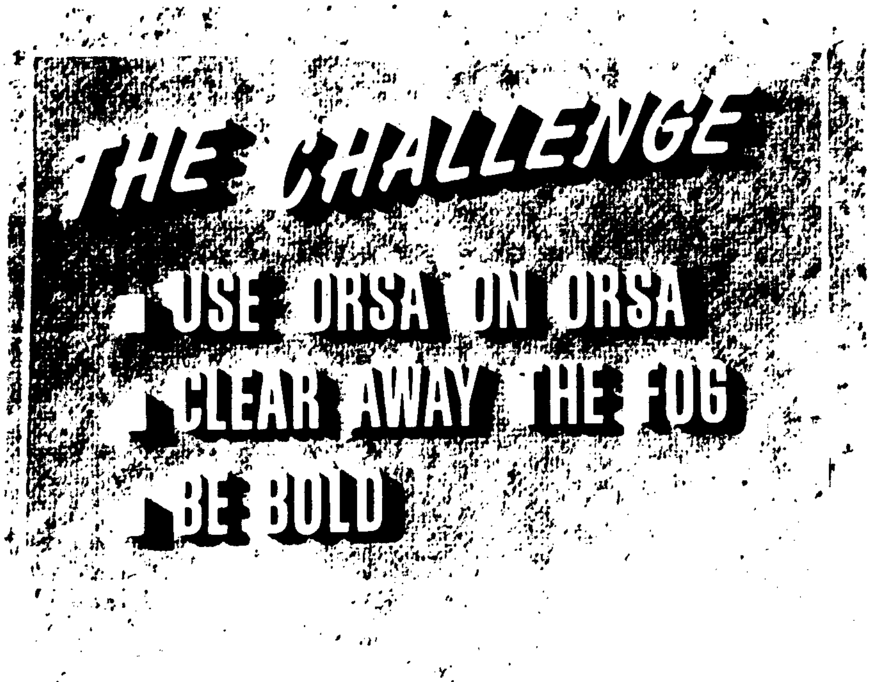


Figure 3

In the search for new initiatives, there are three challenges that I will give you. If you can respond to these three, you will attract many "True Believers" out of the management leadership who now don't believe that an ORSA solution is the best solution for most of our key problems. Let me develop these three challenges one at a time.

USE ORSA ON

O R S A

Figure 4

First I want to tell you what I mean about using ORSA on ORSA. I mean that you ought to be able to put your skills to work in helping managers to decide how much value ORSA can contribute to a given problem and also where to apply the ORSA talent that we have.

The decision-maker in Washington, or in the Army, always faces these two problems. He asks himself: "How much better -- or worse -- will my conclusions be if I invest in an ORSA-type study than if I use other sources of information?" Also, he knows only too well that there are a limited number of people available -- civilian or military -- who have the talents and the training required to conduct good ORSA studies. In Combat Developments Command, we are pushing ahead with certain ground rules -- I have asked the question, "What are the things that lend themselves most, and what are the things that lend themselves least, to the ORSA-type solution?" This is the first step towards finding a more methodical way within the Command of using our resources. We are constrained by the number of people we can assign to studies, and by the amount of money we can spend to buy studies from civilian contractors. These are two of our biggest headaches. More initiatives are needed by this, and similar groups, to tell us how we are going to use ORSA to solve these problems.

So place yourself in the shoes of the decision-maker. You are confronted with several ways of studying a problem. How do you know which is the best way? Let's take an example. Let's take STANO -- the Surveillance, Target Acquisition, and Night Observation program -- abounding with new technology and new possibilities. We need this desperately on any battlefield. STANO has a potential to impact on all echelons of command from squad on up. It involves airborne systems, unattended ground sensors, attended ground sensors, and everything that ties them together. For the purpose of this study, is it best to stratify the problems of equipment mix, organization, doctrine, and phase-in by functional areas? by echelon of command? equipment detection ranges? or what? This next example will show two ways of slicing up the STANO pie.

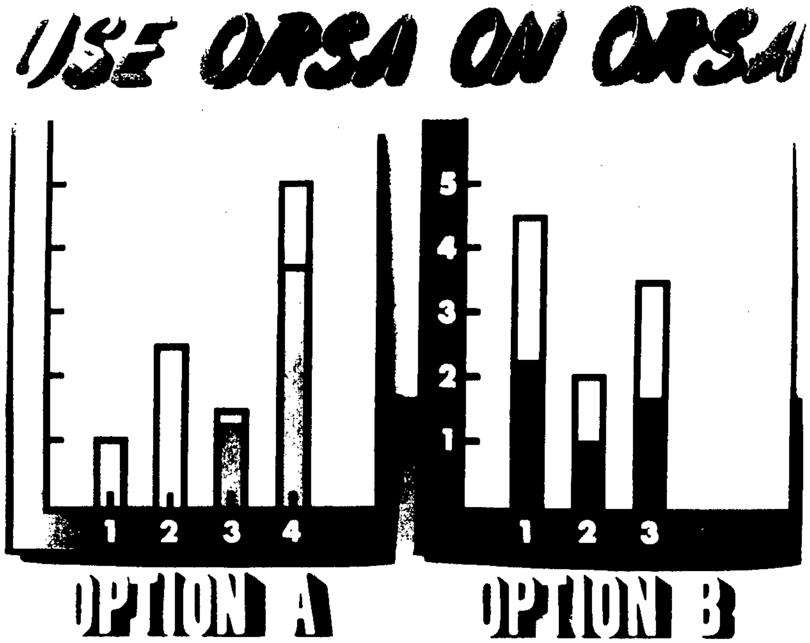


Figure 5

Let option A represent an organizational breakout and option B a structuring by target acquisition means (airborne, unattended ground sensors, or attended ground sensors). Each method may have its own measures of effectiveness. Let the shaded areas represent the parts of the entire study that can be attacked through systems analysis and the unshaded part represent the nonquantifiable parts of the problem. The length of these bars may represent professional man-months of effort or dollar value of the systems under study, or relative importance of each part. Now would the same choice be best in each case? Can we be sure there is a "best" way of structuring the problem? How much better is one option than the other? What will be the impact on the validity of the completed study if the shaded parts are reduced by half? And perhaps the most fundamental question of all: how much better, or worse, are either of the two options than when ORSA is not used at all?

If we must rely on the conclusions that are provided by the non-ORSA supported studies, how much less reliable would our decisions be than if the ORSA studies had been conducted? Are you still with me? I hope so -- I started to state the problem in terms that would be more familiar to this group, but frankly, I couldn't sort out my X sub k-j's from my Y sub 1-m's. The point I want to make is -- if you tell me how cost-effective a conceptual weapons system is going to be, then you ought to be able to tell me how cost-effective your study methodology is. You should be able to show trade-offs between using ORSA and not using ORSA.

The other side of the coin is the question concerning "where?" Given a limited number of ORSA resources, where should we employ them? How do we make best use of the available expertise? We're not waiting to get the answer to that question -- we're marching on. We are already heavily committed on a lot of fronts: force design, new tactics, command and control, intelligence and many others. Even so, we don't think that we have our problems so well solved that the ORSA talent is necessarily in the right places. We are deeply concerned with the questions of where and how should the talent be distributed.

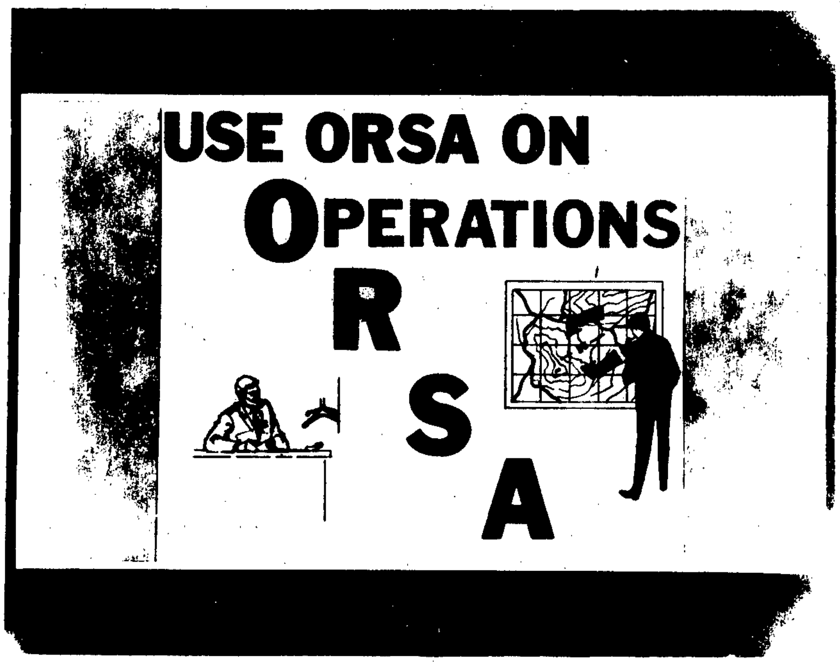


Figure 6

One alternative is to apply ORSA talents to tactical operations. This was started back in the early days of World War II, and it produced a lot of good. Systems analysis solutions, in some cases, saved battles the next day or saved lives the next week. We have begun some tests in this area, and we have plans to start placing ORSA-trained captains and majors in the G3 or S3 sections of some of our combat divisions to see how well they can assist unit commanders and staff planners.

In addition to the use of these officers in planning or evaluating tactical operations, there are perhaps other places where ORSA could be used in a tactical situation: For example, logistical planning, airspace coordination, targeting of our reconnaissance missions (STANO missions) or analyzing the use of artillery. Most people who have been through one or more wars know that tactical decision-making has moved ahead so fast that we desperately need ORSA-type talent up front to fight day-by-day. What happened the first day of LAM SON 71-9 could have been analyzed and plugged into the 7th day. Well qualified personnel trained in ORSA techniques will be useful in enemy pattern recognition. We may be able to put into the computer the aging effect of what happens on any part of the battlefield -- so if the "Old Man" says: "What's happened here for the last two weeks?" -- and all the grease pencils have rubbed off -- we ought to be able, with good ORSA techniques, to reconstruct what has happened. The institutional memory on the battlefield rapidly disappears when you change overlays or when you change commanders. There is much to be done here, in other ways, to the areas of battlefield control, reconnaissance, and surveillance. Do we have Army ORSA talent committed in the field of these areas, commensurate with the amount of emphasis that we're putting on it in other developments? I, for one, say definitely not.

If, after applying ORSA techniques to the problem of where to put ORSA people, you determine that a larger percentage should be devoting their talents to improving our tactical operations -- then the problem becomes "how best to employ them?" Should they all be down at Fort Hood, at MASSTER? Should they be in our schools to give a knowledge of ORSA techniques to more students as they go through the various officer and NCO courses? Should more ORSA personnel be set to work developing techniques and formulas to be used in basic references -- to be available for planners at all levels within a tactical theater? Or should ORSA-trained officers be used as advisors to commanders and staff officers through the Field Army area? I think we can use more ORSA skills in tactical operations, and we need your help in pointing out the best areas, where you will be most efficient.

It would be fine if the battlefield were the only place where ORSA help is needed right now. There are other places, however, that are equally deserving. One is the administrative field throughout the whole Army.

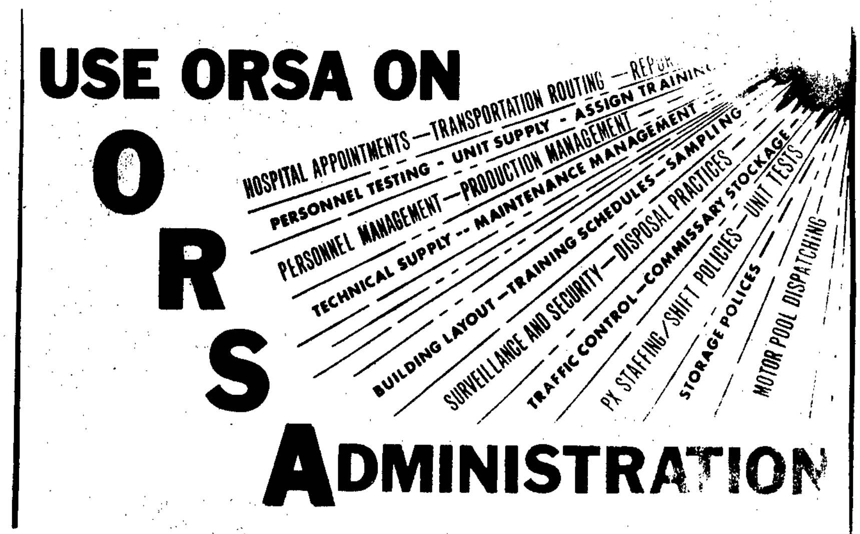


Figure 7

We define administration as the daily management and execution of our business. There are many areas where perhaps deficiencies can be realized through the use of operations research techniques. You are no doubt better qualified than I am to say where the administration of our daily business can be improved through more extensive use of ORSA techniques at the grass roots level.

The last phase I will discuss is the one you know the best. At the present time, this is the area that's using a preponderance of our military and civilian ORSA talent: the areas of research and studies conducted in the CONUS.

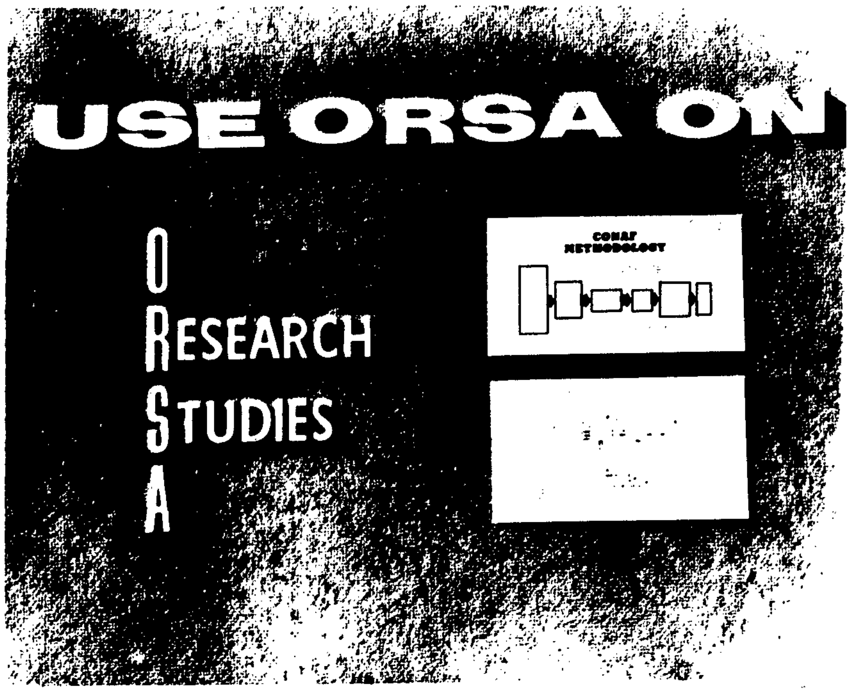


Figure 8

These research study efforts are being done for all the major commands in the CONUS and by Department of Army. Most of you who are involved in this area are working on the Army's major problems and concepts. You are trying to answer the major questions that are being asked by our civilian and military leaders. Is this the best place for you, and if so, what is the best way to use you there? I have a feeling that, given our constrained resources of ORSA capital, we are perhaps investing too big a proportion of it in this area. Maybe it's the glitter. Maybe it's the elevation of the activities. We need to investigate ourselves here. Maybe we have become too accustomed to our comfortable world of studies, while the worlds of tactical operations and administration are really crying for help.

You note that I said "maybe." That's what I'm asking you to look at -- the ORSA balance of commitment.

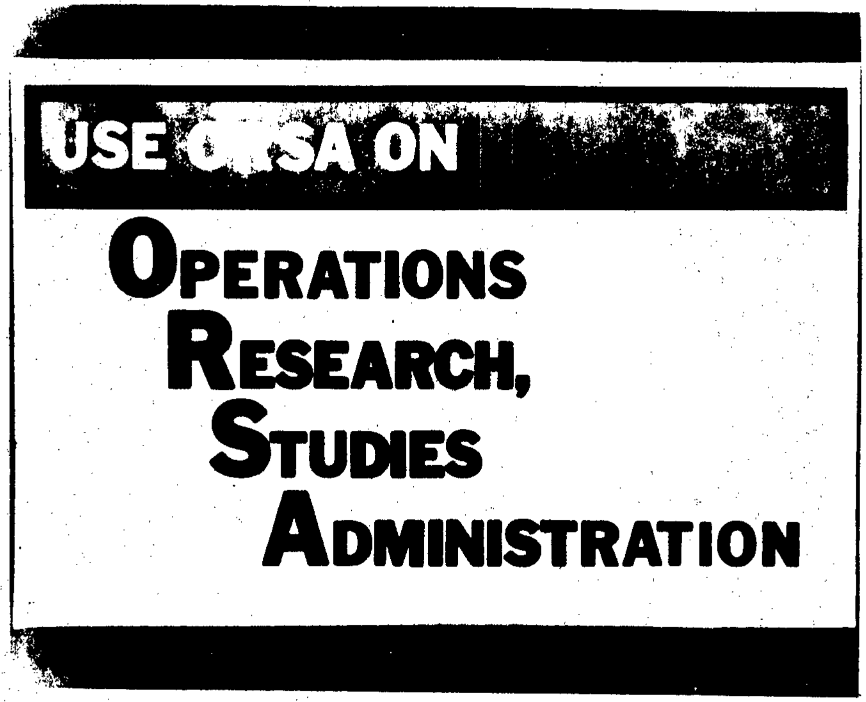


Figure 9

I challenge you to tell us where our ORSA talents should be employed. What percent should be used in tactical units in trying to improve our fighting operations? What portion should be used in the CONUS on research and studies? And, finally, how much should be used in improving the efficiency of our small business -- running motor pools and supply rooms -- through widespread use of ORSA at the unit and installation level?

The use of ORSA to rebalance our ORSA commitments constitutes, in my opinion, one of the areas where we definitely need new initiatives. I'm not saying that all the drive for a rebalance has to come from the ORSA community. But you have achieved a stature now, and a collective wealth of experience, making it even more imperative for you to get into this question and to start providing some answers, and to make yourself heard.

Now I want to move to another challenge -- another field where we can use some new initiatives. Now this is the one I mentioned earlier -- "clearing away the fog."

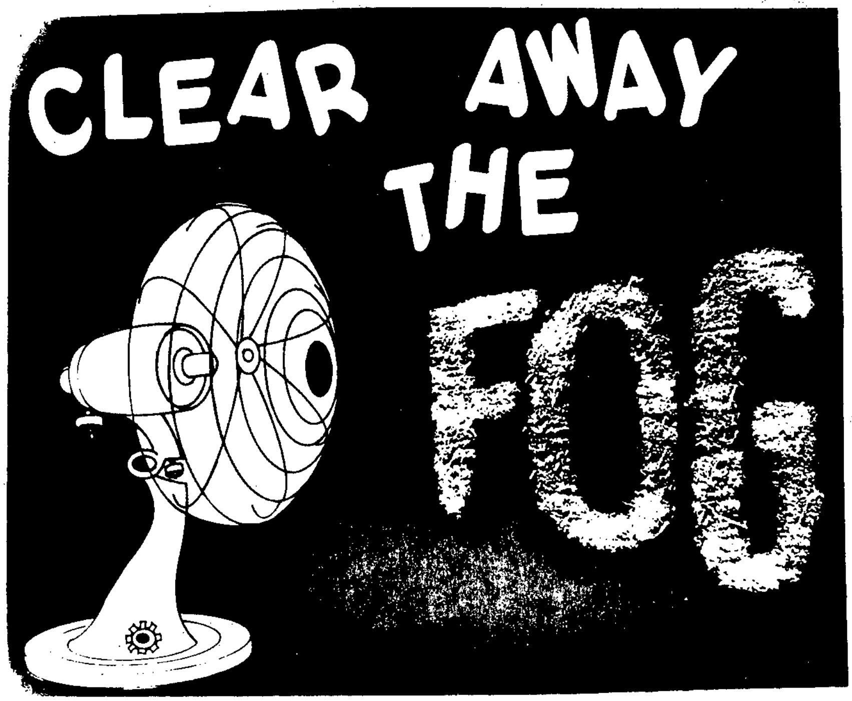


Figure 10

All too often, I believe that we are too obscure, too mysterious in our presentations of ORSA results. This isn't to say that some of the managers and leaders who have been "passed up" by the technology shouldn't get busy and study up on it! But if there is too much mystery surrounding ORSA comments, it is hard to see the problem, much less the solution. Many recommendations are couched in ORSANESE. Here is an authentic example of ORSANESE.

HIS IS F

$$P(\text{at } X \mid O_2) = \frac{P(\text{at } X)\,P(O_2 \mid \text{at } X)}{P(\text{at } X)\,P(O_2 \mid \text{at } X) + P(\text{at } X)\,P(O_2 \mid \text{at } X)}$$

$$= \frac{(0.4)(0.1)}{.52} = \frac{.04}{.52} = \frac{1}{13}$$

$$P(\text{at } X \mid O_3) = \frac{(0.6)(0.0)}{.20} = 0$$

THESE CONDITIONAL PROBABILITIES ARE THE POSTERIOR PROBABILITIES THAT THE MUNITIONS ARE OR ARE NOT AT X GIVEN A PARTICULAR OUTCOME OF THE EXPERIMENT.

Figure 11

This is a fairly new language -- about ten years old -- and you're all familiar with it. Here is another example.

MORE FOG

SCOPE OF STUDY: **"THE GEOMETRIC STRUCTURES OF EQUIVALENCE CLASSES OF PROBABILITY MEASURES ARE INVESTIGATED. THE RESULTS WILL BE USED TO FIND BOUNDS ON SYSTEM PERFORMANCE AND TO FIND SUBOPTIMUM STRUCTURES WHICH ARE EASILY INSTRUMENTED.**

PROBABILITY MEASURES OF HILBERT SPACE AND APPROXIMATIONS OF THEIR LIKELIHOOD RATIOS ARE INVESTIGATED. WIENER MEASURES ARE USED TO INVESTIGATE LIKELIHOOD RATIOS FOR CERTAIN CLASSES OF STOCHASTIC PROCESSES."*

***FROM AN UNSOLICITED PROPOSAL**

Figure 12

You'll have to admit that sometimes even you don't know what comments like this mean in English. Here is a graph that shows where I think we are going in the ORSA field if we keep up this practice of ORSANESE.

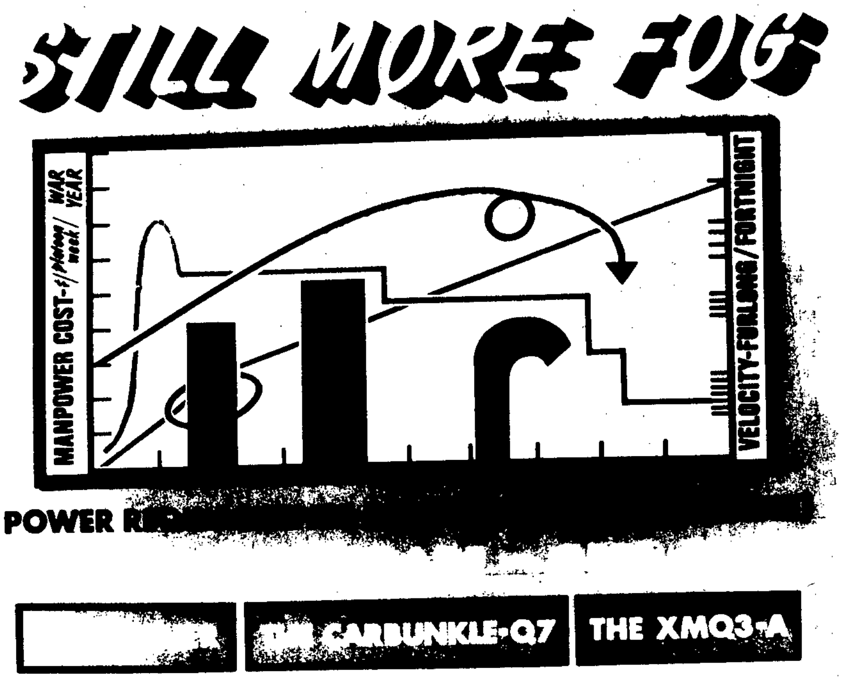


Figure 13

This is the "fog" I'm talking about. This last example may be somewhat farfetched, but the point is, we've got to find ways to make ORSA clear enough so that a decision-maker knows what you mean by the quantities you assign to the alternatives. It's your job to communicate as well as to analyze. In addition to developing ways of explaining what you have done, you must also come up with more convincing ways of validating your mathematical models so that studies that lean so heavily on them are more believable. Until we do this, we run the risk of having the good work ignored. In other words, brush away the fog of uncertainty about the credibility of our methods.

If these challenges to "use ORSA on ORSA" and to "clear away the fog" are not enough, I have another one for you.

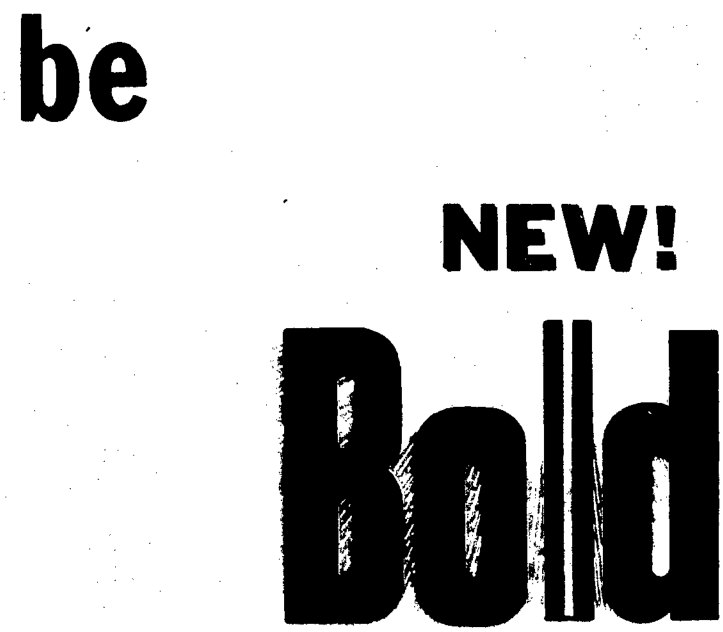


Figure 14

This is the time to be bolder -- and to be smart about being bolder. In fact, the last bold thing we did may have been getting started on the ORSA trail in the Army ten years ago. What is there in ORSA that can be called "new?" We are relying heavily on techniques that were developed in the ORSA explosion during the 40's and 50's. We are relying on classical mathematics. What are the breakthroughs? Do we really have any classical major improvements? I'm inviting this group to move out and come up with new and different ways of attacking our basic problems, and I'll show you where to look.

Figure 15

We are able to assign fairly satisfactory measures of effectiveness, as you know, to firepower, mobility and logistics. As I've said to the President of the Army Scientific Advisory Panel -- these measures, these indices aren't enough. All they do is drive us into adding more and more to that side of the equation that we can measure the best -- firepower and mobility. The firepower indices; movement rates; tonnages -- these are pretty much the same down through the years. In most cases they are hardware-dependent and "hard data" may be obtained to support their use. But now with the technology really exploding -- with the communications electronics technology, for example, exploding on the battlefield -- we don't have the measures of effectiveness in hand for intelligence, command and control. They are harder to find. We talk about timeliness and accuracy -- these measures of effectiveness look fine at first glance, but they really don't tell us much about effectiveness. How much more effective will a fighting unit be if good intelligence is presented to a commander in thirty seconds; compared to thirty minutes, or even thirty hours? We desperately need better measures of effectiveness for intelligence and command and control -- and there'll have to be measures that can be supported with believable data!

There are other people that are setting themselves up to taking a harder crack at this. If we don't move quickly on this, we're going to be hampered in making wise investments in the new electronics. The shortcomings of many of our ORSA studies is that we've been unable to evaluate these aspects that I've mentioned -- and also morale, and fatigue, and leadership, and training -- and weather, and terrain -- and even fear. The impact of these factors on the outcome of an engagement is at present very unpredictable. We have been content to call them "unquantifiable." But in telling you to be bold, I'd have to say that in one way or another, we must deal with the unquantifiables because they often dominate the outcome of land combat actions.

Trade-off analyses between noncompetitive systems are still a major problem within the Army. Is it better to spend our money on an extra artillery battalion -- or on a different type of reconnaissance unit? When you're able to come up with more convincing ways of comparing these "apples and oranges," and when we can prove that our methods have merit, this group will have performed one of the most significant contributions to ORSA since the Lanchester equations. As I recall, Lanchester is of the same vintage as the Spad and the Sopwith Camel.

And what about data? It seems like all too often we get the impression that the studies demand more detailed data than the quality of the algorithms warrant. I laud your efforts to use only unbiased data -- but I suggest that experienced judgment -- yours -- and expert opinion -- yours -- may be less biased in many cases than the data produced by some of the tests and experiments. I think all of us really want to be sure we're working on the right problems. We don't want the thing rigged. We don't want to set up a wargame that's going to be debugged from the start so that it works the way we think it should. We don't want to say, "Well, that's about the right exchange ratio I'm looking for -- run about fifty iterations." Using experience and the judgment, however, is usually the only way to get to the root of a problem. I'm, therefore, encouraging you to step up and make yourself heard. You don't have to be a battlefield veteran -- your experience is applicable to the problem, and there's plenty of additional room for more experience and judgment. In other words, I'm in favor of your using all of the best objective inputs, including your own, as long as we don't sacrifice any professional, intellectual integrity by making the studies "prove" preconceived notions.

Now I repeat my third challenge. BE BOLD! Find new and better ways of quantitatively evaluating alternatives. We may be asking for too much, you know -- breakthroughs cannot be programmed. But I get the distinct impression that you are getting weary of having to answer a request for ORSA help with the statement: "We don't know how to solve that kind of problem."

In summary, let me say this. Considering its relative youth and the discipline -- ORSA has made a phenomenal impact on our decision-making ability in the Government -- including the Army! Many of our decision-makers are convinced, as they should be, that ORSA really stands for -- quote: "The Only Reliable and Substantiative Analysis." In order to follow the course that you have charted for yourselves, you've GOT to have new initiatives. You have to recognize them -- and not necessarily accept the ones I'm giving you, although I am a customer who desperately needs your products. I will give you three ways to get started. (See Figure 3.)

1. Tell me in ORSA terms how better to use ORSA.

2. Clear away the ORSA fog.

3. Be bold in developing new tools to use in this trade of quantitative analysis.

This brings me to the most important point of all: the solution to the Lieutenant's problem of weighing the mail with only four weights. As we know, the weights come out of this equation. The answers, of course, are 1, 3, 9, and 27.

$$N^3 + N^2 + N + 1 = 40$$

Figure 16

But today, I'm talking about NEW INITIATIVES. That old problem won't be a challenge to you. I want you to take a couple of minutes now, and show me how you would solve the Lieutenant's problem -- with three weights!

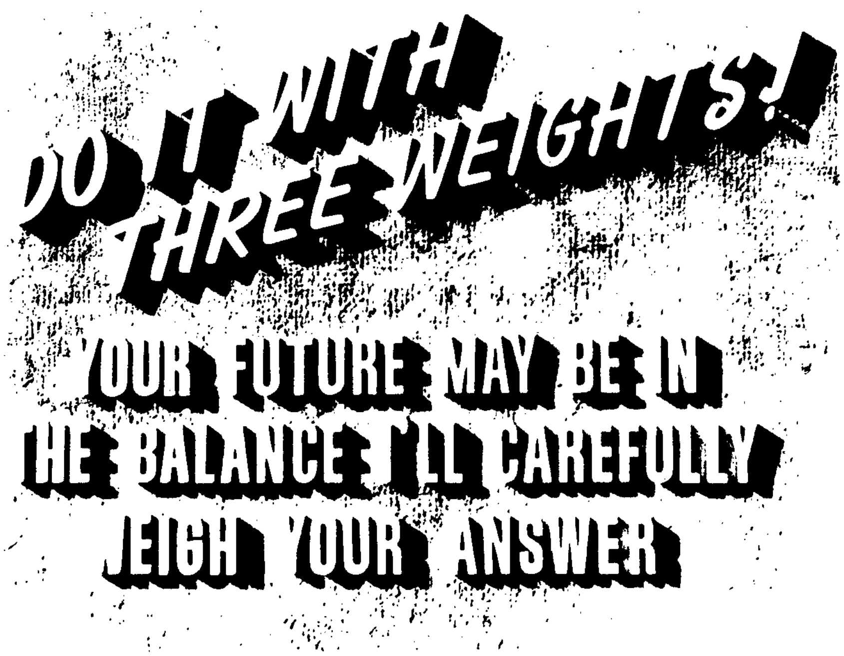


Figure 17

I wish you success in the panels and talks during the rest of this very vital Symposium.

Thank you.

INTEGRATED BATTLEFIELD CONTROL SYSTEM

Dr. Marvin E. Lasser
Chief Scientist, Department of the Army
Office, Chief of Research and Development

Introductory Remarks

I am most pleased to be here today and have the opportunity to discuss one of the Army's newest programs, the Integrated Battlefield Control System, or, as it is better known, the "IBCS".

As you will soon see, the IBCS is a most complex subject. Our discussions today are most timely, for the IBCS is still in its embryonic stages and there is much room for new ideas and original thought. And, there is much need for help from the OR/SA community.

There is much we could tell you about IBCS, but a complete discussion would easily take the rest of the day. The IBCS is an integral part of Army's land combat process and, as such, bears heavily on the inner working and hidden mechanisms of all of our combat functions.

Since, today, we have only a few minutes to cover the IBCS, I felt it best that we give you a brief overview and then hit hard at some of the more pressing and major problems that we are facing in defining and developing the IBCS.

Colonel Bolduc will lead off our discussions by outlining the general concept of the IBCS. He will be followed by Lieutenant Colonel Galloway who will discuss the intelligence aspects of the IBCS, in general, and a STANO/target development thesis, in particular. Mr. Manny Gale will then go into our position navigation problems, and the problems that are brought about, in the IBCS, by our lack of information on where we are and where the enemy is.

I will then close the discussion with a look into those computers that are currently being used, or are expected to be used, in the IBCS program and some of the problems and pitfalls that we have encountered in the ADP area. At the conclusion, I hope that we will have answered a few questions and posed some interesting new challenges.

INTEGRATED BATTLEFIELD CONTROL SYSTEM (IBCS)

COLONEL LUCIEN E. BOLDUC, JR.

Chief, Tactical Command and Control Division
Office of the Assistant Chief of Staff for Force Development
Washington, D. C. 20310

SLIDE 1

ASSISTANT CHIEF OF STAFF FOR FORCE DEVELOPMENT

IBCS
BATTLEFIELD
CONTROL
SYSTEM

FRAMEWORK FOR MODERNIZATION OF
ARMY TACTICAL COMMAND AND CONTROL

I would like to take a few minutes to outline the problem involved in improving Tactical Command and Control. The framework for our improvement efforts is the integrated battlefield control system or IBCS. To best discuss the IBCS, let me start with its definition and purpose.

SLIDE 2

IBCS DEFINITION/PURPOSE

The IBCS is the structured framework of personnel, organizations, concepts, doctrine and equipment designed to integrate the functions of land combat into a coherent system.

An IBCS will facilitate planning, directing and controlling the execution of operations throughout the land combat system.

IBCS involves, as we state in the definition, a good deal of everything that goes to make up the structure of the field Army.

Its purpose involves activities familiar to all of us - planning, directing, and controlling combat operations -- accomplishing these functions in the most timely and efficient manner.

SLIDE 3

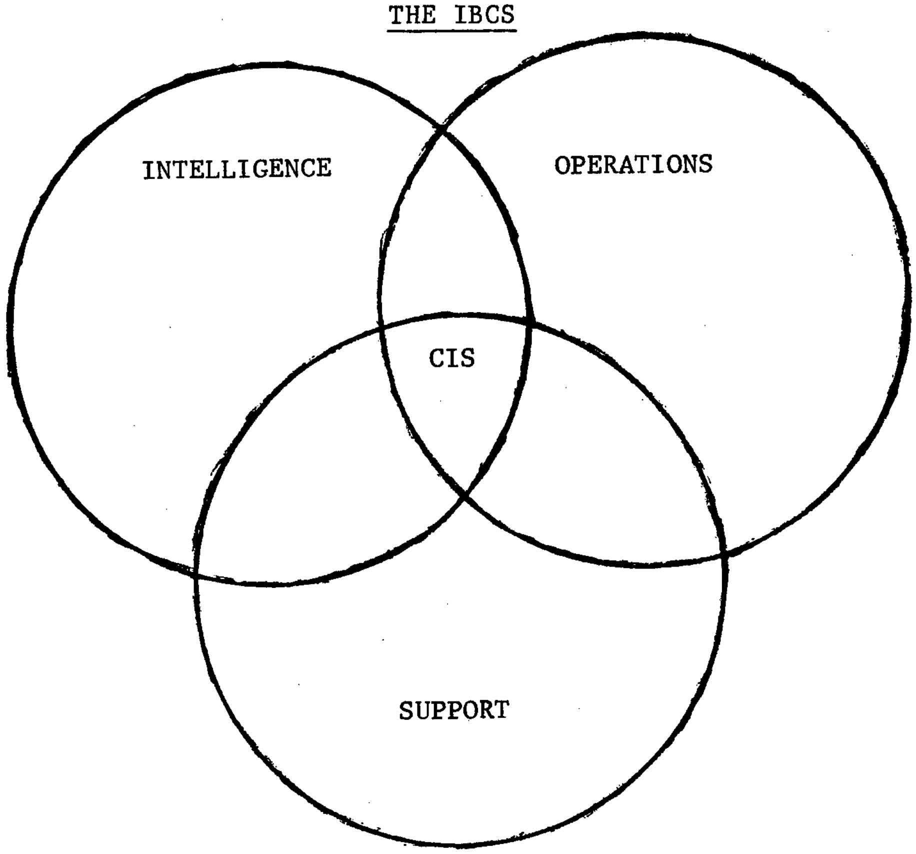
COMMAND AND CONTROL

An arrangement of personnel, facilities, and the means for information acquisition, processing, and dissemination employed by a commander in planning, directing, and controlling operations.

IBCS is intimately related to command and control which, as you see, ties together the same essential elements of planning, directing, and controlling.

SLIDE 4

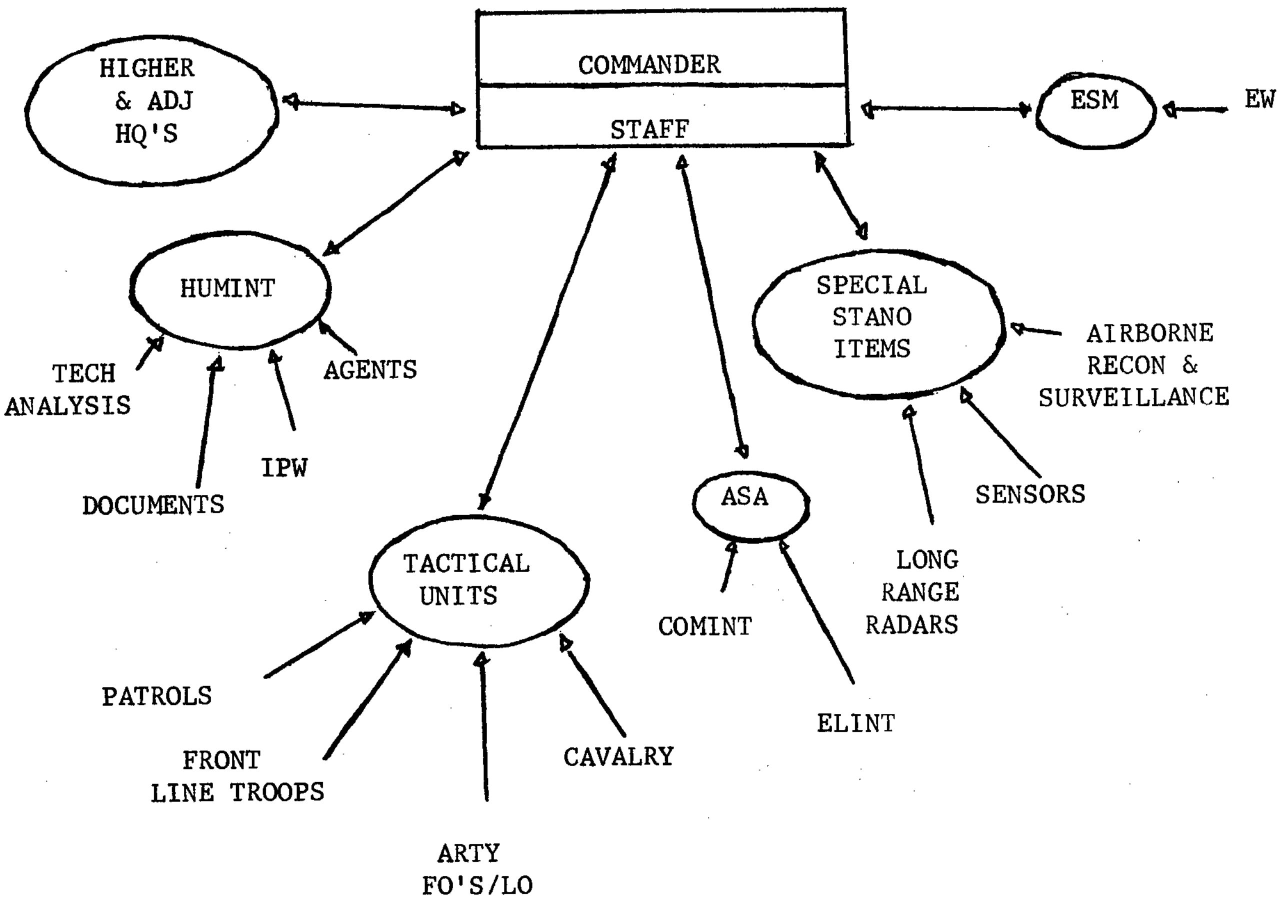
THE IBCS



The IBCS is made up of four subsystems - the three so-called working subsystems - intelligence, support, and operations - and a tie together subsystem - the commander's integrating subsystem. Let me talk to you about each of the subsystems.

SLIDE 5

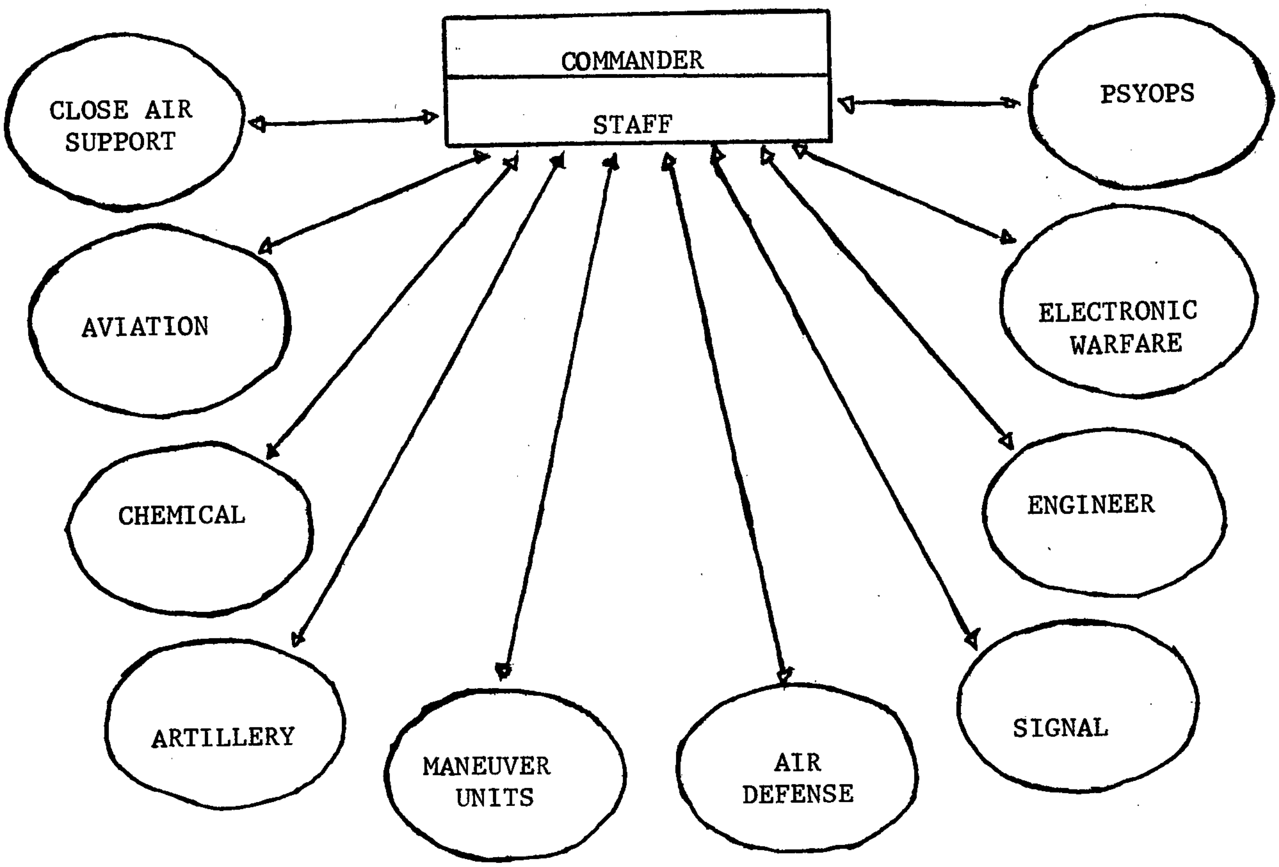
THE INTELLIGENCE FUNCTION



The intelligence function is, at best, a loose confederation of many groups setting out to achieve the same fundamental mission of locating, identifying, and tracking the enemy and maintaining information on his intentions and capabilities. The information generated by all of these activities is -- or should be -- passed to the staff and commander manually through communications systems, and couriers or word of mouth. Analysis is difficult because the memory is small and retrieval difficult. Key bits of information may be left out of an analysis simply because the volume of information is so great that it cannot be effectively handled. The goal of the IBCS is to control and integrate information about the enemy into the continuous production of intelligence for the commander.

SLIDE 6

OPERATIONS ACTIVITIES

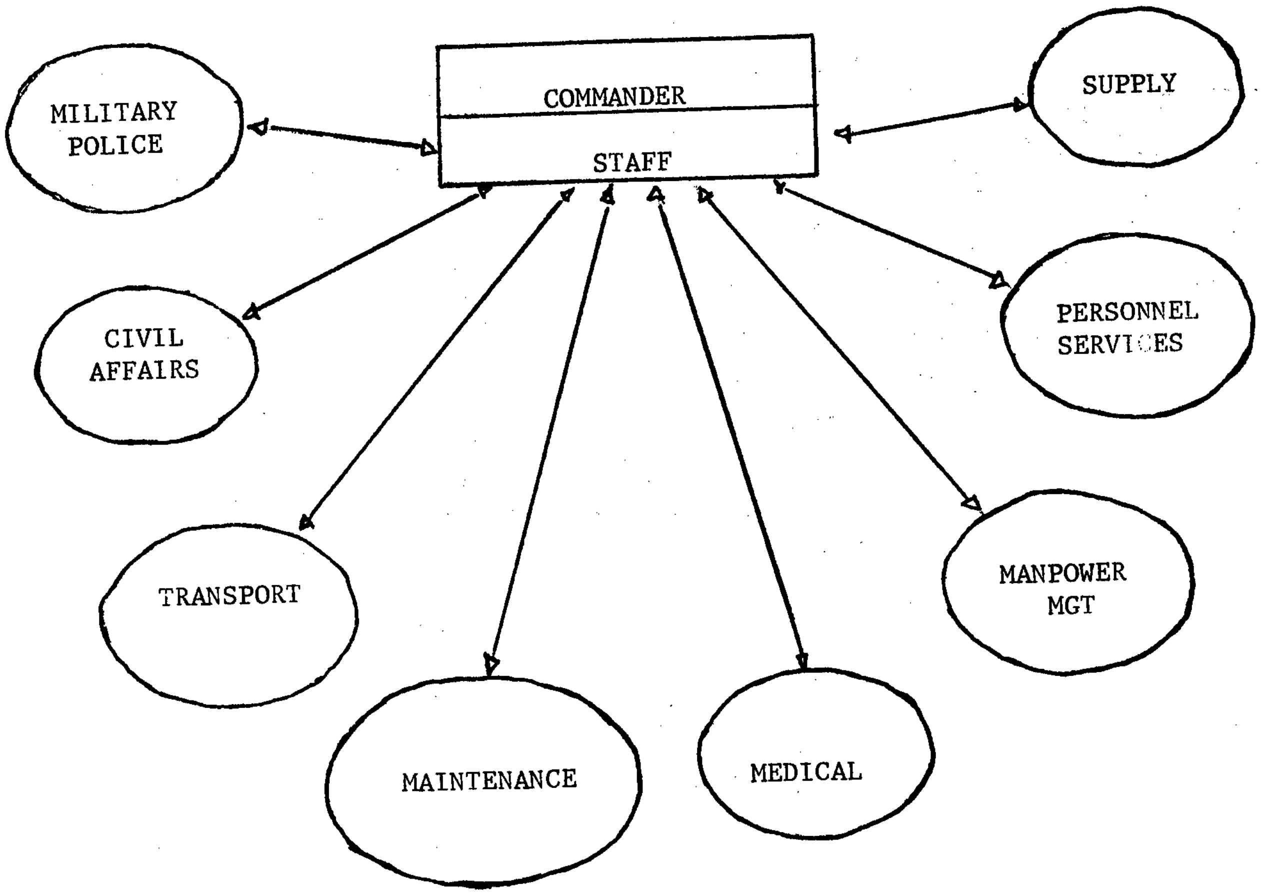


In the operations area, we have many different elements reporting in, and a considerable flow of direction from the commander to his units. Today the operations people try to maintain control of airspace, keep track of the enemy moving towards us in the air, and manage the operation of many different and widely dispersed combat units.

The G3 is like a juggler with many balls in the air. Communications are slow. Reports take too long to process. Fire missions take minutes instead of seconds. Often the staff operates with less than the big picture. The assessment as to how operations are proceeding is sketchy. Under the IBCS, our goal is real time tactical and technical control over the employment of means at our disposal. I will return to this subsystem in a few moments.

SLIDE 7

SUPPORT SYSTEM

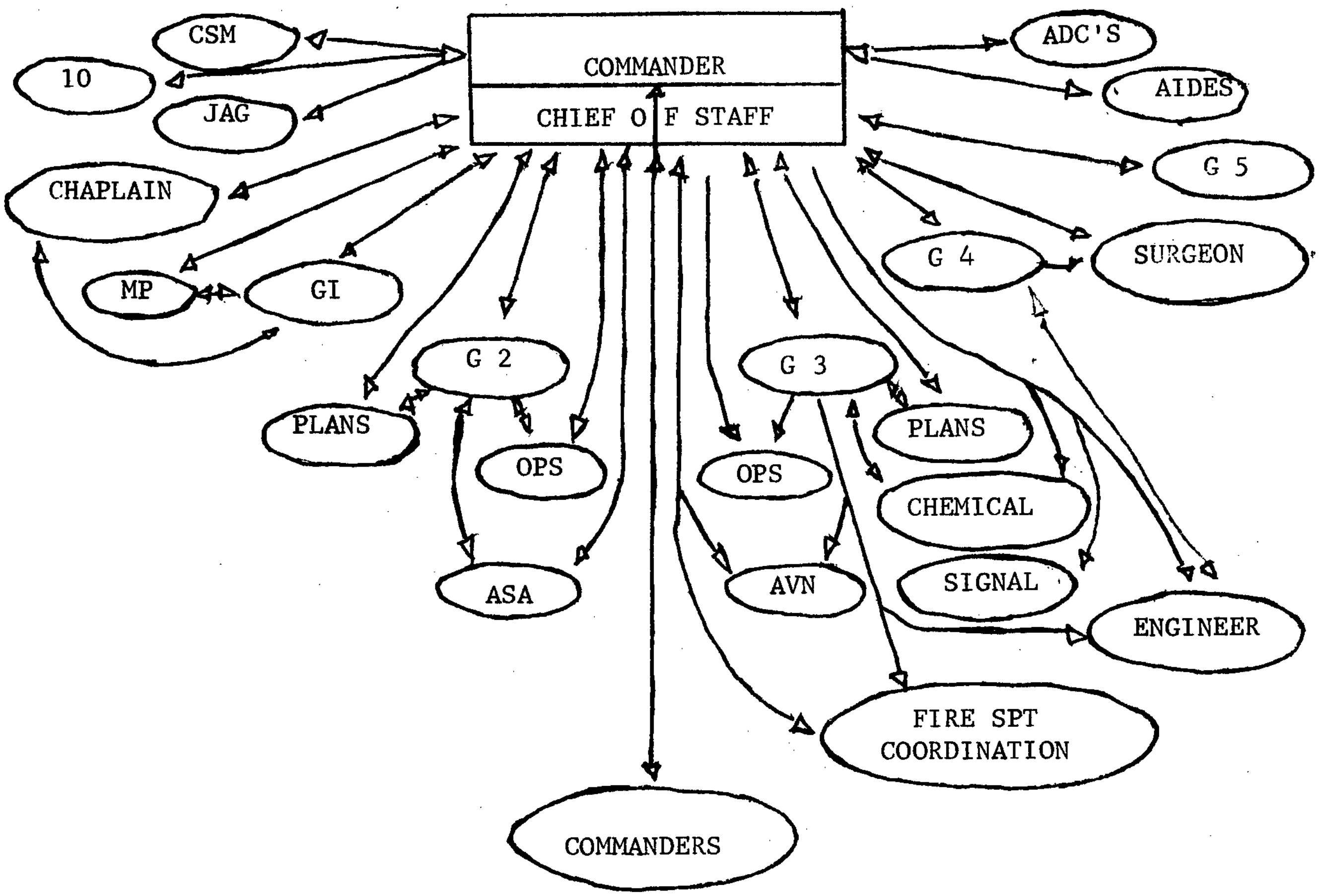


In the support subsystem the functions are obviously classic but increasingly sophisticated. We are currently operating with unlinked systems some of which do have ADP assistance. Most operate, however, in a manual environment. Information retrieval is slow, and analysis requires many, many hours.

The goal, under the IBCS, is simple: To improve our combat service support.

SLIDE 8

ACCESS TO THE COMMANDER

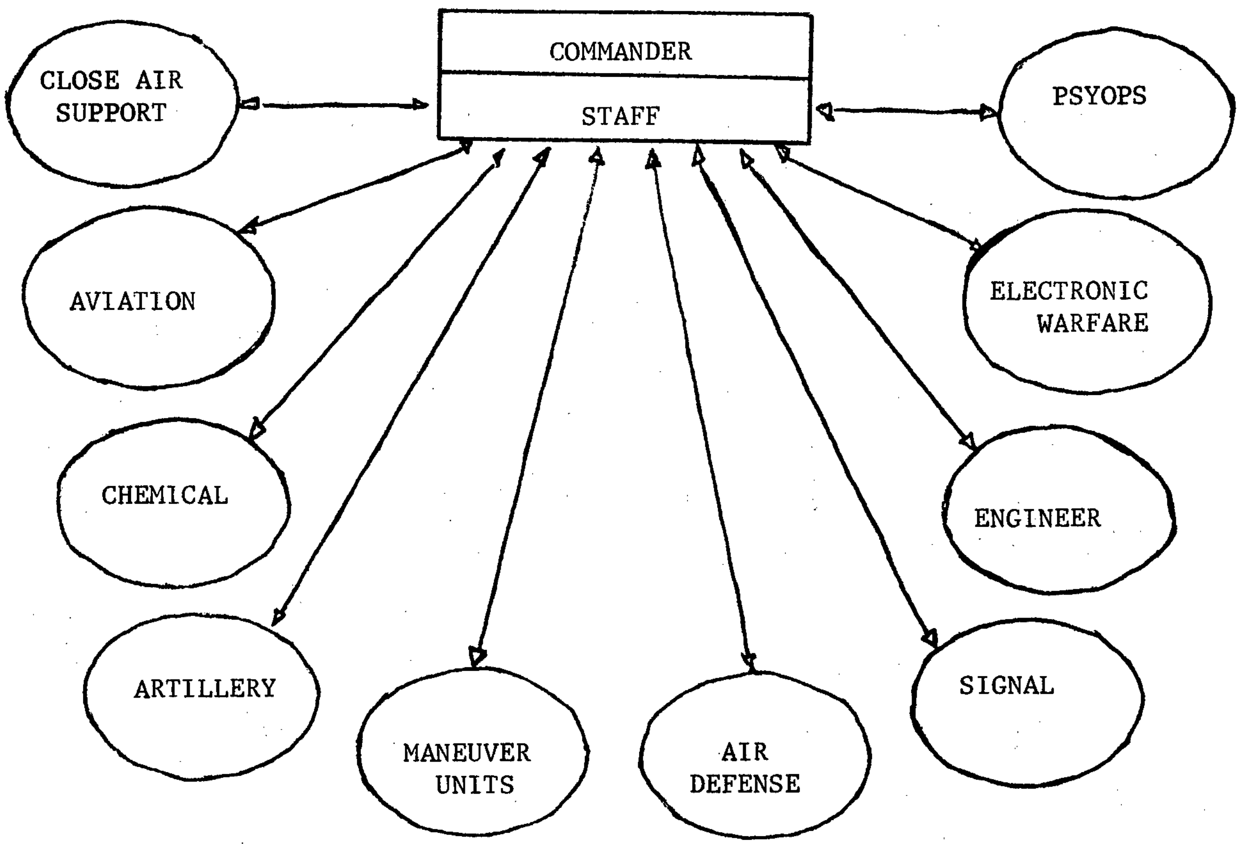


The final element is the commander himself. Everyone wants to get to the commander with information. Everyone in the CP talks to the commander and the commander talks to everyone. When he wants information, someone goes and gets it. The relation of this information to information that came in a few minutes earlier, or from another source, is difficult to determine.

Under the IBCS we will tie together all inputs to the commander, and bring together the subsystems, so that this information may be displayed for the commander's analysis, and decision making.

SLIDE 9

OPERATIONS ACTIVITIES



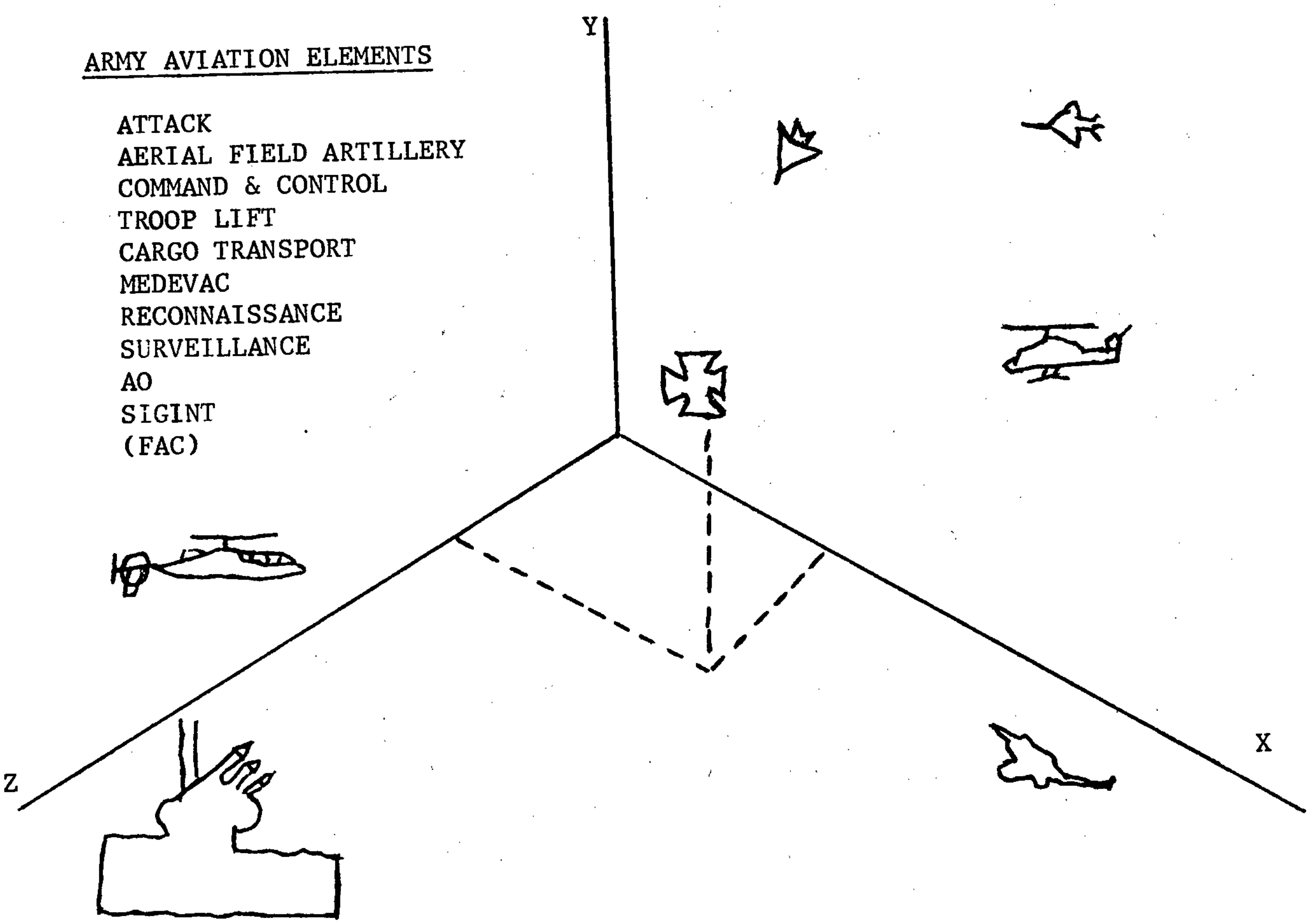
Let me return to the operations subsystem, which poses some special challenges.

As Doctor Lasser will point out, we are putting priority effort on improvement of command and control in three functional areas - Aviation, Artillery, and Air Defense.

In an attempt to improve command and control we are running smack into a larger problem - airspace coordination.

SLIDE 10

AIRSPACE CONTROL



This is literally a four dimensional problem with friendly and enemy tactical air, helicopters, missiles and artillery rounds all competing for the same point in space at the same time. It is a "now" problem -- real world and real time.

The problem has existed since World War I, but has become increasingly acute because of a number of changes that have occurred.

First, there have been significant increases in the rate at which the many vectors converge.

Second, nap-of-the-earth flying has compressed the range of altitudes used by helicopters and high-speed tactical air alike.

And third, while working to improve control of our artillery, aviation and air defense components we are accentuating the need to coordinate them, to grapple directly with the air coordination problem.

The classical solutions we have used in the past:

Vertical separation, that is stacking the vectors one above another.

Horizontal separation by using zones and corridors or, sequential separation, by alternating the exclusive use of an area are no longer sufficient.

As you recall we used three active verbs to describe command and control. The first two of these, planning and directing, occur prior to the operation, and pose some exceedingly complex doctrinal problems. For instance, who on the special staff representing the functional commands should plan the use of airspace? Many of you will be able to appreciate that aviator, artilleryman, and air defenseman are all quick to attempt to control the airspace in his own interest. Should one of these special staffs or someone else be given overall control?

Controlling, the third of the three verbs which describe command and control, deals with matters in progress. The Tactical Commander must now grapple directly with real time or near real time execution of decisions which he previously had time to staff. What can be done to help him?

As one example, of what faces us, let us consider only the interface between Army aircraft and the Air Defense system in the Division Sector.

Take, for example, a typical deployment of the friendly air defense weapons in a division -- CHAPARRAL, VULCAN, REDEYE. Try to imagine the potential threat to an Army aircraft flying in this sector. In addition to which is shown here our pilot must also contend with, among others, the fires of division artillery, other Army aircraft and Air Force tactical aircraft which would be traversing the area.

It is not yet clear who should control the space over the division - either the aviator, the air defender, the artilleryman -- or someone else. Even when we decide who, we are left with the how -- integration which will accommodate the needs of both centralization for concerted effort, and decentralization for initiative and flexibility.

You can see that doctrinal, organizational, tactical and technical problems are all converging. We would welcome an organized attack by you on all or any of these.

The challenge is great.

Our goal - significantly improved in command and control -- is well worth our effort.

TARGET DEVELOPMENT

LTC Gerald E. Galloway
ACSFOR

You have heard from Colonel Bolduc much about the problem the commander in today's Army faces and he has discussed with you the plight of the commander in the intelligence area. The commander has lots of people reporting to him, many sources of information. To term this conglomeration a loose confederation is doing it too much of a service. A typical division commander has thousands of different individual sensors reporting to him; these range from messages from individual soldier on patrol to reports from complex electronic devices. To be effective he must blend the output of these sensors together in such a manner that the results come out sounding like a symphony and not an orchestra during warm-up. This requires skillful management of his acquisition sources and careful processing of the acquired information. (Slide 1)

This morning, I would like to talk to you about a thesis in this area of finding the enemy, and how the validity of this thesis is so dependant on the successful development of an IBCS. Throughout my discussion I would like to highlight some of our tradeoff problems, because there are many and right now we are only marginally able to effectively deal with them. If you have any ideas, please let me know. (Slide 2)

History tells us that soldiers never have been much good in the find the enemy business. Large troop movements during Napoleon's time were hardly noticed and it was not unusual for a force of several thousand men to slip by unnoticed within a few miles of an awaiting enemy. (Slide 3)

The Battle of the Bulge tends only to support the fact that we learned little about finding the enemy in the 150 years between Napoleon and Eisenhower. (Slide 4)

Our early days in Vietnam gave birth to such terms as "search and destroy", "search and clear", where "search" meant you needed to find the enemy before you could do anything to him. Those of you who have been to Vietnam recognize that since 1966 we have made some improvement in our find the enemy capabilities. We have produced new STANO devices and we have tapped all the other sources of intelligence to give the commander a great deal more information than he has ever had in the past. (Slide 5) (Slide 6)

We also know from our analysis of future land combat, that in mid or high intensity warfare, the penalties for not knowing where the enemy is located are even more severe than we have seen in the past. One 10 KT warhead properly placed can do a great deal of damage to an infantry battalion. We must not stop or slow our efforts to improve our capabilities to find the enemy. In this field of finding the enemy the gains that have been made and will be made, will be those that take place through following the target development thesis. (Slide 7)

Target Development means the active management and employment, at all echelons, of all available information gathering resources, to progressively refine intelligence about the enemy, in order to continuously portray the developing enemy situation for use by the commander as the basis for reaction decisions. Through target development, information of enemy activity is generated as an integrated process. All sources of information are tapped and the results used to more precisely locate the enemy over time and space. No one bit of information in itself provides all that we need to know about the enemy. But all of these sources of information, channeled into a focal point and then given thorough analysis can give us the capability of accurately determining the enemy situation. To illustrate this thesis, I would like to take you briefly through two target development sequences. One is in a sea environment for low intensity and the other is in a European environment for the mid-high situation.(Slide 8)

Target development begins with surveillance planning, as all collection means are focused on locating possible enemy targets. In a low intensity environment, we know that the enemy is somewhere out in a vast area in the jungle - or located in the tree lines along the paddies and rivers.(Slide 9) POW interrogation reports, captured documents, agent reports, other sources of intelligence - the human factors - are continuously screened for basic information. What are his objectives?What are his plans and missions? Where will the enemy be moving? When will he be coming? With this information as a guide our intelligence assets are directed towards the general area where the enemy might be expected to move or operate. As an example, we have learned from agents and other sources that a major enemy unit is coming down from one province into the next. This information must be refined. We can learn from other sources of intelligence that the enemy is operating in a specific base area. With electronic support measures -ESM- airborne radio direction finding equipment we can keep track of the enemy's movement within and around his base area.(Slide 10) We could put long range patrols on the ground to seek out and verify the enemy's activity. (Slide 11)

Using this information we next might target with the "people sniffer" and send it out for surveillance of a given area to confirm that the enemy is in fact operating in that general location. Several readings from the "people sniffer" give us further significant indications that the enemy is, in fact, in the area, again LRRP's could be put in to verify. (Slide 12)

At this point hand emplaced, air or in the future, we hope, artillery delivered unattended ground sensors can be emplaced near trails and in assembly locations to pinpoint and monitor enemy activity along his probable routes of movement. These probabilities are based on the intelligence analysis obtained to that point in time. When these sensors are activated and we have plotted what we

(Slide 13)
believe to be the enemy's movement, we turn to air cav units, airborne surveillance systems, night observation devices and ground surveillance radars. Readouts from any one of these devices enables us lock on the enemy. If we felt that the enemy we were watching happened to be part of a larger group - perhaps part of a group carrying 122MM rockets, we might track them with our long range patrols and wait until they all assemble and then attack the entire group by fire - artillery or air strikes. We might also deploy a battalion or more to the subject area to saturate it and fix the enemy in position and destroy him. (Slide 14)

No one of the surveillance devices that I have mentioned, in itself, could have acquired the enemy, followed him, or developed his probable intentions or mission. We know that the proper combination and coordination of these sensors with human intelligence, tracking the enemy, gives us the capability to locate him in time and space so that we can selectively determine how we wish to attack him.

The question still to be answered is how many "people sniffers", how many radars, how many UGS, are needed to give us the most cost effective means of locating the enemy. (Slide 15)

In the mid and high intensity environment the target development sequence is similar, in principle, to that in low intensity. The target development sequence is affected, however, by the location of the target. In low intensity, you operate "everywhere" and so does the enemy. In mid and high intensity warfare, the enemy echelons his forces out behind a FEBA. In the areas beyond 60 kilometers from the FEBA, the information about the enemy will be gross--not very refined.(Slide 16) We start our target development sequence with information from agents and other national sources. These elements give us a general indication of the nature of the activity - the enemy is moving - a long range missile unit moved through a particular area and was headed west. Selected intelligence from all sources - Air Force, Army, and Navy define areas that must later be covered in detail through reconnaissance by Air Force high performance aircraft or possibly drones or perhaps tactical satellites, at some point in the future. These systems, ideally would pinpoint the exact location of the enemy, normally in near real-time; but again our response might have to be delayed. The important thing is to be able to track him over time. (Slide 17)

We might feel it appropriate, because of our capabilities, to let the enemy move into the area 25-60 kilometers from the FEBA where he will be concentrating for tactical maneuver at the FEBA. In this area maximum reliance will have to be placed on reaction by missiles and friendly air interdiction support. Our target development process continues with narrower cuts - attempts to refine information obtained earlier in the target development sequence. (Slide 18)

Signal intelligence provides us general information as to the type of enemy unit and activity. ESM systems tell us of the presence of the many radars and communications systems that will exist in a mid-or-high intensity environment. Surveillance missions by manned and, in the future, unmanned aircraft, focus side looking radar and photo systems on probable enemy locations. The moving target indicator radar on the Mohawk seeks out movement by the enemy towards assembly areas. Drones could give us IR coverage of the assembly areas and tell us when the enemy is massing. If the enemy was close enough, we could put long range ground surveillance radars in operation to maintain contact with the targets as they moved. (Slide 19) (Slide 20) (Slide 21)

To prevent weather from overtaking us, as it did in the Ardennes in 1944, unattended ground sensors provide 24 hour all-weather near real time surveillance of the critical areas and routes. These sensors would be placed at the key road junctions to tell us where traffic was moving and hopefully with advanced techniques, to tell us what type traffic was moving; such as self-propelled artillery, tanks, or wheeled vehicles. If sufficient information (Slide 22) were developed, we could put our force to bear and begin to fire at the enemy. As the enemy moves into the area 25 kilometers or less from the FEBA, he is entering the area where our units are equipped with conventional tube artillery systems. (Slide 23)

Ground and airborne radars, airborne surveillance systems, ESM and UGS, as an integrated and coordinated effort, all are put into play in the sequential process by which we track the enemy into our position. Long range patrols are available for direct observation in the enemy rear area. Once the battle is joined our counter-battery/counter-mortar radar systems would be available to pinpoint the enemy as we engage him with our high-accuracy weapons systems.

I am sure that many of you are saying that we won't have to look for an enemy in Europe because our problem will not be too few - but too many of the enemy. I would ask you, however, to look at the tens of thousands of radios facing each corps, to view the thousands of vehicles that will be moving across the battlefield and to accuratly determine, based on a few bits of information, which of these targets are targets that count and should be attacked immediately. Today, we can't tell a tank from a Volkswagen with our Mohawks, by airborne means. The only way we are going to be able to do this is by an integrated approach to collection of information about the enemy. (Slide 24)

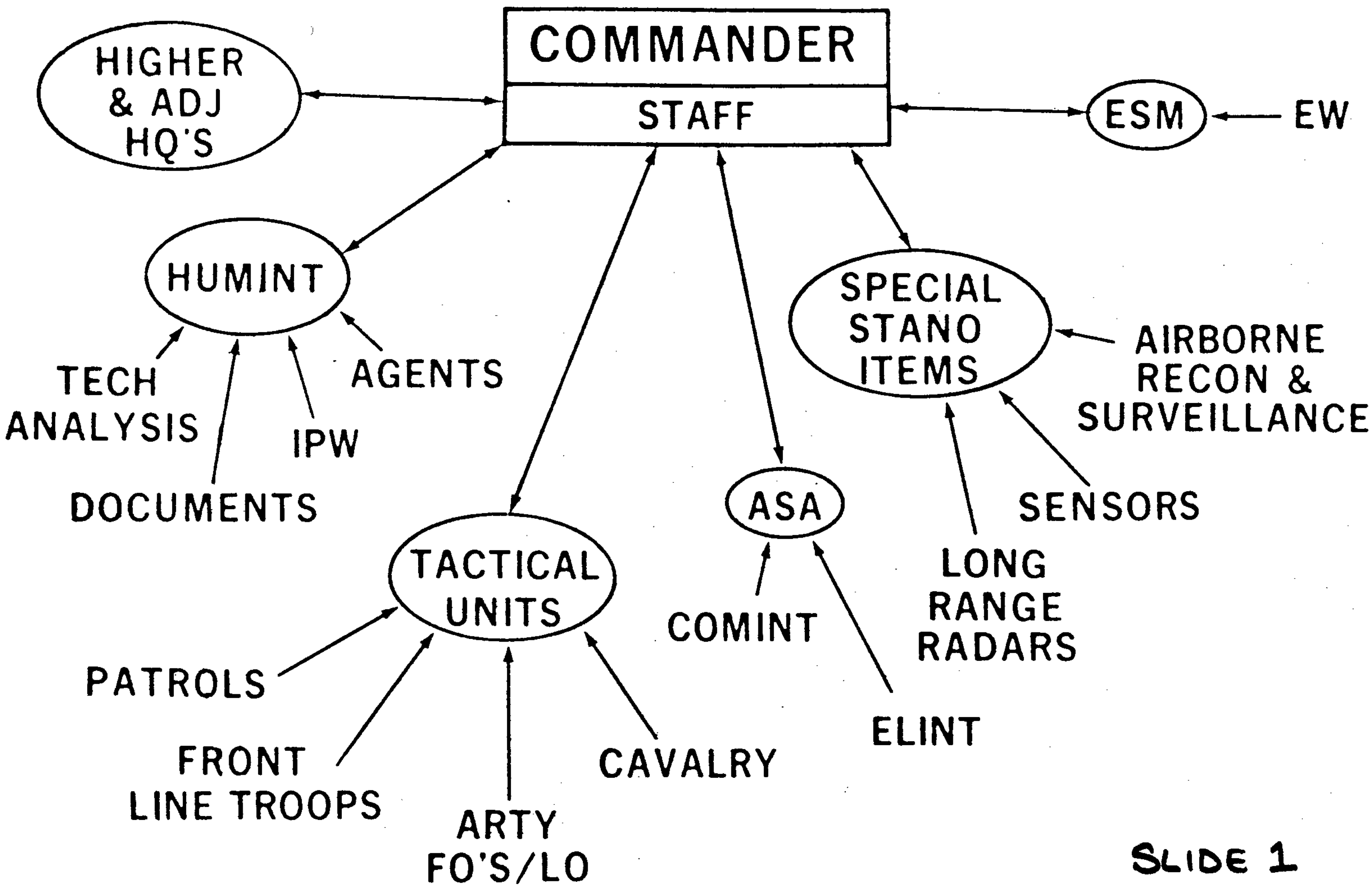
Through target development, we get information and start it moving back to the commander. It is then that the processing function becomes all important for this information and must either be immediately displayed for the commander or stored to be retrieved when required for analysis. The required information, properly processed will be used to predict and define the enemy's courses of action. (Slide 25)

We are doing reasonably well in the target development hardware area. We are coming up with newer sensors and from a hardware standpoint, the picture looks bright. It is when you begin to discuss the optimum mix of these sensors and the optimum operational arrangements that we begin to develop problems. What is the most effective mix of unattended sensors, night observation devices and radars for use by the company? What type of aerial surveillance system should be provided to the corps to supplement or complement the information acquired from long range surveillance radars? To whom should an aerial platform report--a patrol, the company commander, or the corps commander? We are relying on CDC through modeling, field experiment and MASSTER testing to meet this challenge! (Slide 26)

As you can see, our biggest problems now are our information flow problems, the processing problems, the communications problems. This chart indicates as of this moment the ways by which information gets from the STANO devices to the command post. This is a hardware driven concept - maybe even a soldier's concept - but it is untested, it hasn't been field validated. We know that real time information flow can be achieved. We know we can't store and with recall all the information available but we know there must be a way to sort out and filter what information is really needed. (Slide 27)

This is the message I would like to leave with you. We have made reasonable strides in the STANO area in the last two years. We know that by giving our sensors we can realize their full potential. We are not on the trail of the best mix of "collection devices". We know that ADP offers us much promise in our intelligence analysis. But, we are like a man who has just been presented with his son's new bicycle. We know where the wheel is. We know where the frame is, but until we do a little studying, we don't know how it all goes together. We will be busy performing analyses, experiments and tests in order to find the most effective uses - you can play an essential role in this endeavor.

THE INTELLIGENCE FUNCTION

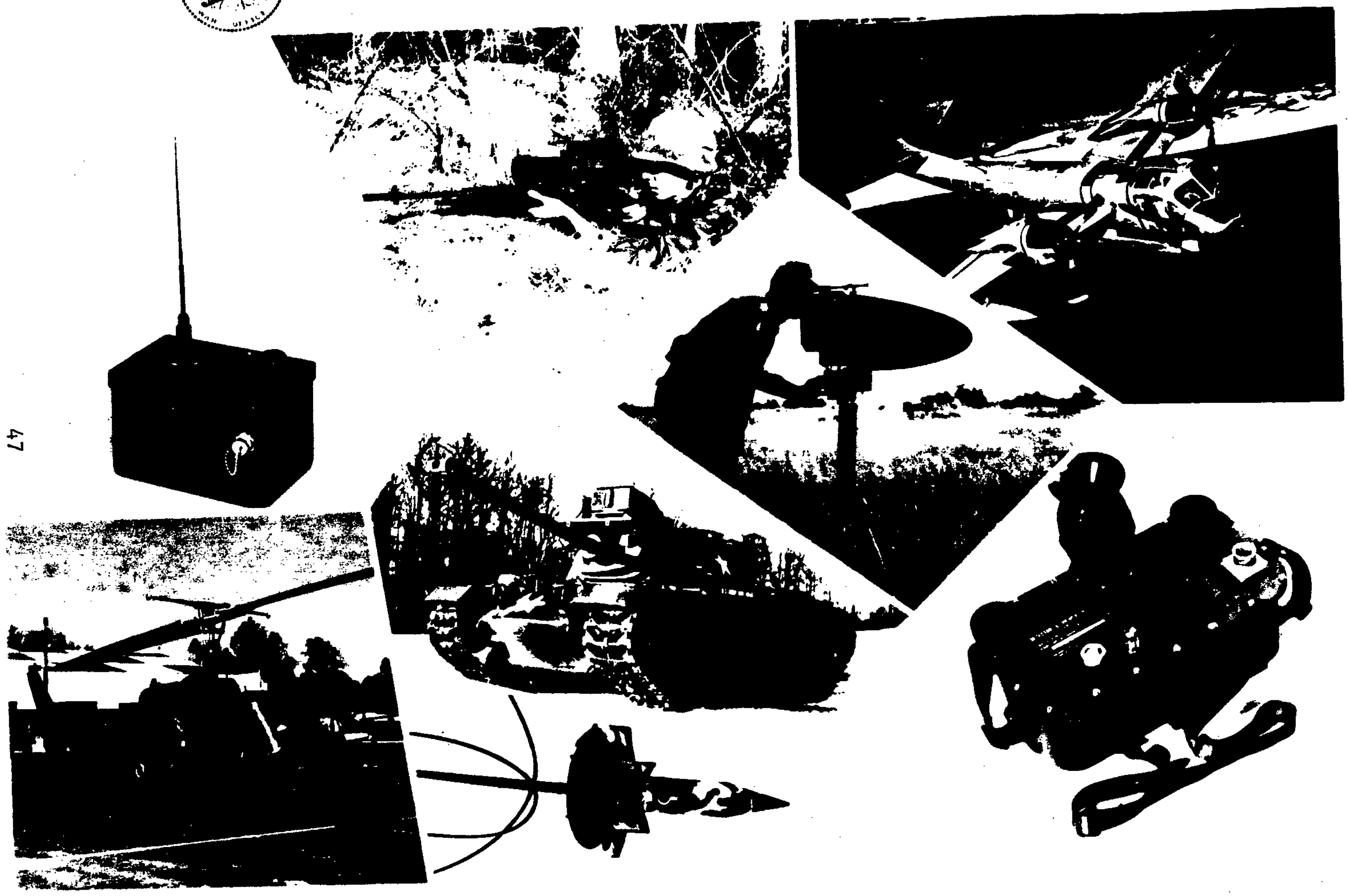


SLIDE 1

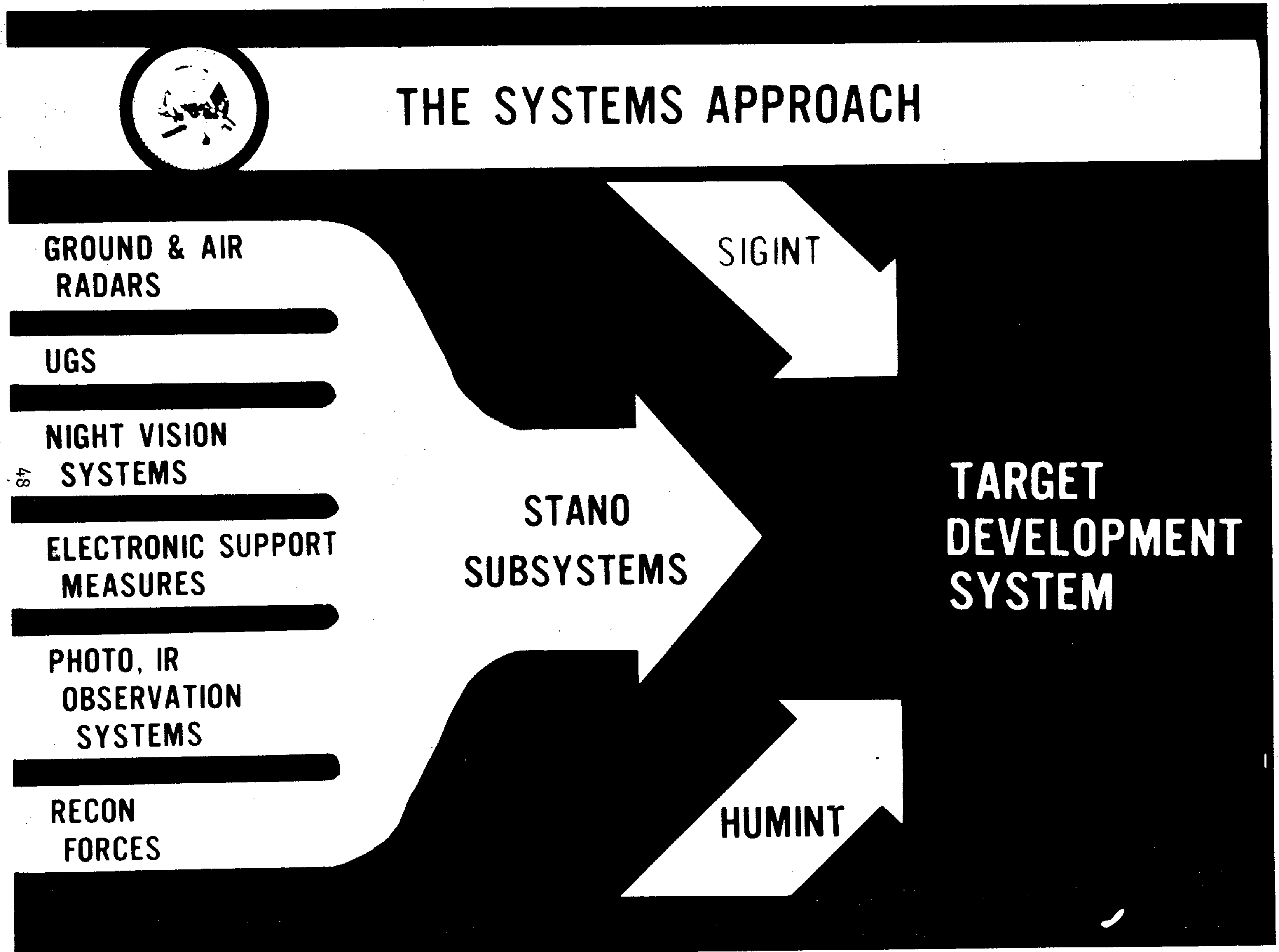
SLIDE 3

SLIDE 4

STANO

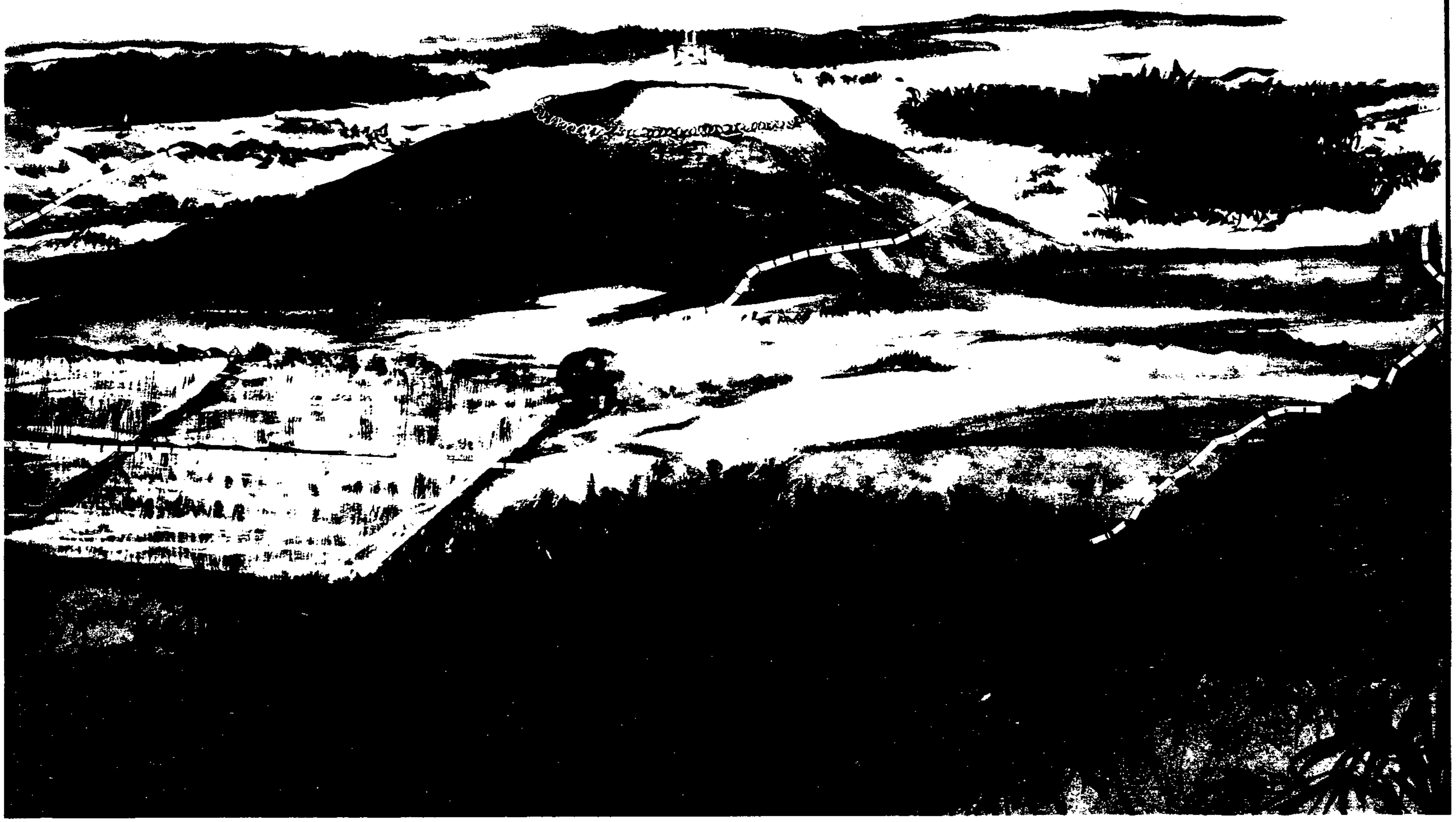


SLIDE 5


THE SYSTEMS APPROACH
GROUND & AIR RADARS
UGS
NIGHT VISION SYSTEMS
ELECTRONIC SUPPORT MEASURES
PHOTO, IR OBSERVATION SYSTEMS
RECON FORCES
STANO SUBSYSTEMS
SIGINT
HUMINT
TARGET DEVELOPMENT SYSTEM

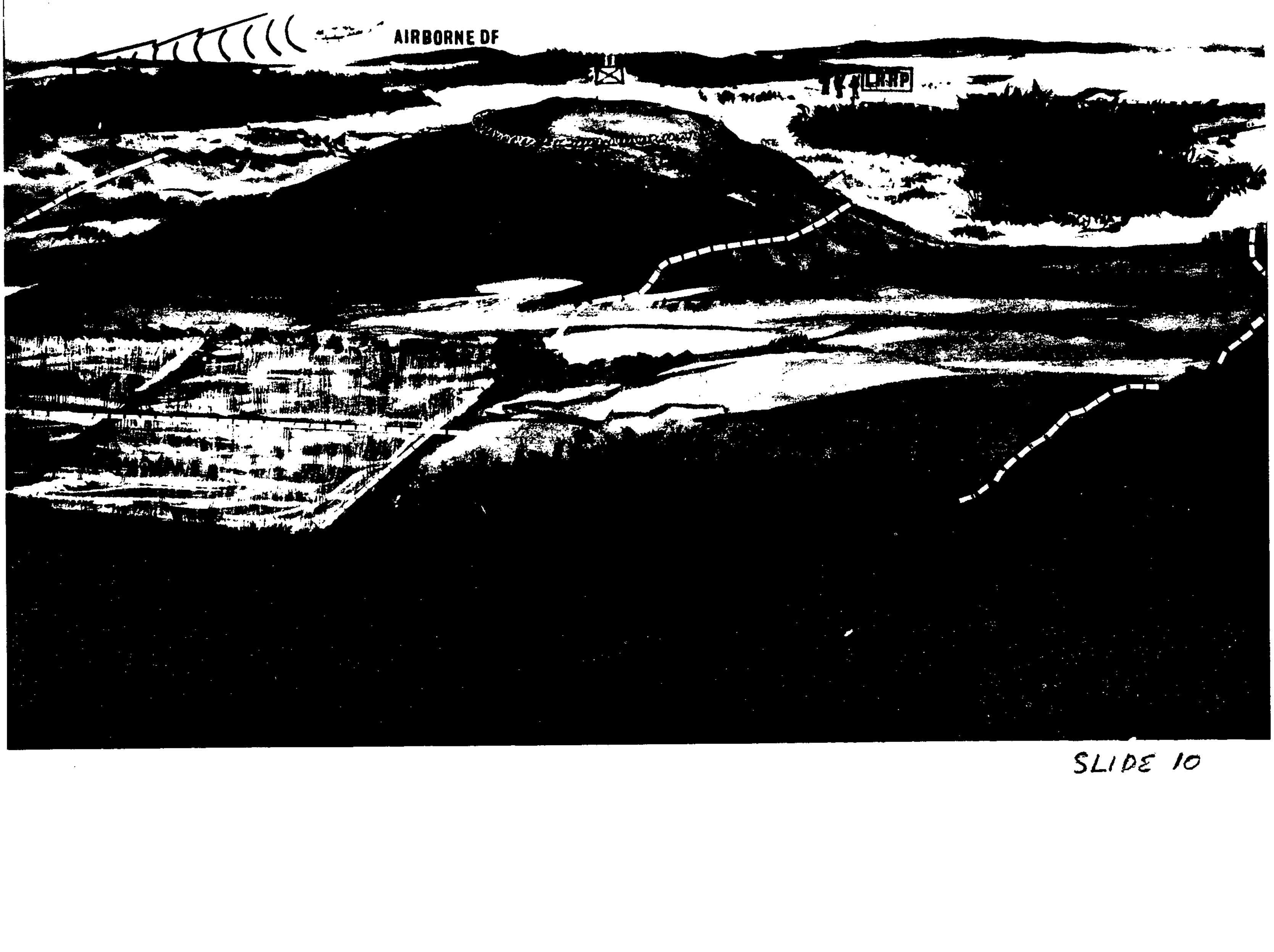
SLIDE 7

TARGET DEVELOPMENT



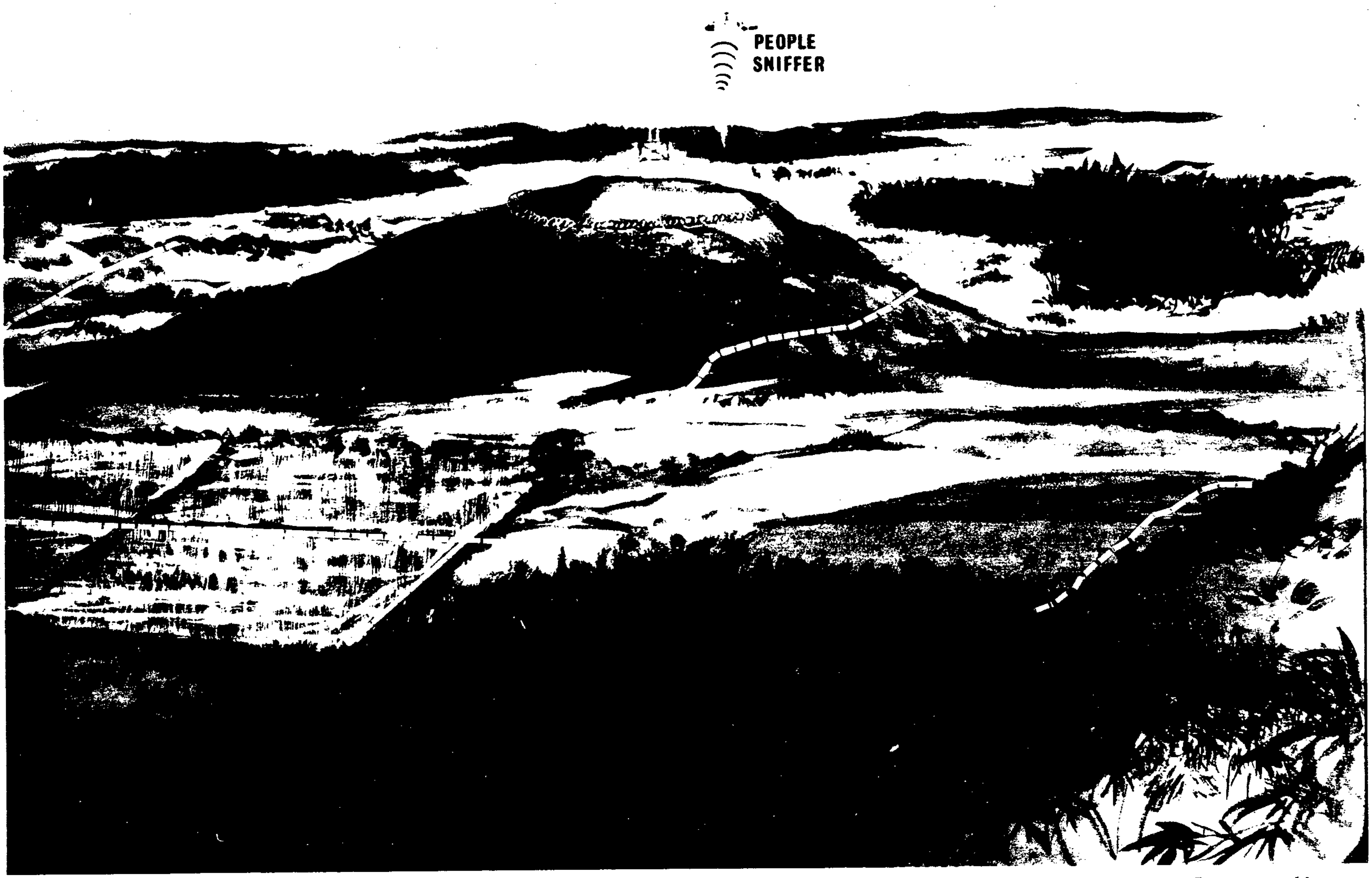
SLIDE 8

TARGET DEVELOPMENT



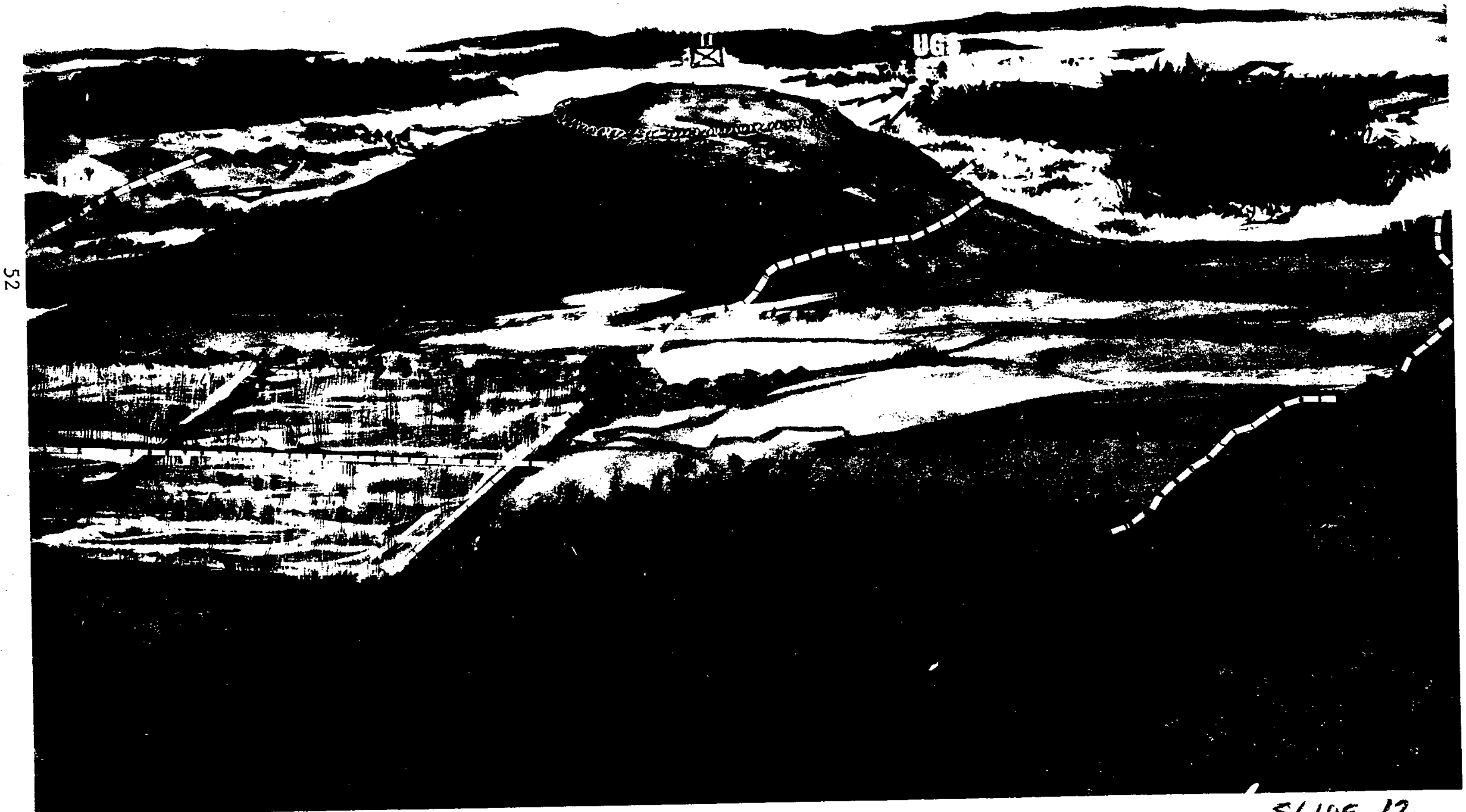
SLIDE 10

TARGET DEVELOPMENT



SLIDE 11

TARGET DEVELOPMENT

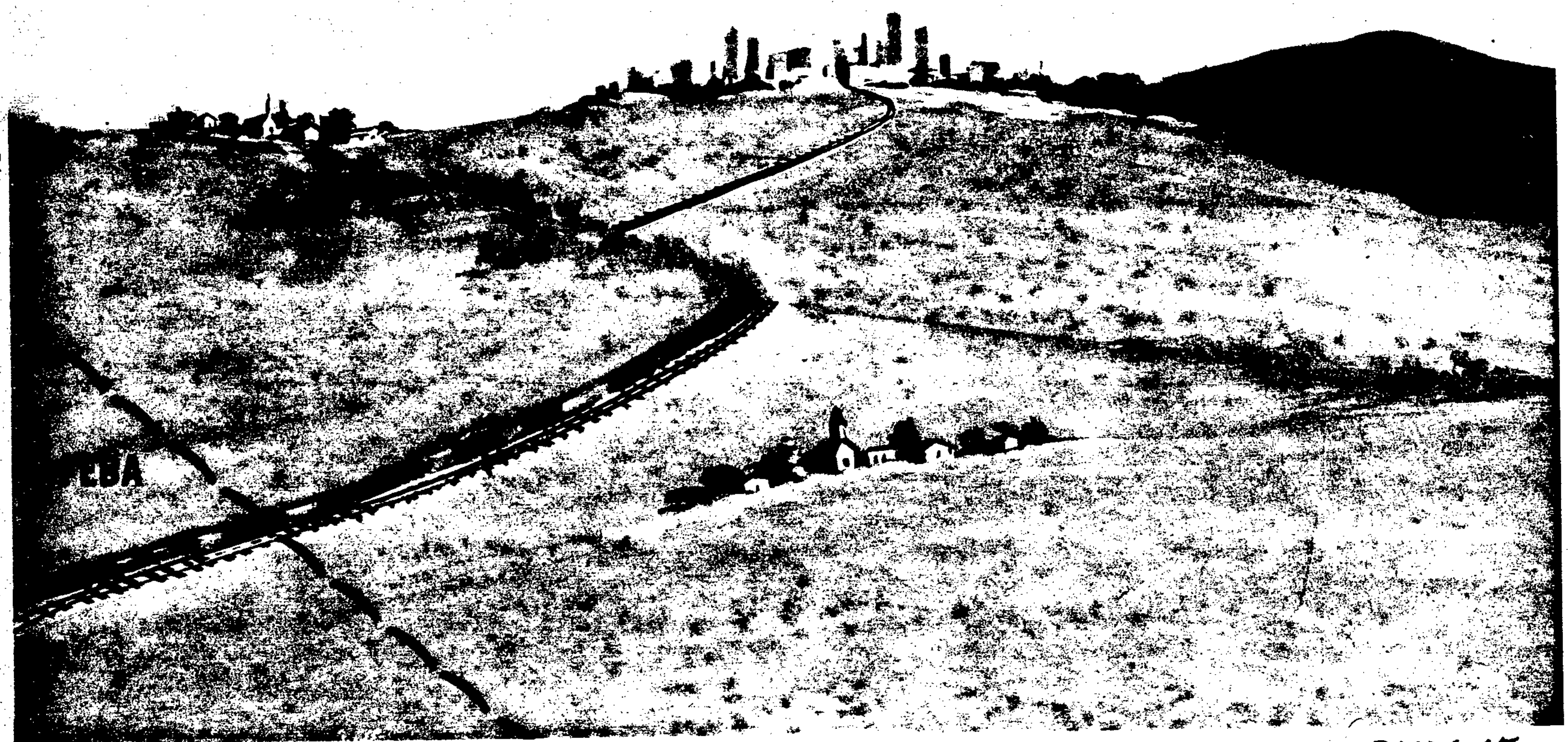


SLIDE 12

TARGET DEVELOPMENT

SLIDE 1A

TARGET DEVELOPMENT

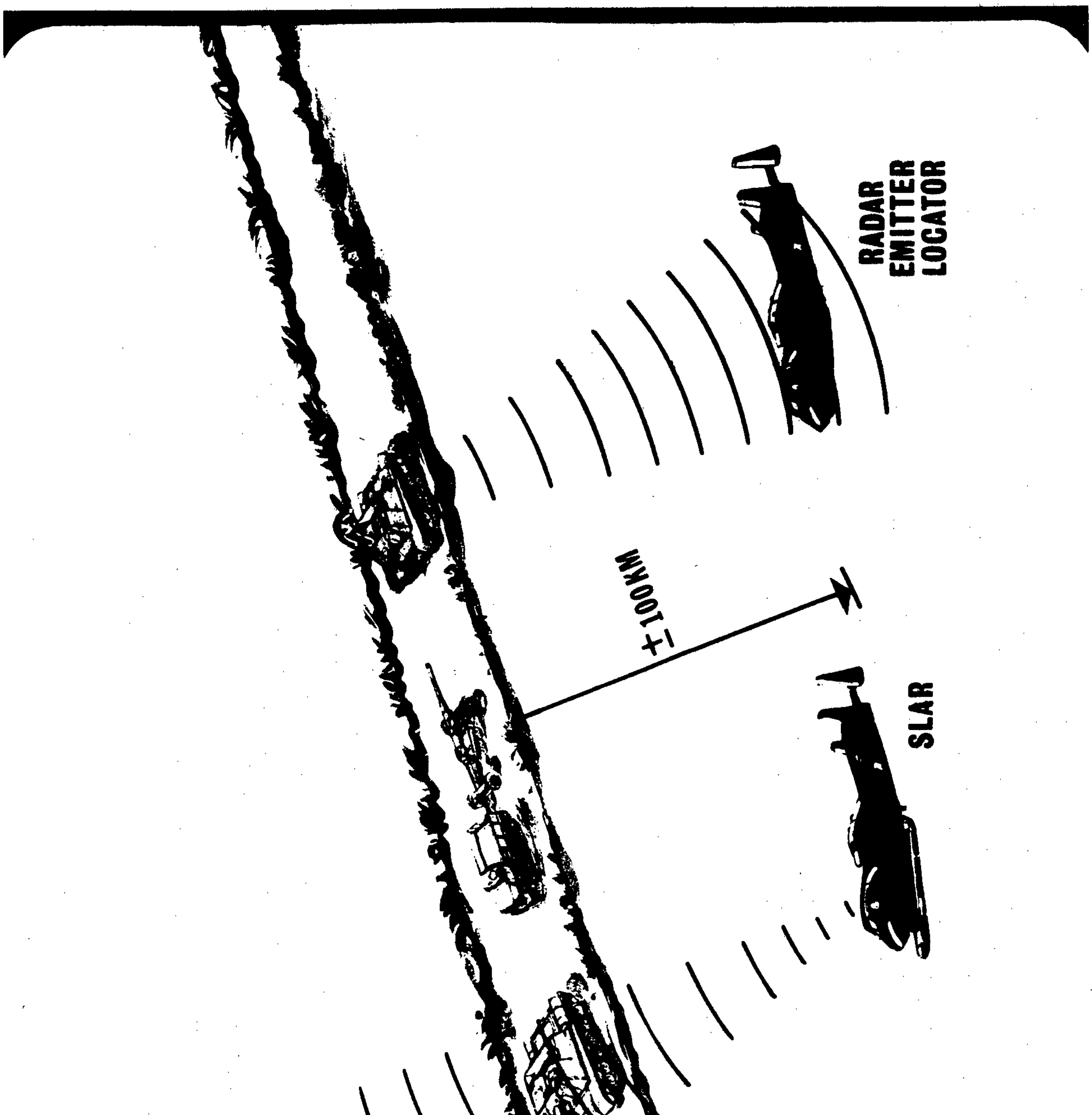


SLIDE 15

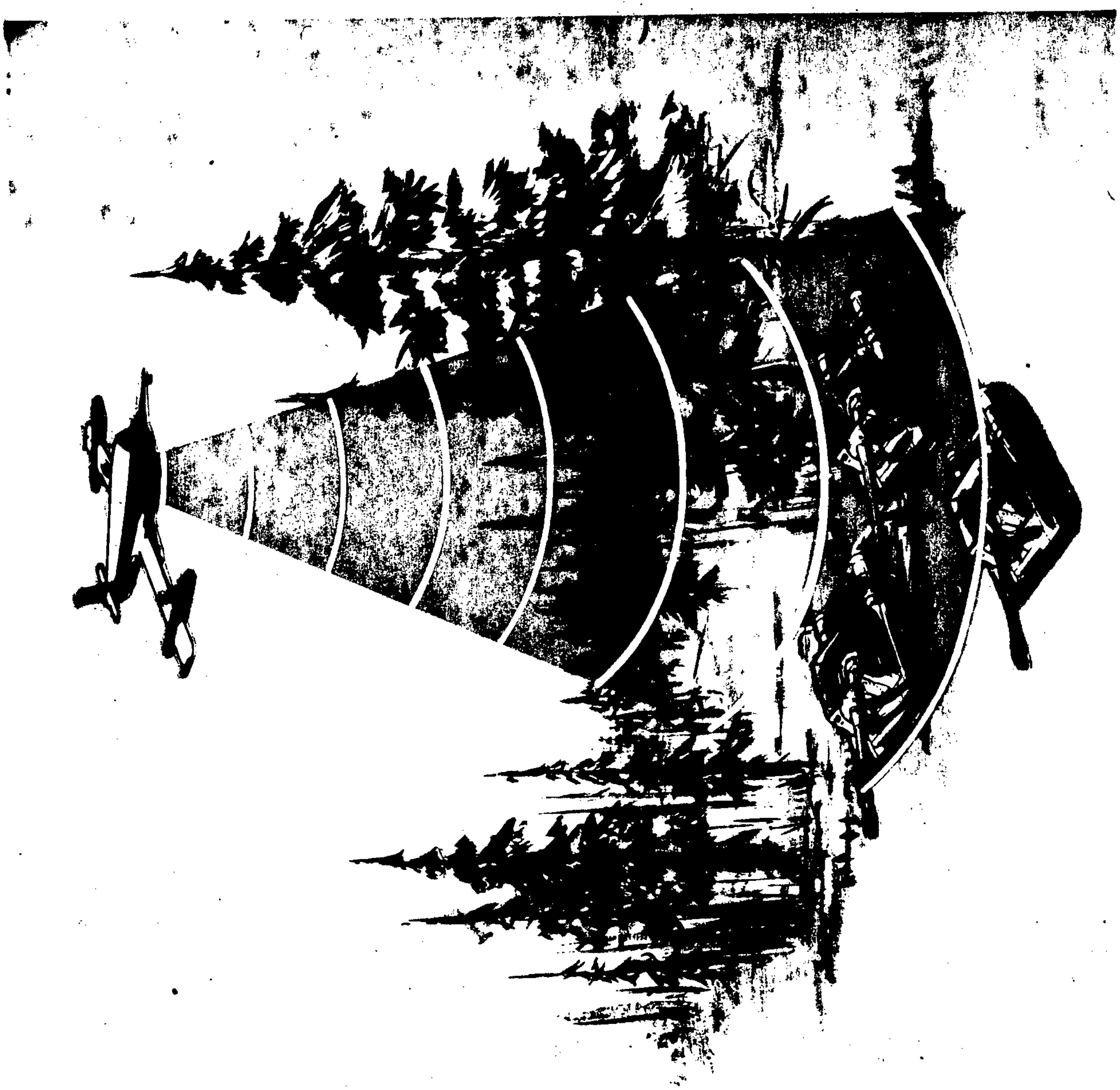
SLIDE 16

TARGET DEVELOPMENT

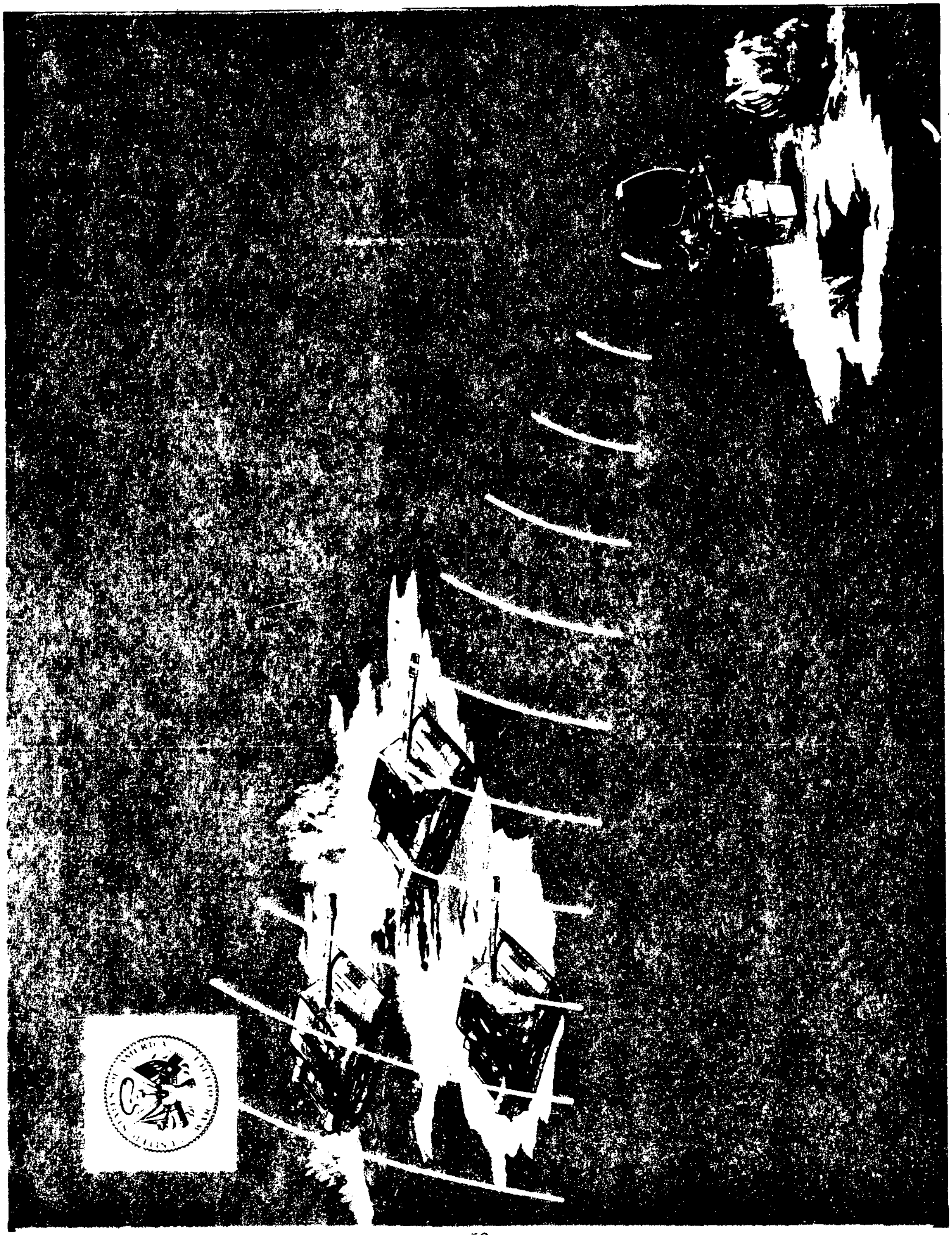
SLIDE 17



SLIDE 18

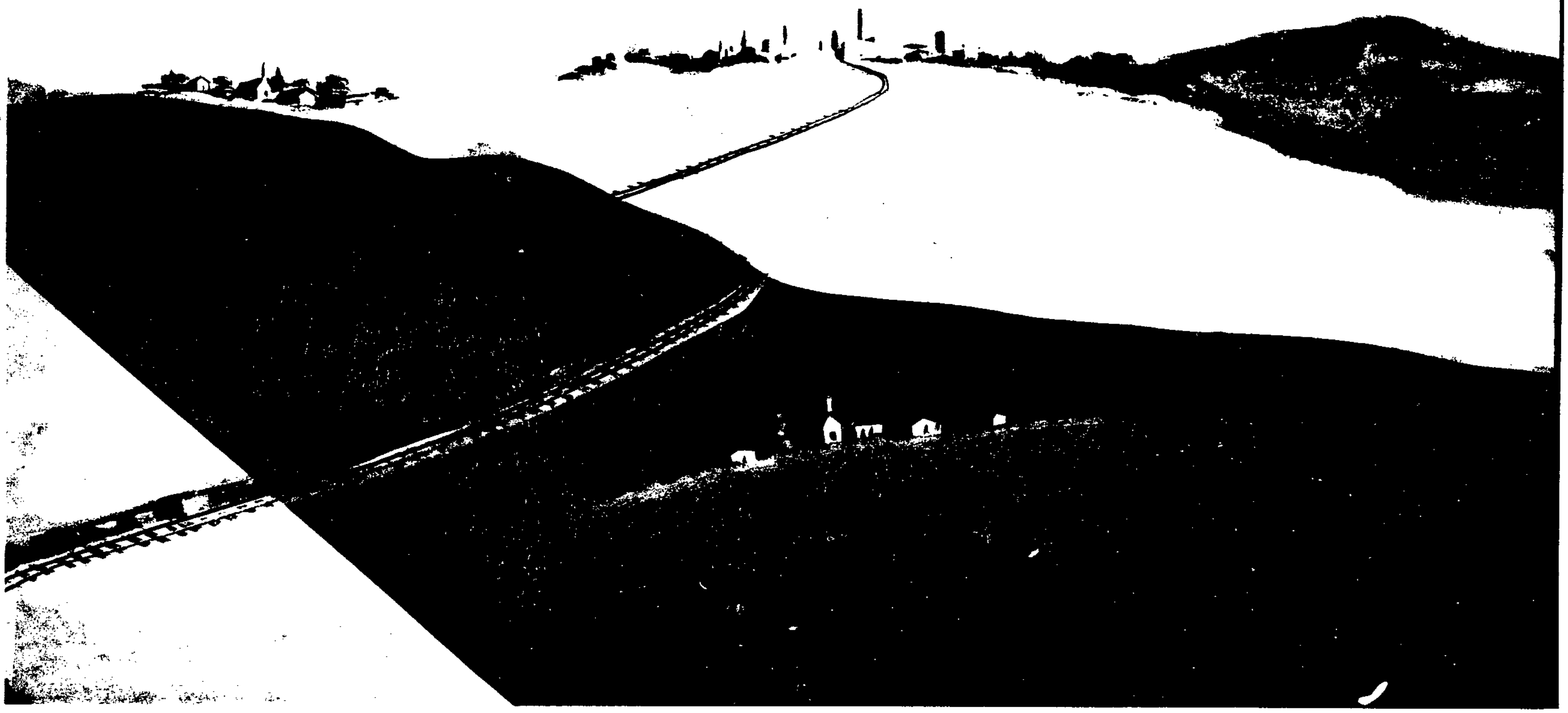


SLIDE 19


SLIDE 20

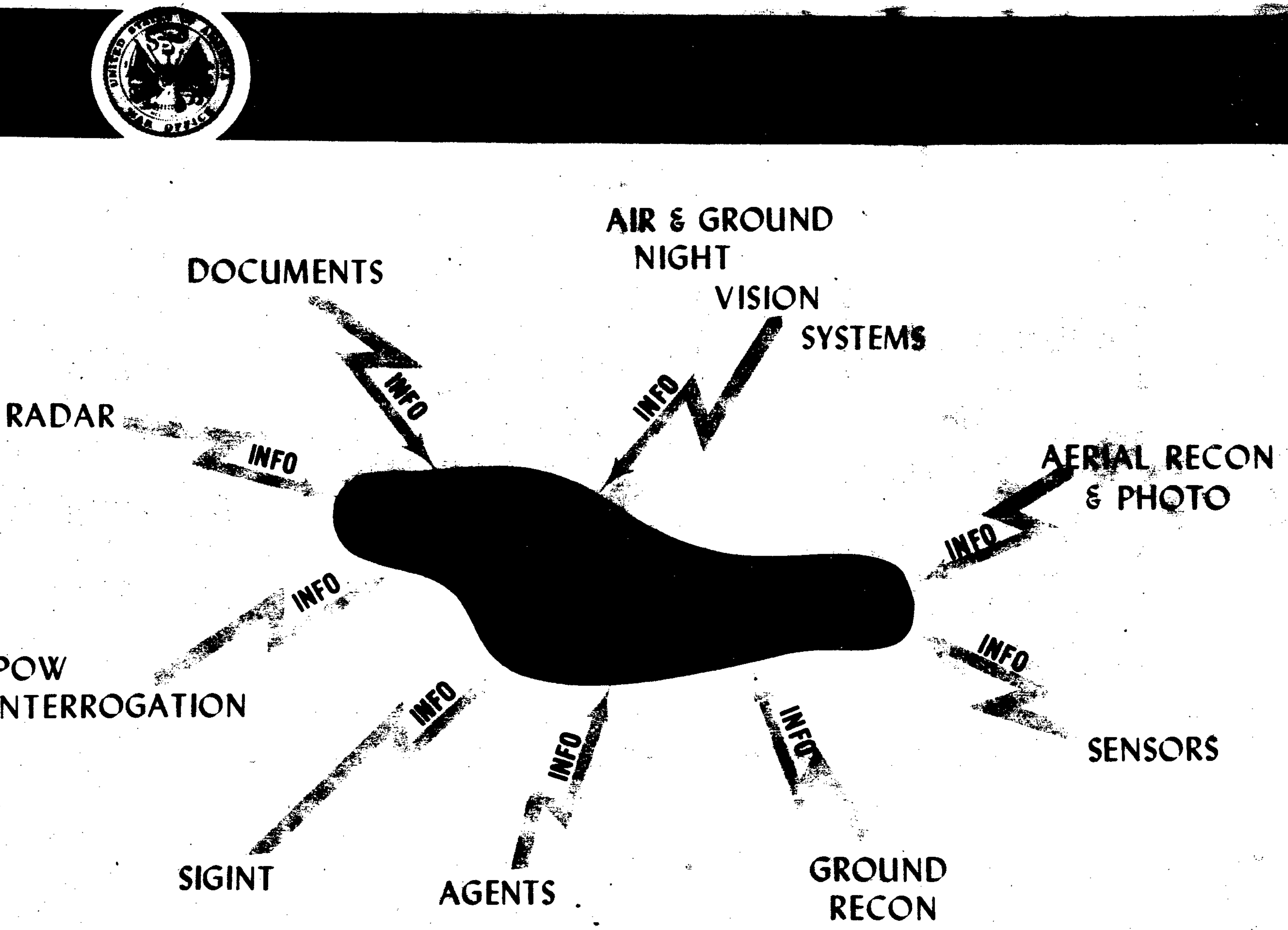
SLIDE 21

TARGET DEVELOPMENT



SLIDE 22

SLIDE 23


DOCUMENTS
AIR & GROUND
NIGHT
VISION
SYSTEMS
RADAR
AERIAL RECON
& PHOTO
POW
INTERROGATION
SENSORS
SIGINT
AGENTS
GROUND
RECON
INFO
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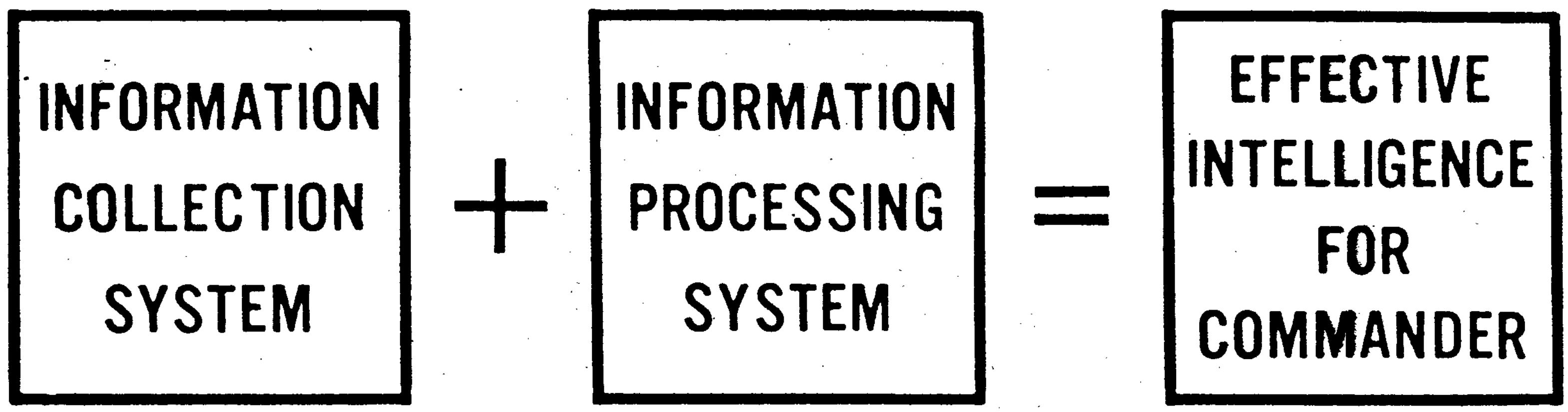
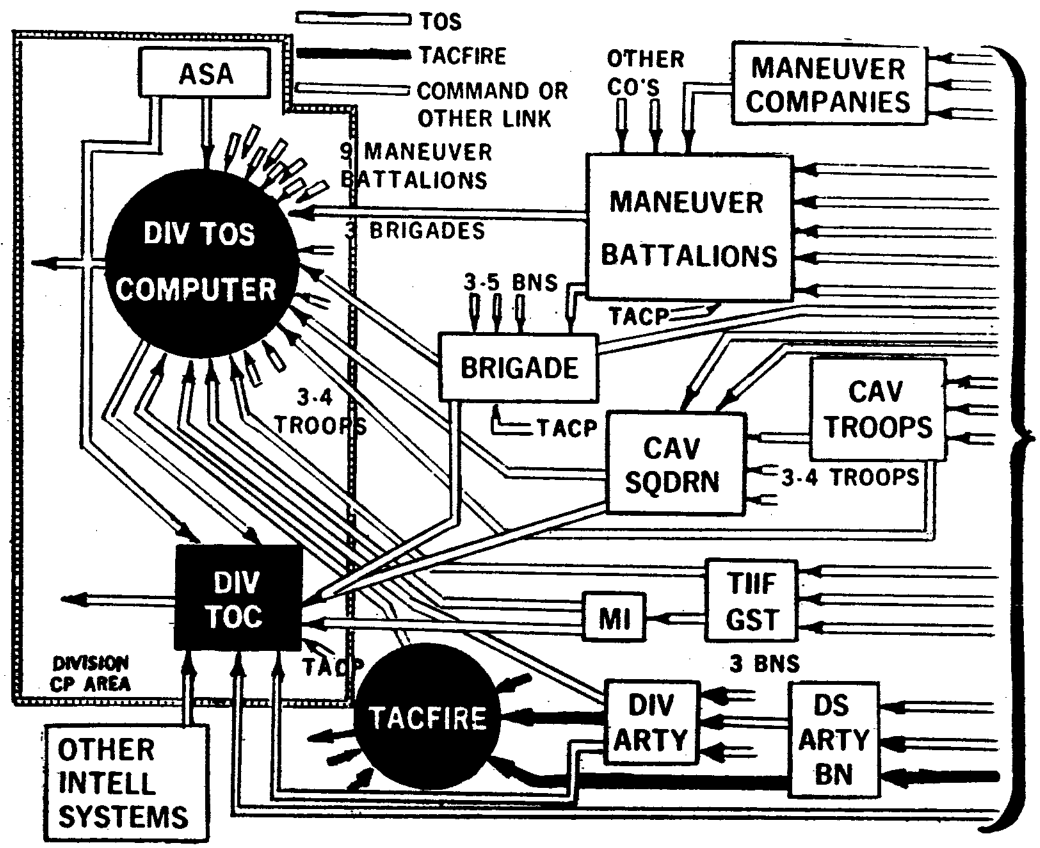
SLIDE 24

RECONNAISSANCE AND SURVEILLANCE



SLIDE 25

STANO INTERFACES



STANO SUBSYSTEMS

- SCOUTS
- PATROLS
- OBSERVERS
- ARTY FO's
- HELICOPTERS
- FIXED WING ACFT
- GROUND RADARS
- ARTY RADARS
- SENSORS
- NIGHT VISION SYSTEMS
- DRONES

SLIDE 26

A REVIEW OF THE POSITION LOCATION/NAVIGATION SUBSYSTEM OF IBCS

Mr. Manfred Gale, OACSFOR

There are many subsystems to the overall battlefield control system and we have had a tendency to emphasize the obvious - STANO, communication, ADP, command and control; however, I want to address briefly an equally important but often neglected subsystem: Position location/navigation - the forgotten dimension of IBCS. Where are we? Where are we going? Where is he? (SLIDE #1)

The predominant common denominator of the battlefield is time - time to assess, time to decide, time to locate, time to communicate, engage, disengage, negotiate......and since the time available is an ever shrinking function for military engagements, the ability to act in an environment of high mobility depends much on the ability to navigate and determine locations of manenver elements. Furthermore, the success with which enemy targets can be effectively engaged is critically dependent on real time location parameters, particularly since the perishable nature of these targets is continuously increasing.

Within the concept of the Integrated Battlefield Control System, we nect like to consider some of the key elements which are concerned with the execution of position fixing and navigation tasks. (SLIDE #2) The project manager NAVCON, has the primary Army responsibility for hardware; this is closely coordinated with targeting and location requirements of STANO subsystems, surveying and geographic/intelligence missions of TOPOCOM, and the future implementation of Satellite-based techniques.

Faced with some forty, or so, different position navigation requirements, the Army in 1970 set its sights at providing a common system to meet as many of the requirements for navigation and position fixing as is possible, within the constraints of systems/cost effectiveness. The long range aid to navigation (LORAN) system has been selected as the common system for the 1975-85 time frame. (SLIDE #3) User equipment will be developed within three subsystems: airborne, manpack vehicular, and marine. The LORAN airborne system has top priority in the position location program. This equipment will provide the primary navigation capability for Army aircraft in the post-1975 time frame. The LORAN manpack vehicular subsystem will provide enroute navigation for Army watercraft. Exceptional requirements, which cannot be satisfied by LORAN, will be met by special subsystems. As an example, a lightweight, low cost, navigation device may be used in certain critical cases where a self-contained capability is essential. An inertial device may also be used to augment LORAN and the follow-on satellite navigation system. Also, specific vehicular application may have selected needs for other self-contained systems such as the magnetic and gyrocompass automatic navigation systems.

To date, we do not have a complete functional system definition which could be applied in an effectiveness analysis of the common system, from the point of view of optimizing cost, training, and performance.

I want to discuss briefly some "common" tests which were conducted in November 1970, at Clemson, S. C., using initial models of the Army's LORAN position fixing navigation set AN/PSN-4. (SLIDE #4) The PSN-4 includes a self-contained, manportable, fully automatic LORAN C/D receiver. It is constructed using advanced design practices including Microelectronic Modular Assemblies making feasible the lightweight, low-power design.

Unlike earlier LORAN receivers designed for shipborn use, this receiver uses no mechanical servos and requires no operator assistance to receive, lock-on, and track LORAN signals. Once certain LORAN chain parameters are inserted into the receiver; when first entering a chain, the sets will function without operator assistance.

The time difference codes are fed to the coordinate converter which changes time difference A and time difference B data into Universal Transverse Mercator map coordinates that can be used to plot present position on U.S. Army Military Grid Reference Charts. The coordinate converter is a special purpose computer with stored reference data. The converter receives time-difference data from the receiver unit, and sends UTM data to the receiver unit, where it is applied to the digital transmission circuit and the UTM display.

PSN-4 demonstrated that it is suitable for use in moving tanks and automobiles as well as in manpacks. At Clemson the PSN-4 was operated in both vehicles without any degradation in performance. The search and settle time was the same in the tank and automobile as it was in the backpack. The presence of the vehicles did not appear to cause anomaly although some care must be exercised in antenna placement to insure this. The PSN-4 tracks well in moving vehicles in spite of the fact that the PSN-4 Control Indicator averages 100 repetition intervals. The position readout represents an average of where the receiver was located during the last 10 seconds. In slow moving vehicles this averaging is not of particular concern. When precise dynamic position data is required in fast moving environments, such as aircraft, a different display which doesn't average and presents both time-difference numbers simultaneously, if necessary.

The PSN-4 will operate in aircraft without any modifications if an external antenna is provided. As in vehicular use, its performance is in no way degraded. The search and settle time is the same whether it is moving at high speed or standing still. Its second order tracking loops insure precise tracking at all aircraft velocities and its short time constants prevent losing lock in maneuvers and wash out any lag in a few seconds. These design parameters are an integral part of the LORAN Receiver design of the PSN-4 and are well suited for aircraft operation. The Control Indicator portion of the PSN-4, however, is not suited for aircraft for the reason cited in connection with the vehicular application. Another Control Indicator without averaging and with dual time-difference display is recommended for aircraft use.

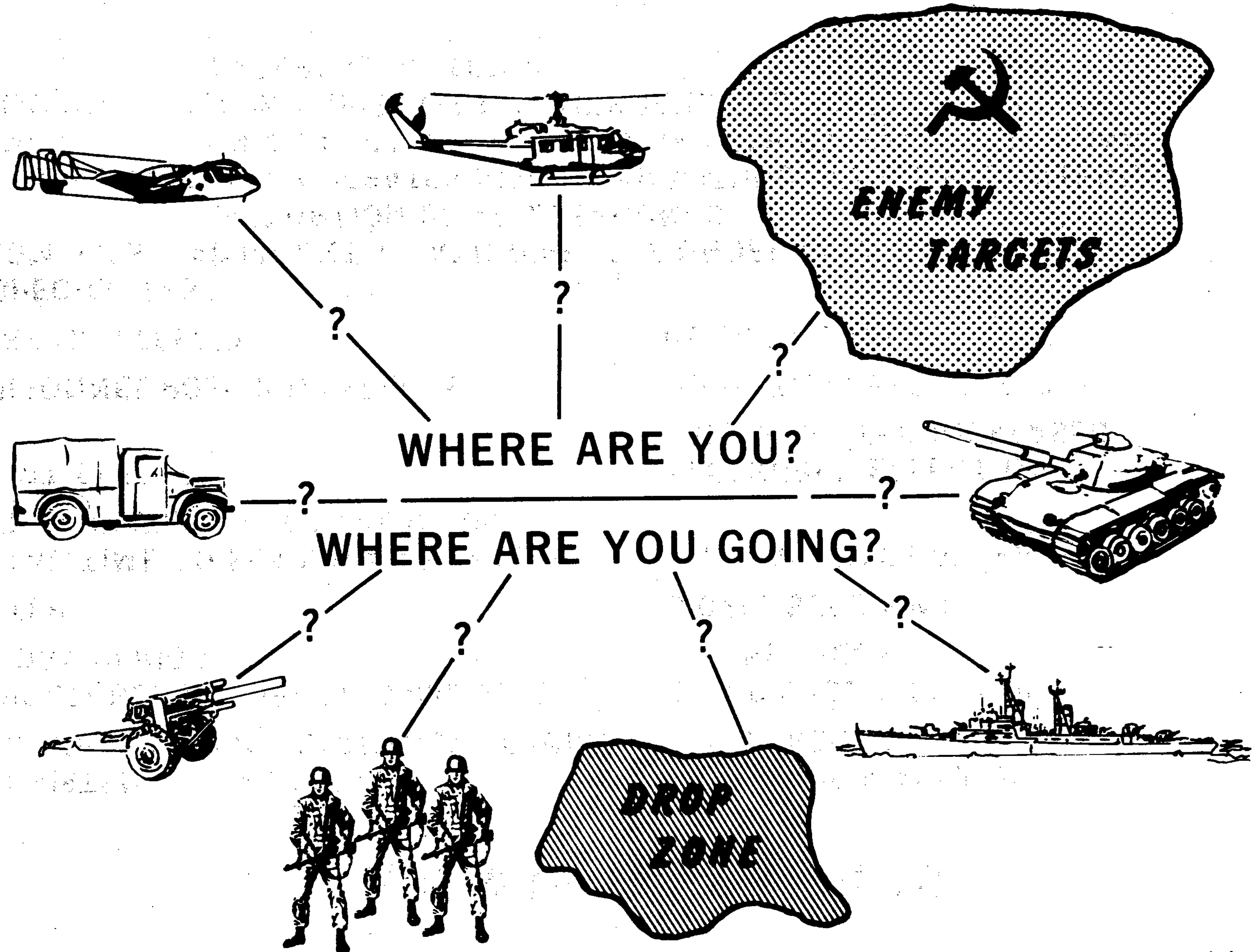
The overall results of the Clemson tests are shown on this slide. (SLIDE #5) Please note that the change in TDA is equivalent to a repeatable accuracy of 73 feet and the change in TDB is equivalent to 29.5 feet.

Another particular application of position fixing capability is basic to the functioning of the computer assisted Flight Operations Center. (SLIDE #6) This center is part of the Air Traffic Management System of IBCS.

The ATMS program responds to the Army's need for improved air mobility by providing a system which assures the safe orderly flow of air traffic over the combat area and provides the means for coordinating all airspace useage while imposing minimum constraints on the tactical commander's use of his aircraft assets. The required operational characteristics are shown on the next slide. (SLIDE #7) The system will consist of a family of ground communications and regulation facilities, airborne equipment, including navigation instrumentation, and system interfaces. The system makes use of state-of-the-art advances in computer technology and high speed, digital data, over the horizon communications to accommodate the high density of low flying aircraft operating in the field Army. The attended area tactical landing system is the highest priority item in the ATMS program. Other major components are the airport terminal control facility and the flight operation center. The application of automation in ATMS is considered essential for safe and efficient operation of Army air vehicles in a combat environment, and the requirement for real time position knowledge is critical to the success.

We don't know all that the rapidly developing technology will furnish us in the future, but it is quite certain that Satellite systems (SLIDE #8) will play an important role. There are speculations that we may have either low, medium or synchronous orbits; also, how many will be deployed in order to keep the updating cycle within a reasonable time is still being studied. I have shown here the Air Force's candidate of an XYZ, velocity and time indicating satellite, which depends on master station updating for data accuracy.

In conclusion, again, I invite your attention to the problems of assessing the effectiveness of integrating advanced future systems with the Army's program (SLIDE #9), in order to accomplish those important position location missions. The preparation of the material need documentation for a common system has brought the location dimension of IBCS out of hiding; we intend to keep it that way.


ENEMY TARGETS
WHERE ARE YOU?
WHERE ARE YOU GOING?
DROP ZONE
#1

SUMMARY OF RESULTS

CONSISTENCY (TWO PSN-4'S COLLOCATED, SIMULTANEOUS READINGS)	10 METERS MAXIMUM DIFFERENCE
REPEATABLE ACCURACY (SAME SITE 4 DAY PERIOD)	TDA 0.073μ SECS; TDB 0.059μ SECS
JITTER	0.020μ SECS RMS
TOTAL TIME TO SEARCH AND SETTLE (FROM POWER ON TO VALID TDS)	3 1/4 MINUTES AVERAGE
NIGHT EFFECT	NEGLIGIBLE EFFECT ON MEAN: JITTER INCREASED
PERSONNEL POSITION EFFECTS	NO NOTICEABLE EFFECT
TERRAIN EFFECTS	NO NOTICEABLE EFFECT

SPECIAL TESTS

ANOMOLIES	ADJACENT TO AND DIRECTLY UNDER POWER LINES DISTORTION UP TO 2μ SECONDS
AUTOMOBILE	PSN-4 OPERATES INSIDE CAR WITHOUT EXTERNAL ANTENNA
TANK	PSN-4 OPERATES INSIDE TANK WITH EXTERNAL ANTENNA
HELICOPTER	MARK 1 OPERATES IN AIRBORNE HELICOPTER WITH EXTERNAL ANTENNA

#5

REQUIRED OPERATIONAL CHARACTERISTICS

Large Traffic Handling Capability

No Degradation In Traffic Handling Capability Due To Weather

Means For Tracking Large Numbers of Aircraft Below Groundradar Coverage

Full Compatibility With Air Defense Units

Close Control In Terminal Areas

Compatible Landing And Taxiing Aids

Full Compatibility With Cooperating Air Force, Navy and Marine Units

Mobile, Easily Deployable Ground-Based Units

Full Compatibility With Existing Communication And Data-Link Networks

Compatibility With Aircraft Navigation Subsystems

Minimum Degradation Of Aircraft Security

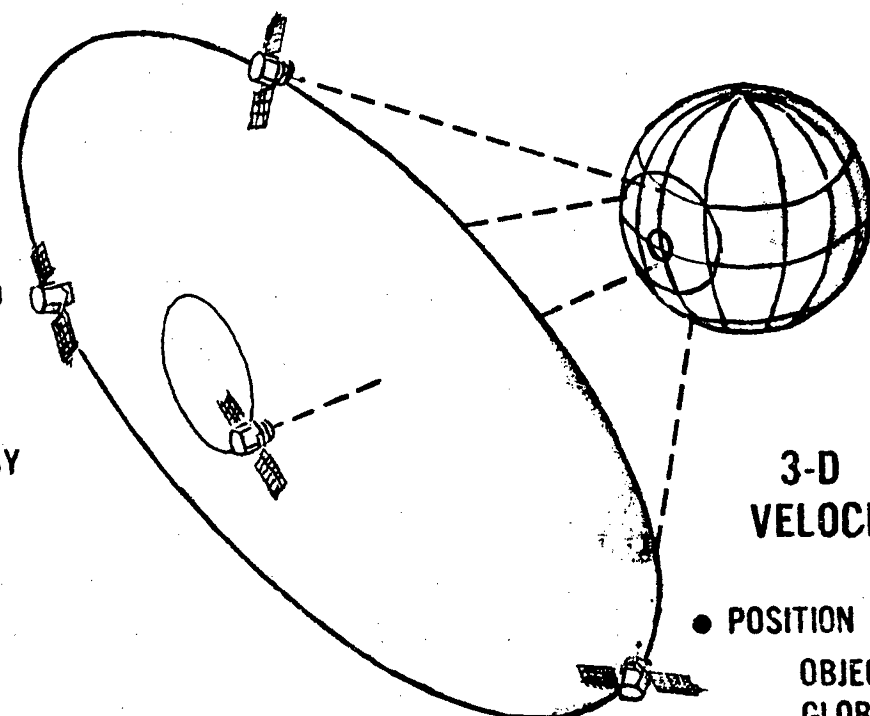
Capability Of Operating In An ECM Environment

Minimum Aircraft-Mounted Equipment, Preferable Multifunction

7

SYSTEM TECHNIQUE

- EARTH SYNCHRONOUS ORBITS
- SATELLITE POSITION:
  MASTER STATION RANGE & RANGE RATE AUGMENTED WITH MONITOR DATA
- NAVIGATION SIGNAL GENERATED BY SATELLITE, UPDATED BY MASTER STATION



3-D POSITION, VELOCITY, & TIME

- POSITION ACCURACY
  OBJECTIVE AREA ~ 10-100 FT
  GLOBAL ~ 100-400 FT
- VELOCITY ACCURACY ~ < 0.5 FPS
- SYSTEM TIME ~ 100 N SEC

8

POSITION LOCATION MISSIONS

- PATROL LOCATION
- POSITION FIXING
- DESTINATION LOCATION
- TACTICAL ENROUTE (A/C)
- TARGET LOCATION
- AIR DROP ZONE
- FIELD GROUPING
- ARTILLERY SURVEY

#9

INTEGRATED BATTLEFIELD CONTROL SYSTEM

Dr. Marvin E. Lasser
Chief Scientist, Department of the Army
Office, Chief of Research and Development

Closing Remarks

As we examine the problem areas that have been discussed by the previous speakers, there is an obvious, but perhaps not well-understood, solution to a significant portion of the problem. This solution is to turn to computers. The problem then is: which computers to do what? To illustrate the magnitude of this problem, I will outline the uses and potential interoperability questions associated with the large computer systems that are presently under various stages of development. I will briefly discuss each system, and then suggest some ways that we might proceed to include the present Army efforts to manage the tactical ADP program.

The Army is developing the first full-capability computer to automate a major portion of the artillery tasks. I am referring to the TACFIRE computer system. The comparative capabilities of the TACFIRE to the presently fielded system called FADAC is often not too well understood.

The FADAC, primarily, serves the functions of solving ballistic trajectory and survey problems as compared to the tasks that TACFIRE accomplishes that include ammunition and fire unit status, fire planning, artillery survey, artillery target intelligence, distribution of meteorological data, and tactical and technical fire control.

For the particular interest of this audience, I would like to point out that, at least as far as I know, there is no cost-effective analysis of TACFIRE that adequately covers the total system capability that TACFIRE provides. The cost-effectiveness studies that have been performed are related to the time it takes for artillery to respond to a given fire mission. On this basis, it is argued that the TACFIRE pays for itself because it can greatly increase the responsiveness, and therefore the effectiveness, of artillery. I believe this conclusion is correct, but not all of the capability, such as, target intelligence and the value of preparing fire missions plans, is considered in the cost-effectiveness studies that I have seen.

One of the significant challenges for this audience is: how do we perform cost effectiveness studies on new computer systems such as those we are discussing today? The principal difficulty appears to stem from a lack of precedence with which to relate. Therefore, innovative techniques are necessary if we are to optimize cost effective solutions, not only within complex ADP systems, but more especially among these complex systems.

An area of further interest concerns the considerations for expanding the role of TACFIRE, and the arguments are quite straightforward. The computer clearly has the capability to do a number of jobs. At one time, it was suggested by the artillery community that because aircraft form an essential part of the artillery system, we certainly must exercise traffic management of the Army aerial artillery. Whether or not you believe that aircraft are part of the artillery is not the question I think we should worry about too much, but I do think that the computer system has the capability to provide traffic management of aerial artillery, or whatever you care to call it. However, before we move out and acknowledge that the TACFIRE should assume this rôle, let's look at what else is coming along in the way of ADP systems.

The next ADP system to become available (and I am assuming all schedules are as envisioned today) - is the AN/TSQ-73 air defense system. The function of the TSQ-73 is to handle the data that are required for air defense. It provides tracking information on enemy and friendly aircraft and relates the capability of the air defense weapon systems to engage the enemy threat targets. Another way to look at the TSQ-73 function is to say that its task is to track enemy and friendly aircraft - differentiate between these - and assign missiles to attack the tracked enemy.

Let's go back now to the question of traffic management of friendly aircraft. I said before that it was proposed that TACFIRE provide traffic management of the Army gun-ships in their role of aerial artillery. Of course, aerial artillery is only a small portion of the air mobile function. It, therefore, appears reasonable that a system like the TSQ-73, that is utilized to track enemy and friendly aircraft, could also provide the ADP support for the air traffic management system. This has, in fact, been considered by the TSQ-73 Program Office.

Let's move on to another system known as the TOS, or Tactical Operations System. The TOS provides a whole new capability to control and monitor the great wealth of data that are normally assigned to the G-2 and the G-3 on Army staff organizations. To explain a little more what is meant by these terms; let me first mention the initial functional areas that TOS is intended to address. These three areas are: (1) enemy situation, (2) friendly situation, and (3) air operations. The enemy situation encompasses the identification, description, location, activities, losses, and capabilities of enemy troops, weapons, installations, equipment, fortifications, and obstacles, to include enemy tactical air support. So, you see that it pretty well covers much of what the G-2 has to know. The friendly unit information pertains to disposition, identification, activity, status, location, and task organization of combat units. So, you see it is involved in much of the G-3 operation. The Army air operations aspect involves the collection, maintenance, and use of data pertaining to the current location, availability, status, capabilities configuration and current and projected employment of aircraft. Let me emphasize here that the TOS does not provide aircraft control but essentially handles the logistic aspect of air operations by describing the status and location of aircraft rather than the control of airborne aircraft. I understand that this is normally a G-3 function, but, for example, it is also the responsibility of the Airspace Control Element as part of the division Tactical Operations Center (TOC). At the danger of sounding repetitious, I am forced to admit that the control of air space has been proposed by TOS proponents as one of the tasks that they should carry out. In fact, it was high on their list of priorities of tasks that the TOS should assume.

A listing of additional functional area descriptions, which have not been approved but that can be applied to the TOS, are:

Order of Battle	Nuclear Strike Effects
Tactical Air Support	Weather Data
Counterintelligence	Hostile Air Defense
Strategic Intelligence	Airfield/Heliport Location and Status
Tactical Troop Movement	Intelligence Collection Management
Communications Planning	Target Intelligence
Electronic Warfare	Engineer Construction Status
Chemical Contamination	Biological Contamination
Nuclear Fire Support	Preliminary Target Analysis
Nuclear Target Analysis	Chemical Target Analysis
Fallout Prediction	Air Defense Information
Tactical Gap Crossing	Barrier and Denial Operations
Psychological Operations	Airspace Coordination
Terrain Intelligence	Nuclear Fire Planning

The need for accurate position location, as discussed by Mr. Gale, becomes more apparent as we develop the TOS operational requirements.

I think that maybe now the point I am trying to make becomes clearer. We have to decide how we are going to allocate our computers. There is another very important and closely related question. That is, how many different types of computers do we need? The functions tend to overlap, although I must quickly point out that there are certain truly separate tasks for TACFIRE, TOS, and the TSQ-73.

At this point, I will briefly mention the large logistical and personnel data handling system known as the Combat Service Support System (CS_3). I must point out that a significant portion of the friendly situation will be produced in the CS_3, but that only summary information will be available and displayed in the TOS. The problem then arises of how to select this summary information and how to transfer the information between the CS_3 and TOS.

Now, let me complete the list of computer systems. There are only two more large systems of the size I am discussing that are being considered, and in each of these cases the ADP subsystem may only control a portion of the total system. The first of these is the ATMS or Air Traffic Management System.

If the Project Manager for that program is here in the audience, he has, undoubtedly, become concerned because it's just his system that I said that the TACFIRE, the TOS, or tht TSQ-73 computer could readily take on. I am sure he would want me to point out, though, that there are aspects to ATMS that have not been considered in the other three systems that I mentioned. For example, ATMS includes things like control towers. It requires high frequency data links so that we can communicate with aircraft that are flying "nap of the earth". The AN/TSQ-73 doesn't have the capability to control "nap of the earth" aircraft because it obtains its information from radars and these can't monitor the low-flying aircraft. We could now, probably, get into an endless debate as to whether one data system should assume the air traffic management function in addition to its primary mission, or whether tasks are so different that they should be done separately. It's pretty clear, though, that as far as the computer is concerned, there really isn't that much difference in looking out from inside the computer.

The final system I have on the list to mention is known as Tactical ASA Combat Support for Intelligence and Counter-measures (TACSINC). Its task is to assimilate the sort of intelligence that the Army Security Agency develops. TACSINC is a little different from the other systems in that it gets into an area that most people either don't understand or aren't allowed to understand because of security classification. If we propose that TOS take on the TACSINC role, this security question raises its head. The argument could be stated that: "We don't intend TOS to be a classified system." Let me take the other tack and say that we can not allow free access to the TOS, because the centrally generated collection of data will be extremely valuable. In fact, we know that's the case. The question that remains to be addressed is: "Do we handle the TACSINC information differently than we do the TOS information?" To expand on this -- do we handle all the information the same way; that is, at the same security level, or do we handle it at different security levels? It's clearly a problem, but I can't help but think that it doesn't pay to go out and buy separate computers before we first consider how to best develop the interoperability of the various computers.

There is a relatively easy solution that is advocated by some people, but one that I, personally, am not particularly enamored of. The approach is this -- take a single one of these systems; and let us pick TOS as the example, and utilize it as the central information processor to bring together the information from all systems. I guess in my description I've gone a little bit too far in saying that it is proposed that all information go via TOS, but it certainly has been proposed that a great deal of what the commander requires should go into TOS -- so that if he needs information from the TACFIRE to understand the fire support problems. he should have that data fed into the TOS. Then, when required, he extracts it from TOS. This does go a long way towards handling the interoperability problem, but to me it has two disadvantages. First, it greatly, or potentially greatly, expands the data bank requirements for the TOS. Second, it does not address the more difficult question of what do you do at the operating level where it is necessary to exchange information between computers without concerning itself about what the commander himself needs? For example, the question of -- "Does the TSQ-73 and the ATMS transfer between them a great deal of information, a little information or what have you?" I think that the way to attack the interoperability question is to start at somewhat lower levels and consider how to make these systems work together. This, in fact, isn't really going far enough, but must consider how, in the limit, one computer could handle more than one task. The air traffic management function is but one of many examples that I could cite where one computer could, perhaps, effectively handle multiple functions. The choice should not be one based on who is the stronger proponent between the two systems; but, rather, how it should be done under the overall management consideration that makes the most sense.

Well, how shall we experimentally evaluate what it is we decide to produce? The current plans call for the delivery of prototypes of these computer systems to Fort Hood to get hands-on experience in order to learn how to interoperate and handle our computer resources. A great deal can be done by studies and, I suppose, we could probably argue either way, but I think that the problem is so complex that unless we develop some of the hands-on experience down at Hood, we really aren't going to be able to answer the questions that I've asked, or really, the larger questions, which I've implied that are directed towards -- how do we take this monstrous problem of handling different types of data for different people and decide who gets what equipment, who's in charge, and how is this information to be disseminated?

The first serious steps taken by the Army to develop answers to management questions were the establishment of the Directorate of Doctrine and Command Systems on the DA Staff and the Army Tactical Data Systems (ARTADS) Project Manager's Office. This latter office is now taking shape under the direction of Brigadier General designate A. B. Crawford as Project Manager. Each ARTADS Project Director functions as a Deputy Project Manager in his area of interest. The Configuration Management Office might be of most interest to members of this audience as this is the point at which hardware and software configurations as well as interface design are developed. The Systems Engineering Office has the mission of assuring standardization and interoperability among the ARTAD systems and of providing for the communications system that will carry the data. This office will also examine new techniques and approaches to solving the ARTADS technical problems on a long range basis.

Today we have attempted to project a feel for the enormity of the problems associated with fielding a system of the magnitude of IBCS, and how far we must go in order to insure a cost effective solution to its many facets. We sincerely solicit comments from all of you. The members of the session will now be available during a question and answer period.

SESSION II - DISCUSSION

Question # 1

COL LeMan: I am not sure I can phrase the question, but my name is Colonel LeMan. I've been associated with Army Command and Control Systems for about ten years. I think, and I hope, in response to General Norton's charge, we asked the question about 15 years ago in Project Michigan. I believe the Project was with regard to how we can use data processing within the field Army. I think this was about 1954-55. I think most of us here in the room have experienced the stages of evolution that our studies have brought us through from that period forward to include CCIS-70, ASAF and currently our ARTADS program. I think, from perhaps the outside, we have developed some experience. We have two things to worry about, one is our product and one is the organization which produces this product. I guess my question is - how can the Army, or can the Army, develop and operate and maintain a data processing system in the combat environment? What have we learned through this past 15 years and how can we apply that to our ARTADS program? What are the questions that we should be asking in terms of the technology or the science or the information sciences that we can apply to developing our product and which will be viable in the combat environment?

Answer:

Dr. Lasser: I think we've learned something, although I have implied we haven't in the way I presented what I said. I think we've learned that you don't start at the top and work down. You start down at the lower basic systems. I think we tend to forget the lesson that we learned in that large look, but the approach that we are taking at Hood is to start with subsystems, see how they operate, then look at how they inter-operate, rather than, as I understand it and before my watch, that it started from the top and tried to do all things to everyone. For example, in the TOS, it started out with that very long list. It was very difficult to get it down to three, and by the way, as you can well imagine, you can take the enemy situation, friendly situation, air operations and put everything back in. We are fighting that off. I think the only lesson that I think I can state is we have learned to keep it simple.

COL Bolduc: I endorse what Dr. Lasser just said and I think it might be useful if I were responsive to a narrower part of the question Colonel LeMan just proposed. I think the answer to what have we learned - have we gotten anything behind us now that we didn't have behind us before; I would take that off in five areas. You mentioned the 15 years that have elapsed since we started getting organized in this area, the CCIF, CCIS-70 and ASAF. I would point out that we are daily doing business with people who have behind them experience in those programs. We have several of them working in my own office with me now. We have Colonel Crawford, who has been in the business a good long time and we have, fortunately, in all of the agencies, which are now concerting their efforts, people who speak a common language by reason of their experience in these earlier programs. We hope that we are going to be able to profit from some of the lessons learned doing the good things better and avoiding some of the bad things.

So my first answer would be that we now have an inventory of people who understand the language better than we understood it before and I would put that as a big plus. Secondly, I would say that in the functional area - computer areas, I would point out that we have a good deal of experience with FADAC, which is helping us with our TACFIRE program. Similarly, we have had experience and this is my third point, we have had experience with the MSG-4 system, which is already deployed in terms of what we are planning to do with TSQ-73. We are actually building on the experience that we have already acquired in data systems which have been deployed. And in the case of the TOS, which is my fourth point, we have had extensive experimentation with civilian, not ruggedized type equipment. Control Data Corporation type equipment. And then in the EUROTOS experiments, we've been able not only to capitalize on the experience achieved in Europe, but we have also been able to get it back to Fort Hood and get it operating. MAASTER is now using that, experimenting with some of the studies. For example, a major test systems set now in progress - the MAASTER-3 test-is involving the use of what we use to call EUROTOS,the same equipment we now call developmental TOS, under the same project manager participating in the testing of MAASTER. We are in fact refining the functional areas that Dr. Lasser described-enemy situation, friendly situation, air operation, based upon our experience with EUROTOS, so we are building on that experience, fortunately. And finally, I would be consoled by a fifth point, which is that we have been able to get the benefit of considerable sustained high level interest on the part of some of the people here in this room already, as well as others who are not, but who are key actors in this game. In each of the major agencies involved in the effort, there has been a sustained high level interest, which is involved very frequent meetings and get togethers. In the 120 days I have had the pleasure to be with this program, I think I have been to about 120 major conferences, at which the principals were present and were expressing a strong interest and a decisiveness about getting on with the task, I thing is very encouraging. We now have a management structure which starts with a steering group which is chaired by the Vice Chief of Staff of the Army and who has already considered some of the aspects of the programs discussed, which consists of principals on the Army's Staff. We have also an Executive Committee meeting bi-weekly to sort out pieces and accelerate the coordination of identified problems and move on them swiftly. Then we have, as you mentioned, the Army Tactical Command and Control Master Plan (ATACCOMAP), while it is a fourth in a series of MAASTER plans, we get a lot of participation with the actors on preparation of this plan. We hope that since they are committed, they appear now committed to things that they feel that we can accomplish and we'll have a voluble structure, so that the visibility in the management structure, I would suggest is a change in the past. And these five factors would encourage me to be optimistic about the future, particularily if we can get the sustained backing of the people, like the people in this room, making in a determined way a significant step forth.

Mr. Gale: I just want to say that, Colonel, in fairness to your question, I think we're just now really planning experiments that will tend to define the required adaptability and flexibility of automatic data processing systems in the way in which it makes sense for the Commander and his Staff to actually use them. What I mean by this is, we talk about fads, like enemy situation, friendly situations and so on, as if they had some sort of holy water sprinkled over them. Precisely, what functions would serve the field best from a point of view of offering alternatives, decreasing response time and increasing effectiveness? This will have to be learned in tests. Now, what we have learned specifically though, in studies, is that if information is of a high degree of certainity that men tend to assemble this kind of stuff just about as well as machines do. However, as the certainity of the information decreases as to probability, and as more trends are introduced, the manual way of assembling that information becomes very difficult and it is probably in that area that Bessel has determined that computers would have the highest payoff. That's what we've learned on the positive side, but there still's a big gap in the so called man-machine, in this case, man-computer interphase.

Question # 2:

Mr. Taylor, Carlisle Barracks, USACDC Strategic Studies Institute: It seems to me that what you have presented for the midintensity level, largely solves all of the problems that were encountered in World War II, and if we fight it again, we will be much improved in our effectiveness. However, looking forward in the next 10 years or so, suppose we consider the likelihood of a tactical bigger level nuclear battle. Where are your systems then, their liability and their vulnerability?

COL Bolduc: I have been privileged to listen several times to, then Commander and now Captain Swanson, who has been involved in a Navy Tactical Data System efforts for some years now and he mentioned one day that the program was under criticism because the NTDS was using shipboard computers of the second generation - several hundred ships. And here he was in 1971 and there was all that third generation stuff out there. He is a witness - he testified that the people who are using the equipment are doing it so much better with that equipment than they would if they didn't have it, that the gap is not apparent to them. I would suggest that we are trying to take some modest steps here. Colonel LeMan was being very charitable when he pointed to the 15 years. I've been in the Army during that period and I'm a little ashamed that we are in fact that far behind where we ought to be. I think we ought to be up - indeed to your question and able to answer it. I think, in fact, we are playing catch-up. I think Colonel LeMan, as I said, is being charitable. I think he knows a good deal more about that than he wanted to state in rough terms. The fact is that we are quite far behind and we are not able to do some of the things that we have known for quite a long time that we need to be able to do. We are, in fact, making a very modest first couple of steps. Dr. Lasser pointed out that we are voluntarily limiting the initial bite we take on information. We're doing that with a very high level review. We have just been through one that lasted about six weeks in which we have been scrubbing these detail after detail in order to limit the first step. Another example of limiting the attempt is that we propose not to do anything about on-going systems, such as TACFIRE, do nothing to interfere or slow them down, so as not to introduce further delay. Another example, is that, as Dr. Lasser mentioned, on integration. We would hope not to start by integrating something that doesn't exist yet and then build the rest of it, which will then be integrated. Which is to say, we are working at the division problem and we are going to have to defer solutions to some of the other problems even though they ought to already be attacked now and as you point out, resolved. The fact is we are going to have to take small bites in order to get somewhere--start making some of those steops so we can make some progress. We are not prepared, I think, at this point to give you a reasonable answer to your question. I do not know how well we are able to meet with the problem the Tactical Nuclear Environment. I only know that we are not able to meet very well with the environment short of nuclear employment, and that we would hope to get better at that and hopefully we will then be better at the other portions.

Dr. Lasser: Let me answer one question this way and that is, interoperability implies backup. Interoperability implies that one computer can take over from another. I think this is an important aspect of interoperability that we always keep in mind. We want to be sure that the data is not in one system - not in one central computer. If the data can be interchanged, one can back up the other and we are no longer as vulnerable as we were. And I think that this is an important aspect that we always have in the back of our mind as we talk about this exchange of information.

Mr. Gale: The functional system definition for the IBCS doesn't exist. A process for deriving it and a methodology for getting there has been initiated, but in the concept of IBCS, as Dr. Lasser mentioned, this manual back-up system is part of the overall process. In other words, we recognize that centralization and vulnerability about which we are talking.

Mr. Taylor: Are we saying that we are accepting redundancy now as an integral part of systems concept rather than add-on logistical problems?

Mr. Gale: I can only say that we are saying this in concept. The system definition doesn't exist--so I can't talk about it.

COL Bolduc: There is a specific effort being initiated now, which will terminate in its first iteration in November. The effort is being conducted by Combat Developments Command and it has to do with the functional interoperability of the systems we are describing and it is going to be followed by a continuity of operation in order to pin down what back-up requirements, if any, are necessary in degraded modes. We do not know the answer to the question by any means; and you are quite right, Mr. Taylor, by putting a finger on it. It may be that LTC Galloway would want to talk in the target development aspect with regard to the pertinency of that to the nuclear problem.

LTC Galloway: I wanted to say something about that. I think that we are certainly moving in target development in reliance on the IBCS in the target development field with the whole point keyed toward nuclear warfare. But more than that, the other side of the house, the concept side - the doctrine side, we are all living right now under the world of the big word called constraints. I think that this is going to govern more than anything else. It is a problem of one of the sessions here in the symposium--how do we live and how do we do all the things you would like to have us do, or we would like to have us do, and still live in a world of fiscal constraints, manpower constraints? How do we put these systems into the field; how do we develop the redundancy we need; how do we prepare them for tactical nuclear warfare? We can come up with a system, you saw that CS3, it is a wonderful system. But like you say, that's not much of a mobile force to move around on a nuclear battlefield. How do we proceed from the CS3 to a shoe box computer system, still keeping in mind that we have to live in the real world. We can't always be stepping ahead, with the perfect being the enemy of the good. I think that is what we're trying to look to on the other side of the house. We've got to move ahead and come up with some sort of a computer system. So rather than looking back, we are looking forward; but we're trying to keep our finger on reality.

Dr. Lasser: Let me try to be as specific as I can to Colonel LeMan's question, where he was adding on; are we going into redundancy to maintain our capability? I think it is a gradual degradation similar to what the TACFIRE has now. We have battalion systems and division systems and they are in a back-up mode with lesser capability, and it is that general approach that is being considered. That is the approach we are taking, I should say.

COL Bolduc: It occured to me, Sir, that with regard to Mr. Taylor's question there are some specific questions aimed at specific systems for certain specific circumstances, the question of whether a computer system or computer assistance within a system is going to be nuclear hardened or not. Now you would identify quickly what the parameters are. The question is whether the tools that are being served are themselves hardened. For example, if you are going to talk about living on the nuclear battlefield in order to harden the system, then we must make sure we are hardening the system and not just pieces of it. So the question of hardening of specific pieces, like the computer, a portion of the system, is a very real question and there are different systems, having different parameters, for these purposes and some of them are perplexing when you want to adapt one to another. For example, in a succession of developments where you have gone one way with one and you wish to then adapt it to a further one. So it is a very real question--a very pertinent one.

Question # 3:

Pete Smith, Cost Analysis: Marv, I want to raise a question that I heard last January, and I'm a slow reactor, but the title IBCS perhaps it's a very bad one. We're not reaching very close to the stage of integration and we don't have a system. We are approaching it, I think, what we are doing down at Hood makes a lot of sense. But the thing that worries me, which I guess is a slow reaction to the statement that you recall from the statement from last January, we're going to be in terrible shape at the GAO for cost-benefit study or cost-effectiveness study on our IBCS.

Dr. Lasser: I guess I was warned at one time that we should call it the IBCC. I don't know what ever happened with that advice.

COL Bolduc: Mr. Smith, my interview with the GAO was two weeks ago. The GAO has already been to see me.

Dr. Lasser: Integrated Battlefield Control Concept. I think we have gone to the Congress and we have told people and we have stressed the point that it is not a system. You can't put one in the room, you can't carry it around in a briefcase and we will never have one laid out on the ground at Fort Hood. And the Congress, surprisingly, I think, has accepted it, at least at the committee level and the people that have talked are cautious about it. I think the special committee, under Mr. Cannon, cautioned the Army to be wary of moving rapidly around with an IBCS. They do recognize that we need some framework to group together these many phases and to make use of technology. We're beyond the stage where we can only do trade-offs at the very simple level and we're going to have to start dealing in the bigger picture. I think the IBCS is our answer to that.

COL Bolduc: I might make two very small points in regard to the title. It's an awkward acronym. It's not nearly as awkward an acronym as the acronym of the MAASTER plan, which we are putting out; but it at least has the merit of attempting to identify the intent--that is, we're not integrated, but we're not all that bad off and we're trying to improve. The title tends to focus more where we're trying to get. The second point is that if I gave the impression that we are not planning to go from a base line in answering, for example, Colonel LeMan, is quite clear. We don't want to go back to square one. It is also quite clear that

Caesar and Hannibal had command and control, and Napoleon had command and control, and we've got command and control today. What we are doing is not trying to invent it, but improve it. And when we pull those two together, we hope to have a title that would be descriptive. Incidentally, I would welcome any specific suggestions with regard to the acronym "dilemma". I think our telephone number is in the book. We would be delighted to get any that would meet the many requirements the good acronym should have.

Mr. Gale: Mr. Smith, it helps me maintain my sanity and it may help you too; I think of the IBCS as a process and not as a system. And the process being one of an evolutionary nature where we are trying to improve as technology and resources allow us to do so. I don't really see in the whole game any sort of step functions here, but rather a kind of a continuous improvement. We are certainly approaching the TOS in various phases that way and the whole set-up will be on an incline.

Question # 4:

Al Sober, CDC, Intelligence Control Systems Crew: I have a basic question as far as interoperability is concerned. Two areas, I believe that have not been properly addressed, at least to the best of my knowledge. One is the software compatibility, primarily for TOS and TSQ-73. They are pretty far down the pike and have been developed relatively in isolation. And the other is the software interoperability compatibility--there is not too much being done in that area.

Dr. Lasser: If that's your comment--that's our program. It's just the software problem that we are addressing. We are aware of the individual capabilities of the TSQ-73 and the TOS and the TACFIRE. It's the ultimate of making software compatible. I just don't feel it is correct to say that we aren't aware that that is the basic problem. And maybe I'm misunderstanding your comment.

Al Sober: I just wanted to raise this question because to the best of my knowledge there hasn't been enough emphasis put into the compatibility of the software. More talk has been about hardware aspects. And another point, that I want to make is the communications requirements. NSA standards are quite restrictive as to what we may have for remote input and output devices. They are all going to impact very severely in our communications area. I know that we have been talking quite a bit about interoperability studies, supposedly addressing all these questions. I just wanted to bring it to everybodys attention that this is really a can of worms that hasn't been addressed and should probably have been addressed a long time ago.

Dr. Lasser: Not only have you stated the problem, but more explicitly stated the problem of the ARTADS project manager - Colonel Crawford: he is located at ECOM, so he can have this communications back-up which is so integral to what he is doing. And he is responsible for not only tying together the hardware, but he's also responsible for tying together the software. What Computer Systems Command (CSC) does on software in these systems, the work they do, is reported to Colonel Crawford. He is responsible for the overall software. He is the one that has to see that the software is compatible and interoperable - or he isn't doing 10% of his job. The hardware is all the same computer, right now anyway. You know, there isn't more to be done up to a point. The computers we have now are all very similar. So getting common hardware is like a zero step. Getting common software is the step.

COL Bolduc: With regard to the two programs that are furthest down the trail, we would see them as being TACFIRE, then TSQ-73, then TOS, in that order by the calander. The software for the first two systems is prepared by the same firm, and there is considerable correspondence in such things as routines, maintainence, and that sort of thing, with regard to the software. There is about 45% or some percentage just short of 50% of the software that is identical. When they started TSQ-73 programming they used those portions of it which were already obviously useful and transferable, since the L30-50 computer happened to be the same computer. With regard to the software for the follow-on system, the systems engineering study, which is going to be conducted, is going to be for the purpose of identifying the software specifications that will then be a software effort. That software effort is going to be under guidance which will hopefully maximize the use of earlier software, so as to minimize the problem of having top software that will be non-interoperable. I hope that that's partially responsive to your question.

NOTE: The comment included in this section is not necessarily complete. It was necessary to delete some remarks as they were unitelligible on the recording.

A TECHNIQUE FOR GENERATING CORRELATED RANDOM VARIABLES TO MODEL BIVARIATE UNCERTAINTIES IN RISK ASSESSMENT

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Quantitative risk analyses may be classified into two groups; one consisting of cost/time analyses, the other consisting of multiple attribute performance analyses. In the cost/time analyses the structure of a project is modeled as a network consisting of arcs (activities) and nodes (milestones). A Monte Carlo simulation of this network determines cost and time uncertainty for the project based on cost and time uncertainties of the component arcs of the network as well as uncertainties in the structure of the network (e.g. nodes with stochastic outputs or nodes whose output depends on stochastic events in the network). In all of the network simulation programs familiar to the author, the time values for the arcs of the network are generated as independent random variables and the cost values are computed as a linear function of the time values. This is equivalent to generating cost and time values from a joint distribution with correlation coefficient equal to +1 or -1. Such a distribution has a line segment as its support. This procedure is deemed adequate by most users because in large networks this perfect correlation does not appear to any large degree in the joint distribution of cost and time for the entire project.

In performance analyses the usual technique is to obtain a set of performance equations expressing the performance parameters of interest (such as cruise velocity, maximum velocity, payload capacity, ceiling, range, and rate of climb) in terms of design variables (such as gross weight, operating weight, fuel weight, gross horsepower, shaft horsepower, coefficient of lift, and coefficient of drag). A Monte Carlo simulation is then used to express the uncertainty of the performance parameters in terms of the uncertainties of the design variables. In all such simulations known to the author the design variables are either generated as independent random variables, or some of the design variables are generated as independent random variables and the remaining ones are generated as deterministic functions (usually linear) of them. It is easy to see that the two situations described in the preceding sentence are equivalent. It is also easy to see the pitfall of generating design variables as independent random variables when in fact they are correlated. For example, one would not want to generate a value of 10,000 pounds for gross weight and a value of 10,500 pounds for operating weight for use in the same iteration of a simulation. It is the purpose of this paper to describe a technique for generating correlated random variables and to suggest a natural set of descriptors for the degree and nature of the correlation between two random variables.

Suppose we have two random variables X and Y. The functions commonly used to describe these random variables are f(x), the marginal distribution of X; f(y), the marginal distribution of Y; f(x,y), the joint distribution of X and Y; f(y|x), the conditional distribution of Y given X; f(x|y), the conditional distribution of X given y; $\mu_{y|x}$, the regression of y on x; and $\mu_{x|y}$, the regression of x on y. In addition, the correlation coefficient, ρ, describes the degree to which X and Y are linearly related. We remark that once f(x,y) is known, all of the other functions and parameters are determined. The goal is then to gather enough information about the random variables to construct a reasonable joint distribution of X and Y. One would be tempted to specify f(x), f(y), and the correlation coefficient ρ and try to build a joint distribution function from this information. The fact is that this much information far from specifies a joint distribution. The basic ingredient which is lacking is the nature of the correlation,(i.e. the underlying functional relationship between the two variables).

The elements we have chosen to construct a joint distribution function are as follows: f(y), the marginal distribution of Y; $m_{y|x}$, the mode of y on x; and a confidence band about $m_{y|x}$. The reason for choosing $m_{y|x}$ is that whenever it is known that two variables are related, one should know what the most likely functional relationship is. This is also the type of information that is most easily obtainable from an engineer or other technical expert. The confidence band about this most likely functional relationship gives the technical expert the chance to express the degree to which this correlation exists. The marginal distribution of Y should be no more trouble to obtain than for any other random variable. We recognize that an arbitrary choice has been made here since in general $m_{y|x}$ and $m_{x|y}^{-1}$ are not the same function if indeed $m_{x|y}^{-1}$ exists.

Figure 1 depicts the information we require to build the joint distribution function.

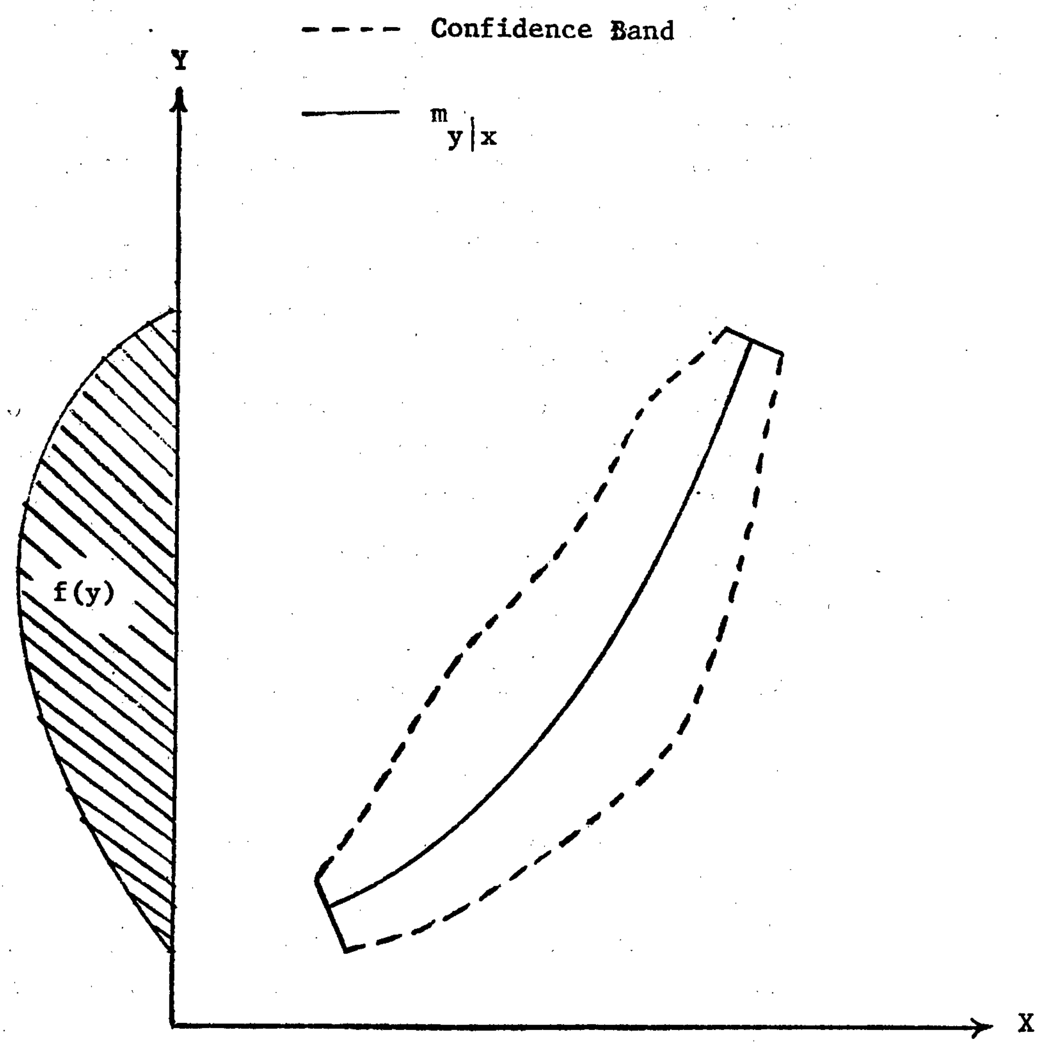


FIGURE 1

Note that we have regarded a joint distribution as a "vague" function in much the same manner as a marginal distribution is often regarded as a "vague" point estimate.

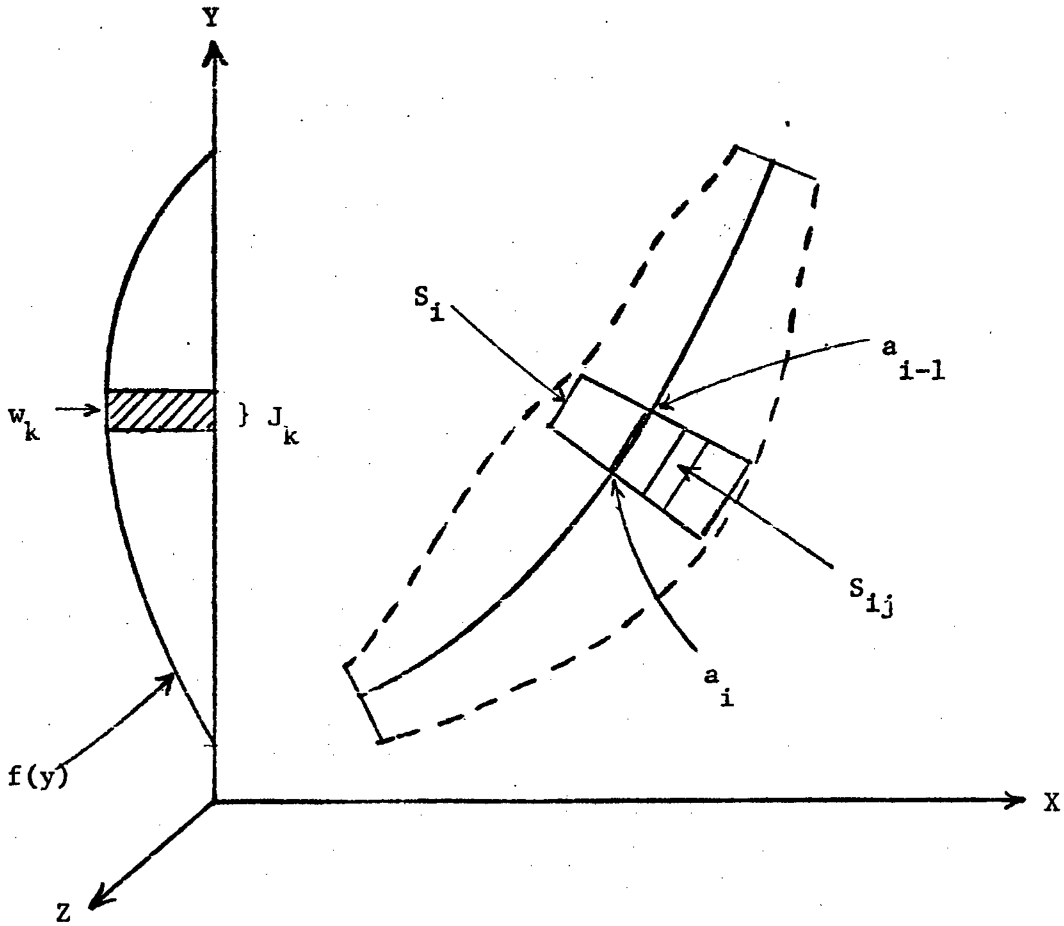
We now take the graph of $m_{y|x}$ and approximate it using a polygonal path where all of the segments are equal. For definiteness we use 20 segments. Label the endpoints of these segments consecutively: $a_0, a_1, \ldots, a_{20}$. Let B_i be the trapezoid whose not necessarily parallel sides pass respectively through a_{i-1} and a_i and are perpendicular to $m_{y|x}$, whose necessarily parallel sides are each parallel to the line segment having a_{i-1} and a_i as endpoints, and whose area is as large as can be for the trapezoid to be contained in the confidence band. Let S_i be the pentahedron of unit volume contained in the first octant having B_i as one face, two triangular faces each having an edge in common with B_i and containing exactly one of a_{i-1} and a_i, and whose only edge not intersecting B_i is parallel to and projects onto the line segment having a_{i-1} and a_i as endpoints. For each S_i, which we shall call a slice, we define for a positive number ρ_i, the set $\rho_i S_i$ by $\rho_i S_i =$ $\{(x,y,\rho_i z) : (x,y,z) \text{ belongs to } S_i\}$. What we shall do is attempt to determine ρ_i, i=1, ..., 20 so that the union of $\rho_i S_i$ for i=1. ..., 20 gives the volume under the surface of a reasonable joint distribution for X and Y. Note that

$$\sum_{i=1}^{20} \rho_i = 1$$

We now take each S_i and partition it into some finite number (we use 10) of subsets S_{ij}, j=1,...,10 so that their projections into X x Y partition the portion of B_i on each of the two sides of the line segment having a_{i-1} and a_i as endpoints into five trapezoids of equal heights.

As a final constructive step we take the domain of the random variable Y (as obtained from the specified marginal distribution f(y)) and partition it into 20 subintervals of equal lengths and call these subintervals $J_1, \ldots, J_{20}$. We set w_k equal to the area under the graph of f(y) which is above J_k for k=1,...,20. We also let $I_k = X \times J_k \times Z$ for k=1, ..., 20.

All of these constructions we have defined are illustrated in Figure 2.



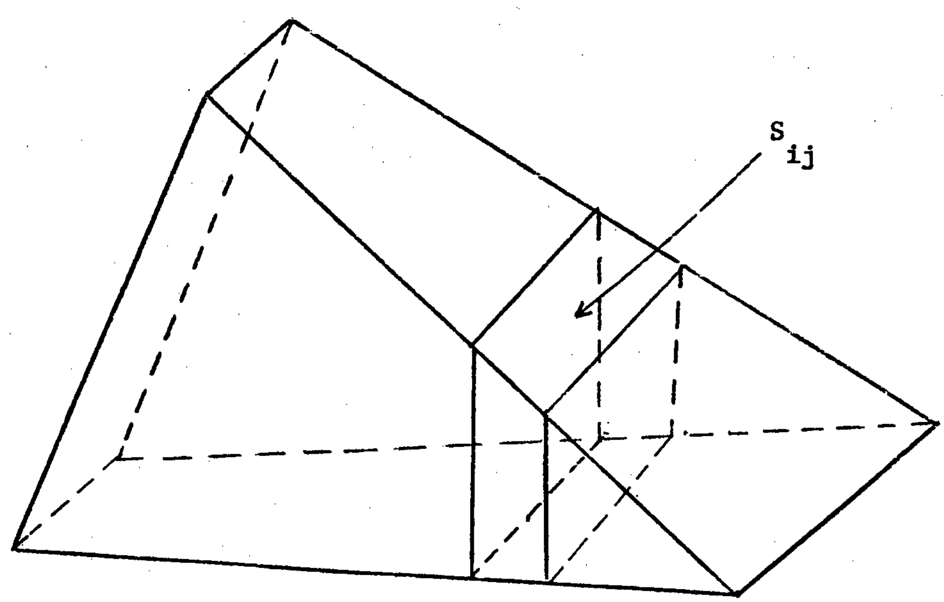


Figure 2

If we let μ be ordinary Lebesgue measure in three space then the requirement that f(y) be the marginal distribution of our joint distribution represented by the union of the $\rho_i S_i$ for $i=1,\ldots,20$ is approximated by the requirement that $I_k \cap (\bigcup_{i=1}^{20} \rho_i S_i)$ has μ measure equal to w_k for $k=1,\ldots,20$. Expressed in terms of our partitions this becomes:

$$\sum_{i=1}^{20} \left(\sum_{j=1}^{10} \mu\,(I_k \cap S_{ij}) \right) \rho_i = w_k \; ; \; k=1,\ldots,20$$

Note that this is a 20 by 20 system of linear equations, which can hopefully be solved to obtain the 20 weights we desire. There are, however, several circumstances which may occur, so far as we are aware, which may make this system of linear equations inadequate for our purposes. The system may have no solution; it may have infinitely many solutions; or it may have a unique solution in which some of the variables have negative values.

We recommend using a linear programming approach to find values for the ρ_i. Instead of using the above linear equations, we convert them to linear inequalities:

$$\left| \sum_{i=1}^{20} \left(\sum_{j=1}^{10} \mu\,(I_k \cap S_{ij}) \right) \rho_i - w_k \right| \leq \varepsilon, \; k=1,\ldots,20.$$

The parameter ε may be assigned any value as we intend to use parametric programming to see how small we can drive this parameter. There are other constraints which we may wish to impose in the interest of prohibiting undue oscillation in the sequence of ρ_i's. If the function $m_{y|x}$ has a derivative which lies in a narrow range, constraintsof the following form are appropriate: $\rho_i \geq .7\, w_i$, $i=1,\ldots,20$.

The number .7 could of course be replaced by any other convenient number between zero and one.

The constraint $\sum_{i=1}^{20} \rho_i = 1$ must also be included to insure that the total volume under the joint distribution surface is unity.

The objective function we use is $\sum_{j=6}^{15} \rho_i$. We use it twice; seeking to maximize it in the first case, and seeking to minimize it in the second. The idea in each case is to find an optimal solution for some value of ε and then perform parametric programming in which either ε is driven to zero or it reaches a value below which there is no feasible solution. In either situation we will arrive at two ultimate solutions; one for the maximization case and one for the minimization case. The ultimate value of ε in each case tells us how close we came to the desired marginal distribution of Y, and a comparison of the two solutions will give us an idea of how much variation is possible in the volume of the "middle half" of the distribution for the given constraints we have placed on the system. If the ultimate value of ε turns out to be zero in each case, then the specified marginal distribution of Y constrains the amount by which the two objective values can differ.

The advantages of using linear programming in determining the ρ_i are several. The ρ_i are guaranteed to be non-negative, and additional constraints can be introduced as appropriate. As an additional fallout we obtain an approximate solution when the desired marginal distribution cannot be achieved.

The only significant computation in this process for which canned computer programs are not readily available is that of finding the $\mu(I_k \cap S_{ij})$. This computation is facilitated by our constructions and can be easily adapted to a computer program.

RISK ANALYSIS VERSUS SYSTEMS ANALYSIS FOR THE MATERIEL ACQUISITION PROCESS

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SUMMARY

This paper examines the structure, theory, and methodology for the subject called analysis of risk for the materiel acquisition process. A generalized model for the analysis of risk is presented, plus some measures to quantify program risk, to show that risk is a new dimension in the decision-making process. The interface between risk analysis and systems analysis is exhibited by an example of a soft-recoil howitzer developmental program. The interface between risk analysis and decision analysis is illustrated by a second example involving an aircraft weaponization system.

I. INTRODUCTION

In the Department of Army, the materiel acquisition process emphasizes the flow of decisions and activities in the development and production of materiel which include actions, reactions, and interactions of government agencies and defense contractors [18]. There are four major phases in the materiel acquisition process: concept formulation, contract definition, engineering development, and production. In actual program decisions, uncertainties are very real and important complications; hence, a program decision should be more carefully stated as a "decision under uncertainties". A model has been constructed [1] which portrays the conversion of unknowns to knowns relative to acquisition time. Two types of unknowns were highlighted which affect the three key dimensions of cost, time, and performance: "the things you know you don't know at the start of the program" (known-unknowns) and "things you don't know you don't know" (unknown-unknowns or unk-unks). Decision making can be categorized into certainty-risk-uncertainty classifications [14]. The difference between the latter two is that the former subscribes to some known outcome probabilities of occurrences, while probabilities for the latter outcomes may not even be meaningful.

With the objective to improve the quality of analysis of cost, schedule and technical risks by optimizing the trade-offs among these variables and to provide an improved basis for decision, the subject called "analysis of risk" was formally instituted by the Department of Defense in 1969. The purpose of this paper is to examine the theory and methodology for the analysis of risk for the materiel acquisition process. The next chapter presents a generalized model for the analysis of risk, the relationship between risk analysis and systems analysis, and some measures to quantify risk. Chapter III illustrates risk analysis with an example involving a soft-recoil artillery system and exhibiting the interfacing between risk analysis and systems analysis. Chapter IV presents another example involving an aircraft weaponization system to show the interfacing between risk analysis and decision analysis.

II. SYSTEMS ANALYSIS AND RISK ANALYSIS

In the acquisition management, we observe that management is the process of converting information into action in terms of an information feedback loop [6]. With the constant need to make management decisions on some quantized basis, defense systems analysis erupted with the theme that defense is an economic problem in the efficient allocation and use of resources [7]. Reliance on systems analysis has been very heavy regarding the resolution of such questions as how much is enough, how should resources be allocated, and what trade-offs among doctrine, weapons, equipment, etc., are feasible for an effective defense posture. Systems analysis has been defined [21] as a systematic approach to help a decision-maker to choose a course of action by investigating the problem, searching out alternative routes, and comparing them in the light of their consequence under an appropriate framework to bring expert judgment and intuition to bear on the problem, without violating exogenous constraints imposed on the problem under study. One school of thought juxtaposes systems analysis and system engineering by establishing system performance objectives versus design criteria for system elements. Decision analysis has emphasized statistical decision theory merged with systems analysis; it is a logical procedure for the balancing of the factors that influence a decision. A generalized model for the decision analysis cycle [16] consists of three phases: deterministic, probabilistic, and information.

Risk analysis, on the other hand, is more concerned with the reduction of risk by risk assessment of technical problems, system and hardware proofing, and risk avoidance trade-offs [17]. The assessment of program success constitutes the basis for so-called risk analysis of a program. Risk analysis is defined as a disciplined process, essential to program decision making, involving the application of a broad class of qualitative and quantitative techniques for analyzing, quantifying, and reducing the uncertainties associated with the realization of cost, time, and performance goals of large-scale military projects. Here, a fourth dimension, risk, has been introduced which is used as a common measure to integrate the three dimensions and to effect trade-offs. Risk analysis can also be envisaged as "systems analysis of risk".

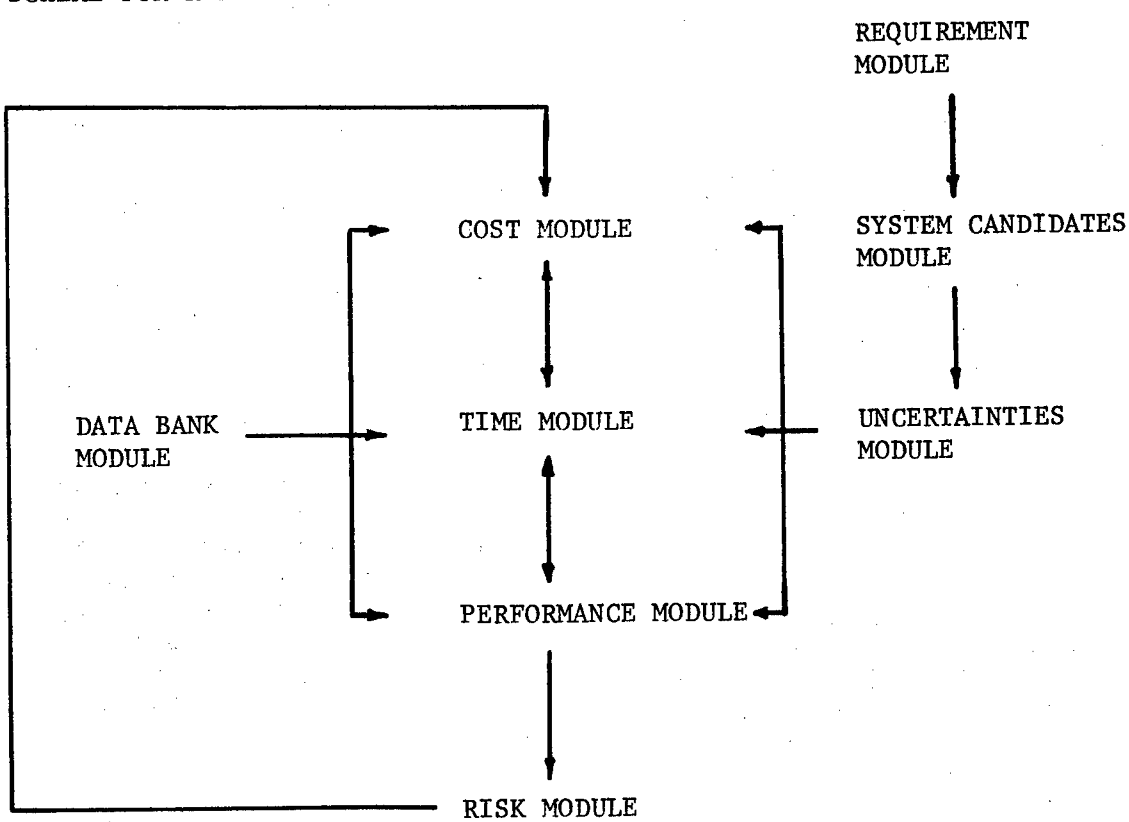
As a basic objective of risk analysis is to create a quantitative and experimental laboratory to generate synthetic information, the general methodology for a risk analysis is quite similar to the steps involved in systems analysis, systems engineering, or industrial dynamics. The steps include the following:

1. form risk analysis team
2. identify objective
3. state alternatives
4. collect data
5. construct model
6. simulate/apply model
7. validate model
8. obtain criteria and trends
9. construct module for manage information system

A typical team should be composed of systems analysts, program/cost analysts, and physical scientists/engineers.

Under the above general scheme, a basic modular approach for risk analysis is shown below with the intent that it may lead to a generalized risk analysis model. The System Candidate Module includes all system candidates under consideration. The Uncertainties Module represents the interface between the environment and the program. The Data Bank Module has two functions: provides a repository of information and data for the model, and serves as a mechanism for updating and maintaining current information. The data are normally in two forms: objective, available data from testing, data bank, or previous studies; and subjective judgmental data obtained from "experts". The Cost, Time and Performance Modules represent the three dimensions. Finally, the Risk Module specifies system risk.

SCHEME FOR RISK ANALYSIS - A MODULAR APPROACH



Risk analysis is by nature an interactive process and must be up-dated and validated at regular intervals. It is proposed that risk analysis be carried out at least during concept formulation, during contract definitions, and prior to a production decision. These analyses should be coordinated with key decision points of the acquisition cycle, as a timely risk analysis can be used as a basis for budget appropriation purposes.

One definition of system risk considers the following probabilities [28]:

$$\text{Prob[performance} \geq \text{minimum acceptability]} = P_p \ ,$$

$$\text{Prob[completion time } t \leq \text{specified time T]} = P_t \ ,$$

and

$$\text{Prob[total cost} \leq \text{estimated cost, given that } t \leq T] = P_{c/t} \ .$$

Risk R can be defined as the probability of failing in at least one of the above categories: $R = 1 - P_p P_{c/t} P_t$. With this definition of risk, we can graphically present iso-risk contours [8]. Furthermore, a cost-risk index I can be defined as $I = (1-R) / \ln C$, where C is the cost [9]. This index has the property that for n sequential time intervals,

$$I = \prod_{i=1}^{n} I_i = [\prod_{i=1}^{n} (1-R_i)]/[\ln(\sum_{i=1}^{n} C_i)] \ ,$$

where R_i is the program risk and C_i the program cost for that time interval. In cost-risk trade-offs, utility concepts can be applied to ascertain the preference pattern u(I) of the decision-makers, where u is the subjective utility function.

In contract definition, the types of contracts must be tailored to the risks involved. In the quantification of contractor risk, three major factors should be included in cost variations [15]. The variation in cost due to the real world uncertainties and contract structure, including contract type, are two factors involved in risk assumption. Finally, contractors with extensive resources or special goals may treat money in a different way than other contractors, and this treatment presumes contractor utility for money. Risk R is defined by $R = \text{Var}[u(F(C))]$, where C denotes a random variable whose value represents the final cost to the customer for a particular project, $F(\cdot)$ is a mathematical expression of contractor structure, and $u(\cdot)$ represents a contractor's utility function for money.

Some techniques of statistical decision theory are particularly useful. First, activity networks [4] have contributed to decision processes by providing a mechanistic procedure for obtaining system figure-of-merits, a communication vehicle to discuss the systems, a starting point for analysis, and a systematic decomposition capability to model complex systems by compounding simple systems [20]. Special simulation techniques include Program Evaluation and Review Techniques (PERT), Critical Path Method (CPM) [13], Industrial Dynamics [6], Graphical Evaluation and Review Technique (GERT)[20], to name a few.

Utility theory has been most helpful to quantify preferences. Axiomatic utility theory was formulated by von Neumann and Morgenstern [21]; utility axioms can also be found in [14] and [5]. A gamble or lottery technique was proposed [24] to develop the a priori probability law over the states. The procedure calls for a series of binary yes-no answers to questions structured in terms of simple betting odds. Besides the lottery technique, the "Delphi" technique, primarily used for forecasting and commonly applied throughout the world, offers some possibilities for magnitude estimation and collection of opinions [3]. Typically, a panel of experts is drawn together to make forecasts or evaluations on some particular subjects at hand. Each one is asked to submit his answers anonymously. Next, a composite feedback of all answers is communicated to each panelist, and a second round begins. This process may be repeated a number of times, and hopefully, convergence takes place. By keeping the identities anonymous rather than an open committee session, a panelist can more easily change his mind at each iteration and is concerned with good predictions rather than defending his very original idea.

III. TECHNICAL RISK ASSESSMENT

In the following, it is shown how risk analysis and systems analysis interface to effect a technical risk assessment by an example which addresses the 105mm, light, towed, soft-recoil howitzer, XM204 [26]. The soft-recoil, or firing-out-of-battery, principle is that the recoiling parts are allowed to build up forward momentum prior to firing. The soft-recoil concept has the distinct advantages of lower recoil reaction, increased firing stability, and lower system weight. Under consideration are three discrete levels of ammunition performance, three different weapon types, and two different cannons. The combination of these results in a total of eighteen alternative system candidates.

Since this system is in the concept formulation stage, the analysis should emphasize more on the technical performance dimension. Three studies were conducted: analysis of hardware major components, analysis of performance characteristics, and analysis of system concepts. While the first two studies are more concerned with risk assessment, the third study is a discrimination model designed to check the feasibility of the concepts, and this third study is more of systems analysis in nature.

For risk assessment, specific requirement statements are extracted from the requirements documents. A rationale is provided to translate those requirements to technical requirements and system behavior. Next, potential problem areas are highlighted, along with a discussion on the resolution of these problems. This very extensive risk assessment was carried out for the weapon system, consisting of the ten components such as cannon, recoil mechanism, carriage, fire control, etc., and the operational areas, including firing stability, safety, mobility, etc. Under each area, technical barriers and potential problems are matched with the five levels of state-of-the-art [23], from existing technology down to only a limited theoretical basis. Other considerations involving administrative and technical expertise levels, conversion to the Materiel Need concept [11], cost data base, cost/time/manpower resources, project priority are all discussed in detail.

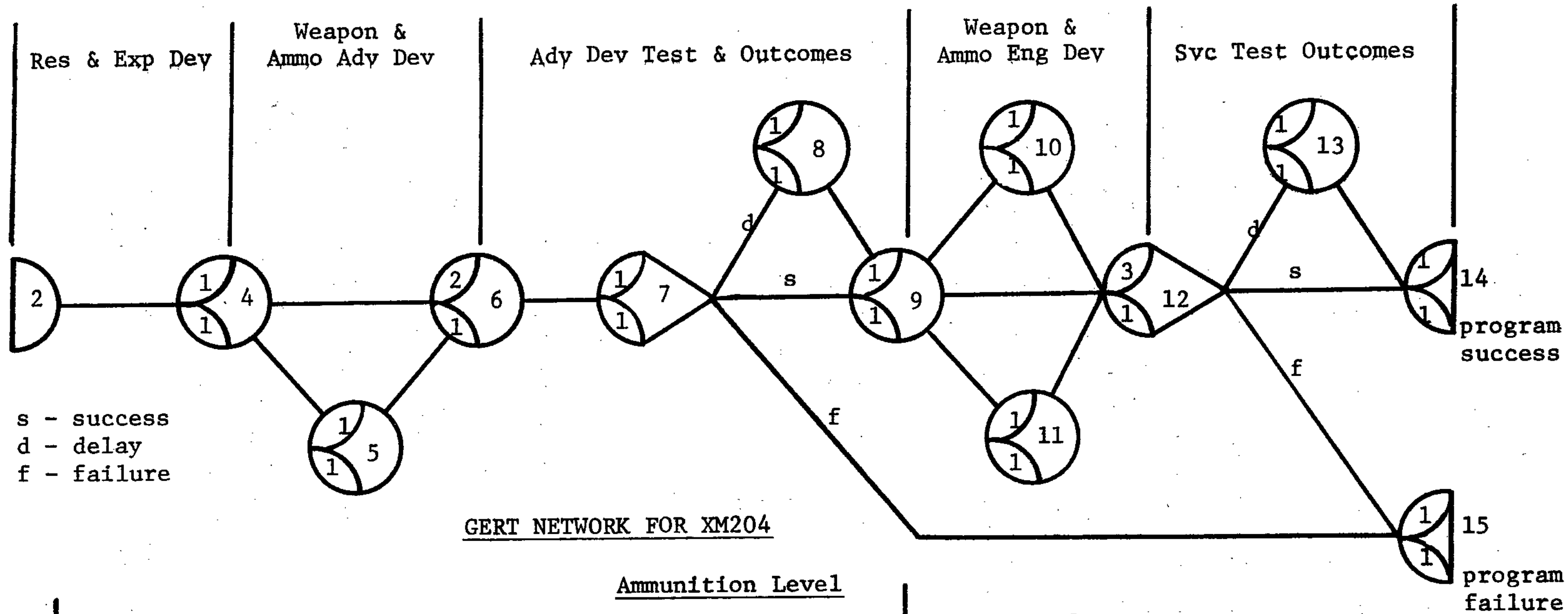
A discriminating model was constructed to quantify the overall effectiveness of a candidate system relative to the other candidates. From the requirements documents, all performance goals and components are grouped into categories of performance characteristics and major subassemblies or subsystems, noting the dependency and independency among the performance characteristics: firing stability, reliability-maintainability and availability, growth potential, human engineering, range/precision, reaction time/rate of fire/traverse capability, mobility and transportability.

Each performance characteristic is rated on a ten-point performance level scale based on the document of the proposed system with the objective to distinguish which ones of the eighteen candidates will meet or exceed the basic QMR requirements. When the candidate is sub-QMR in a particular performance characteristic, it is penalized heavily by squaring the negative difference. This squaring pushes the low ratings further into the negative region, while the high ratings follow a diminishing return behavior. It is cautioned that the results from this model is to be interpreted only as a relative scaling among the eighteen candidates and a discrimination among them.

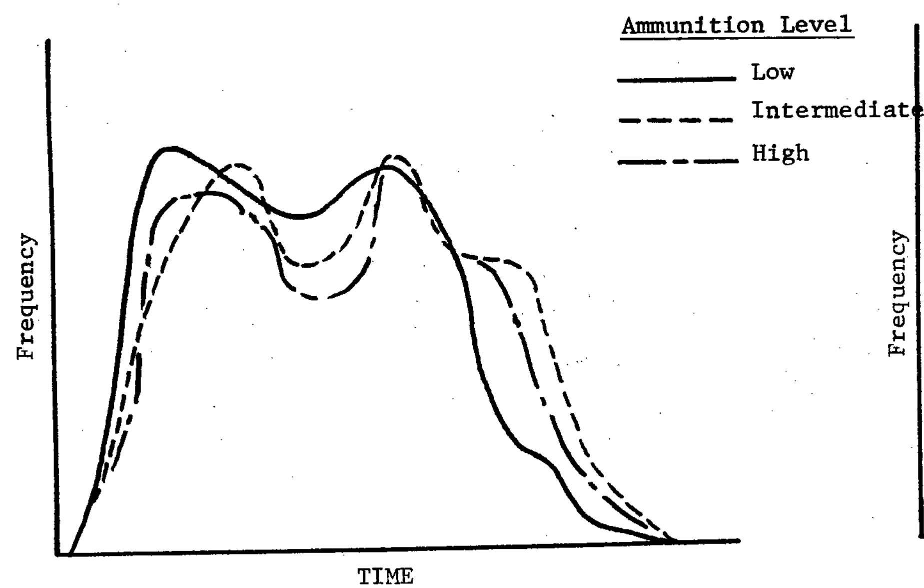
For the cost-time model, a computer program called "Graphical Evaluation and Review Technique (GERT)" [20] is used. The soft-recoil program was simulated through the life cycle with the three distinct levels of ammunition requirements: low, intermediate, and high. The network is found on the next page. Time distributions assume a beta form. Costs are broken down in terms of four main phases for the major subsystems: research and development, non-recurring investment, recurring investment, and operating. Costs are computed as a linear function of time t. The cost/time/performance schedules were based on regression analysis techniques as applied to several recent weapon and ammunition development programs. As a result, confidence levels in these estimates are quite high.

Some results of the simulation of the three networks for the three ammunition levels with 500 iterations each show the ranges of final costs and confidence levels. The tri-modal behavior of the cost density functions is on account of the existence of re-cycling branches in the network. The first peak indicates complete success. The second peak shows that there was a delay, on account of re-cycling, either in the advanced development test or in the engineering test. The third small peak or plateau is caused by the failures and re-cycling at both tests.

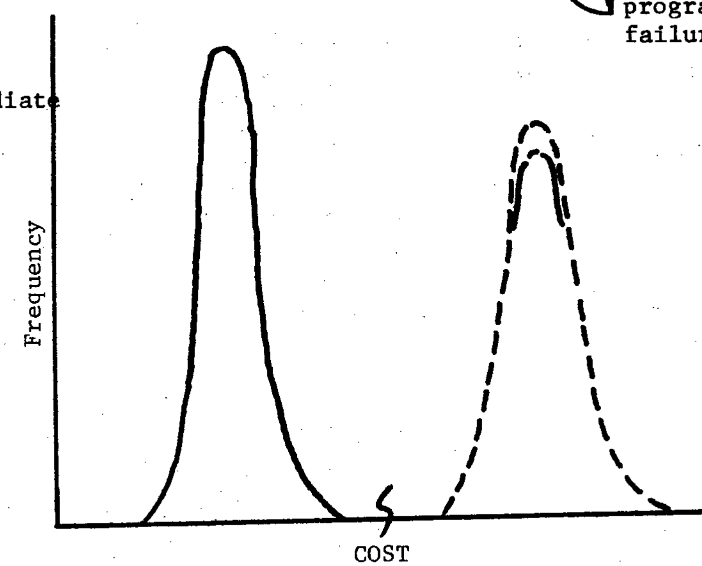
It is seen in this example risk analysis and systems analysis must be linked together, for although systems analysis may reveal, say, the cost-effectiveness of the particular candidate, there is still very little information as to the assurance of program success. A detailed risk



GERT NETWORK FOR XM204



TIME DENSITY FUNCTION



COST DENSITY FUNCTION

analysis facilitates the better understanding of the unknowns in the program development and is, therefore, vital to the program.

IV. DECISION ANALYSIS

A hypothetical example [9] is considered to illustrate how risk analysis and decision analysis interface. The approach is similar to [12].

The example is concerned with the air-armament of two aircraft denoted by A1 and A2. Two gun candidates are available to fulfill the air-armament role; these two gun candidates are denoted by G1 and G2. On performance and effectiveness alone, G2 is more superior to G1. Aircraft A1 can accept either gun. Aircraft A2 can accept G1; should G2 be adopted for it, a major redesign is required in the gun turret, as well as the aircraft structure. On the other hand, G1 is more readily available than G2 and is less costly. The objective is to evaluate the two guns with respect to cost, time, performance, and risk so as to determine the most suitable gun system for application to the aircraft.

With two guns and two aircraft, there are four possible combinations. We identify the four combinations as four performance levels shown below.

	Guns Applied to Aircraft	
Performance Level	A1	A2
1	G1	G2
2	G1	G1
3	G2	G2
4	G2	G1

From a cost analysis with supporting cost rationale, a cost model is constructed by regression analysis. This model relates total life-cycle costs of guns to quantities of aircraft armed with the guns and also of mixes of two guns on two aircraft.

Suppose n_α means the quantity of α-aircraft, and c_α^β means total life-cycle cost of β-gun applied to α-aircraft. The equations for costs in \$-millions are as follows:

$$c_{A1}^{G1}(n_{A1}) = 0.1343\ n_{A1} + 15.6, \quad c_{A1}^{G2}(n_{A1}) = 0.0837\ n_{A1} + 17.3,$$

$$c_{A2}^{G1}(n_{A2}) = 0.1343\ n_{A2} + 15.6, \quad c_{A2}^{G2}(n_{A2}) = 0.0837\ n_{A2} + 10.8 + c_t,$$

where c_t represents the turret development cost for G2 applied to A2.

For the four combinations of performance levels, total life-cycle costs of guns in \$-millions for arming two aircraft are tabulated on the following page.

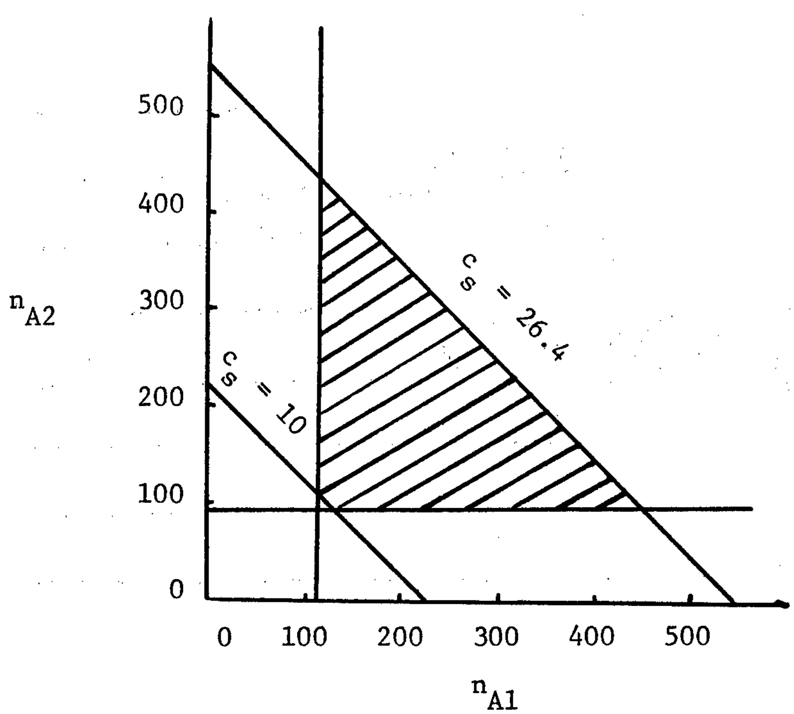
Performance Level	Total Cost		Cost to Arm A1		A2	Duplicating Fixed Cost	Modification Cost
1	c_1	=	$c_{A1}^{G2}(n_{A1})$	+	$c_{A2}^{G1}(n_{A2})$		
2	c_2	=	$c_{A1}^{G1}(n_{A1})$	+	$c_{A2}^{G1}(n_{A2})$	- 5.0	
3	c_3	=	$c_{A1}^{G2}(n_{A1})$	+	$c_{A2}^{G2}(n_{A2})$	- 6.9	$+ c_m$
4	c_4	=	$c_{A1}^{G1}(n_{A1})$	+	$c_{A2}^{G2}(n_{A2})$		$+ c_m$

where c_m is the modification cost which has not been estimated accurately.

From the above, cost sensitivity [19] can be checked on c_t and c_m to derive some criteria which are critical to the decision by assuming various cost dominances.

Cost Dominance	Criteria ($c_s \equiv c_m + c_t$)
$c_1 \leq c_2$	1. $n_{A1} \geq 130$
$c_2 \leq c_3$	2. $n_{A1} + n_{A2} \leq 25 + 20c_s$
$c_1 \leq c_3$	3. $n_{A2} \leq 20c_s - 110$

Criteria derived from $c_3 \leq c_4$, $c_2 \leq c_4$, and $c_1 \leq c_4$ are covered by the above. To search for aircraft quantity mixes which satisfy the three criteria, a plot of n_{A1} versus n_{A2}, plus the estimate $10 \leq c_s \leq 26.4$, is generated where the shaded area represents all feasible combinations of aircraft.



Acquisition times in months up to the end of Engineering Test/Service Test (ET/ST) for the respective guns with the aircraft are as follows.

Gun	Aircraft A1	Aircraft A2
G1	19	19
G2	22	28-60

Since the turret development and aircraft modification are uncertain if G2 is applied to A2, the cost c_s and time t_s are assumed as two random variables. Subjective probability density functions are solicited. Let

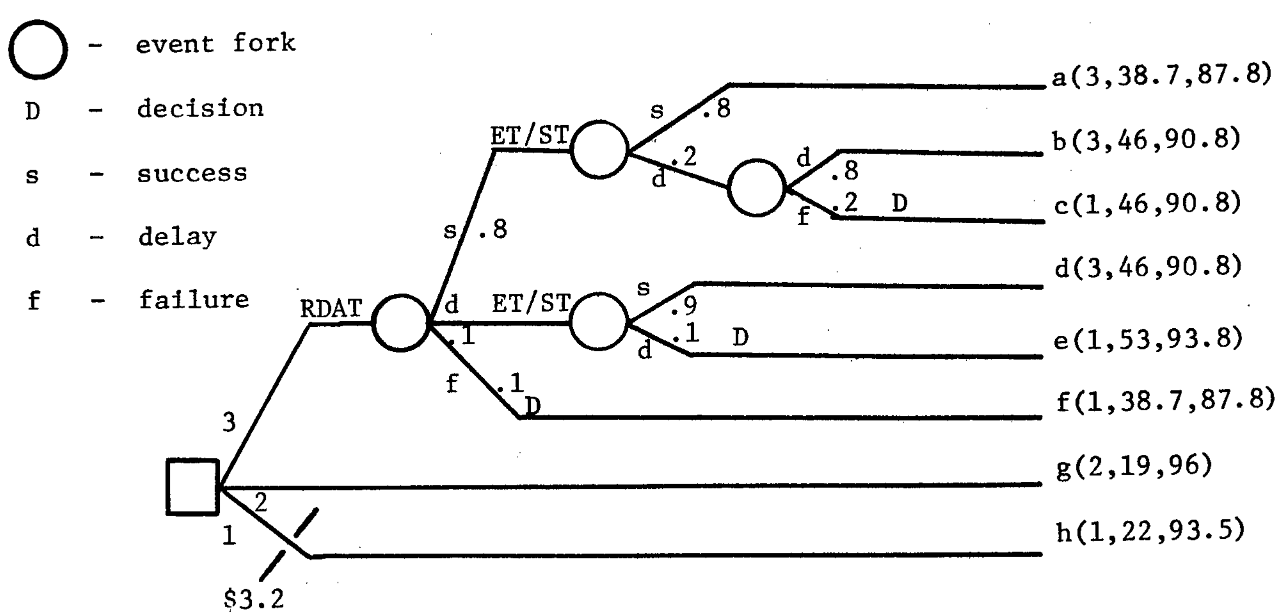
$$p_t = P[t_s = t] = 20 \left(\frac{t_s - 28}{32} \right) \left[1 - \left(\frac{t_s - 28}{32} \right)\right]^3 ,$$

and

$$p_c = P[c_s = c] = 6 \left(\frac{c_s - 10}{16.4} \right) \left[1 - \left(\frac{c_s - 10}{16.4} \right)\right] .$$

Based on these probability density functions, we can calculate the expected values for c_s and t_s, denoted by $E(c_s)$ and $E(t_s)$, respectively. Since p_c is assumed symmetric about 18.2, $E(c_s) = 18.2$. And,

$E(t_s) = \int_0^\infty t_s p_t(t_s) dt_s = 38.7$. From the technical risk analysis, information are gathered so as to interface with the decision analysis. Specifically, careful assessment of the problems, consequences of failure, and judgment of effort needed for a practical solution highlighted problems for the G2 application to A2 such as projectile cook-off, maintainability, recoil and blast, aluminum cartridge case, G-load, and structural modifications. Key milestones include Research & Development Acceptance Test (RDAT) and ET/ST. A decision-tree is shown below reflecting the major program milestones.



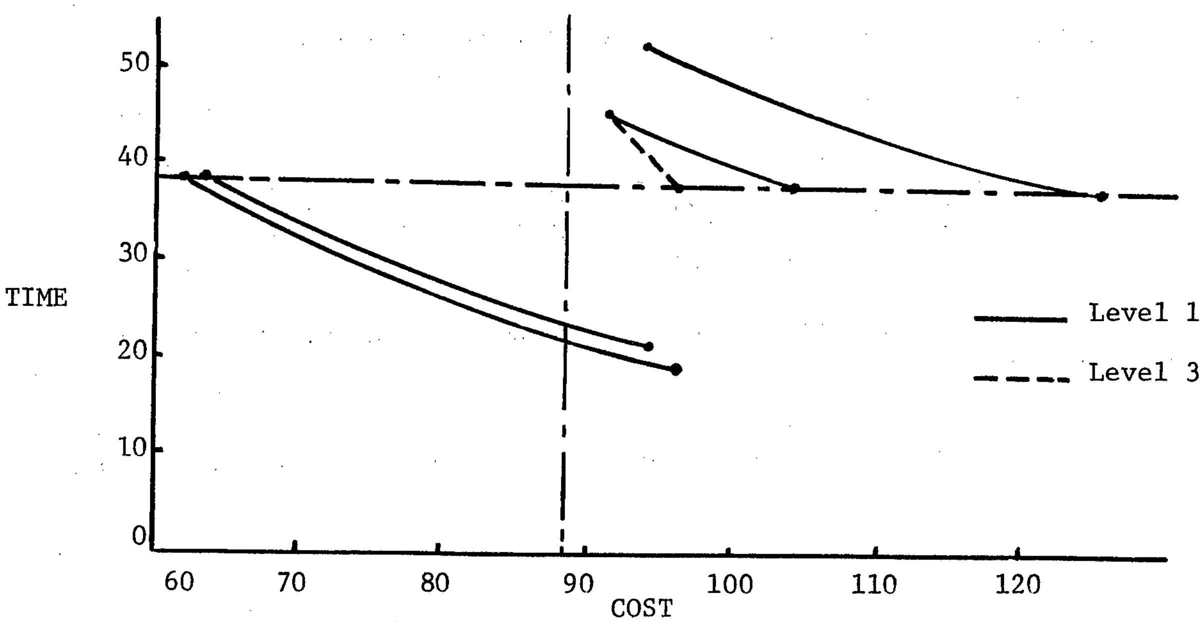
Risk analysis contributed to the establishment of the probabilities of occurrences at each event fork. Outcome triples of performance level, time, and cost are also shown at the terminal nodes. It is noted that if the development is completely successful, we have outcome a. If it is completely unsuccessful, then outcome f results, with G1 as the back-up gun system for A2. If minor problems are encountered at RDAT or ET/ST, then a delay occurs which calls for additional time and resources; timely resolution would yield outcomes b, d, and e. Otherwise, a decision for applying the G1 to A2 results, and outcomes c and e are realized. Outcomes g and h are simply the other two approaches.

The \$3.2 million is the toll for developing both guns concurrently, for parallel development requires an additional \$3.2 allotment of R&D funds. Performance level 4 is not in the decision tree, as all three performance levels dominate that level, provided t_s and c_s are close to the expected values. It should be noted that we are now concerned with one feasible combination consisting of 575 aircraft with 375 A2 and 200 A1. This combination is within the cost dominance solution set in the cost model.

To facilitate utility assessment, we first reduce the dimensions in the triples by eliminating time dimension so that all times are on one equivalent time basis. To accomplish this reduction process, we construct the so-called cost-time indifference curves by posing preference questions to the decision-makers as follows.

For performance level 2, do you prefer cost-time pair 1 or pair 2?

Cost-time Pair 1	Cost-time Pair 2	Choice
(19,96)	(38.7,90)	1
(19,96)	(38.7,75)	1
(19,96)	(38.7,50)	2
(19,96)	(38.7,60)	2
(19,96)	(38.7,65)	1
(19,96)	(38.7,62)	indifferent



By using the cost-time indifference curves, we ascertain the equivalent outcome set shown below, based on the 38.7 reference timeframe.

	Outcomes	Equivalent Outcomes
a	(3,38.7,87.8)	(3,87.8)
b	(3,46,90.8)	(3,96)
c	(1,46,90.8)	(1,105)
d	(3,46,90.8)	(3,96)
e	(1,53,93.8)	(1,125)
f	(1,38.7,87.8)	(1,87.8)
g	(2,19,96)	(2,62)
h	(1,22,93.5)	(1,64)

Next, we assess the utilities of these outcomes and apply the concept of "averaging out and folding back" [22]. Let the utility function of performance level p and cost c be in terms of the best possible outcome and worst outcome: $u(p,c) = v(p)u(1,c) + (1-v(p))u(2,c)$. Then $u(1,c) = x(c)u(1,c^*) + (1-x(c))u(1,c_*)$, and $u(2,c) = y(c)u(2,c^*) + (1-y(c))u(2,c_*)$, where c^* is the lowest cost, and c_* is the highest cost, namely 62 and 125, respectively. To obtain these utility functions, it is necessary to establish four sets of lotteries: $u(1,c)$, $u(2,c)$, $u(p,c)$, and $u(1,c_*)$ and $u(2,c^*)$, with $u(1,c^*) \equiv 1$ and $u(2,c_*) \equiv 0$.

The results of the first two sets of lotteries are tabulated below.

c	62	64	87.8	96	105	125
x(c)	1.0	.95	.60	.30	.10	0
y(c)	1.0	.97	.65	.35	.15	0

The third set of lotteries yields simply the following.

p	1	2	3
v(p)	1.0	0	0.5

Lastly, the fourth set of lotteries results in $u(1,c_*) = .1$ and $u(2,c^*) = 0.75$.

These utilities are now combined to find u(p,c) by the equations:

c	62	64	87.8	96	105	125
u(1,c)	1.0	.955	.65	.37	.19	0
u(2,c)	.75	.7275	.4875	.2625	.1125	0
u(3,c)	.875	.841	.564	.316	.151	0

With these utilities, we can apply them to find the utilities of the outcomes:

Outcome:	a	b	c	d	e	f	g	h
Utilities	.564	.316	.19	.316	0	.64	.75	.955

To fold back, we start from the terminal nodes, multiply the utilities at terminal nodes with the respective probabilities of occurrence, and sum at each event fork. Utilities of the event forks are folded back by again multiplying the utilities with the respective probabilities of occurrences and summing. This process is repeated until the initial decision nodes are reached. In similar fashion, we can fold back the costs and times.

Performance Level	Utilities	Expected Cost	Expected Time
1	0.96	93.5	22
2	0.75	96	19
3	0.5	88.8	40.7

By utility assessment, it is seen that performance level 1 is the best, and 2 second best. This example shows that risk analysis properly interfaced with decision analysis facilitates the decision process.

V. CONCLUSION

In this paper, the fundamentals of analysis of risk are exhibited. It is shown that risk analysis has a close affinity to systems analysis, as it adds a new dimension to decision making in the materiel acquisition process. We observe that systems analysis is particularly useful as a guide to concept formulation and to performance prediction. Risk analysis can take each proposed candidate in turn and assess in detail the potential technical problems, means to resolve problems, and cost/time uncertainties so as to ascertain project success.

This analysis of risk area is still in its infancy; more methodology must be developed. Validation of risk analysis is one missing link, for example. Sensitivity analysis should be formally structured. Dependency among parameters poses some serious problems. Techniques to collect subjective judgment must be developed further. Risk analysis should be a module of the management information system; the proper design to insure compatibility with the rest of the MIS module is not a simple task. Risk definitions presented need to be refined. The first definition was applied to a howitzer system [28]; the contractor risk definition has not been applied. The latter definition offers some possibility for extention, incorporating the milestones, the performance requirements, and the utility of project management.

In this paper, it is emphasized that risk analysis must interface with decision analysis to facilitate decision-making for major developmental programs in the materiel acquisition process. Risk analysis contributes to uncertainties resolution, decision-tree structuring, and probabilities of occurrences of major program events through the assessment of problems, consequences of failure, and judgment as to effort needed for practical solution. The utility concept plays a significant role in the quantification of preferences and subjective judgment. A risk analysis is complete only if these two areas are properly tied together.

Risk analysis can contribute significantly to acquisition management in the identification and better understanding of the following:

1. potential problem areas
2. consequences of failure
3. low risk program areas
4. requirements versus state-of-the-art trade-offs
5. adequacy of acquisition time
6. sufficiency of appropriations
7. optimum allocation of funds
8. data gaps/recommend studies and concepts
9. sensitive/critical parameters

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ACKNOWLEDGEMENT

The author is grateful to Robert Seamands and Louis Artioli for their valuable assistance in the preparation of this paper.

SESSION III A. - DISCUSSION

Question:

How do you assess the performance uncertainties over the whole spectrum of mission profiles--not just one particular condition, I mean, is there a technique?

Answer:

Each problem is different because the criterion that you use to try to make a decision is different. So, it depends upon the situation. That's why you really have to get together with the decision-maker early in the stage of the analysis so that the problem that you solve is the problem that he needs. It depends upon constraints.

The thread in the entire discussion is that of the conventional approach to decision-making and that there is a single decision-maker. In the environment in which we find ourselves, we do not have that luxury. Not only is there not a single decision-maker, but quite often we are severely challenged to find out where the decision-makers really are and who they are. So the elicitation of a set of prior probabilities, and I have noticed that we very assiduously avoided the use of any reference to basic decision theory. That's precisely what we've been talking about this afternoon--decision-making under uncertainty. So the eliciting of prior probabilities from a single decision-maker, as you astutely pointed out, is a very difficult problem. But the eliciting of a set of prior probabilities from a set of unknown decision-makers is not only a very difficult problem, it's an impossible problem. So, you don't have the luxury of going to this decision-maker or to these decision-makers even if you could find them in eliciting this information. You need, in your analysis, to present to whomever it is that makes decisions, where the break points are if your prior probabilities were such that your best fact is here, and so on down the line. You can't do this in analysis-forget it. Forget the concept of trying to elicit prior probabilities. It's not only a costly, time-consuming process, but it is very inefficient and totally unnecessary to analysis.

I think what we get from our decision-makers is not so much the prior probabilities. We try to get that from our experts. Your point is quite right as far as trying to find a decision-maker, and I think that the last point that I made, as far as having a clear-cut rationale, in the case of John's presentation, where he came up with a particular utility for really important decisions, depending upon what the utilities of the particular decision-maker are, will tremendously influence the decision. I think what we have to do is present the clear rationale behind our selection of a decision and our collection of utilities. If we have obviously just one final decision-maker who makes the decisions and if he disagrees with the particular utilities that are attached by the analyst, then if they are clearly presented in a way that he can see how we reached our results, he may change them to what he thinks is the right one since he is the one that has to live with the decision in the end. I don't think that we should confuse prior probabilities which are expert judgments as to what's going to happen in the future with the value on various outcomes, which is what the decision maker would throw into the analysis. I think if the analyst tried to have a good understanding of his decision-maker and if he clearly presents the way in which he reaches his decision then this should facilitate making the necessary changes to adjust to the real decision-maker.

I would just like to tie it up. In the book by Antovan, he talks about how much is enough. He mentions the cult of McNamara as being one decision-maker you could identify. I guess it's quite difficult to pick out who makes a decision in terms of a major project in most cases. I guess in the last analysis, we can always blame the citizen as the decision-maker. With that, I would like to close this session, unless there are some other questions. Thank you.

NOTE: The comment included in this section is not necessarily complete. It was necessary to delete some remarks as they were unitelligible on the recording.

VALIDATION OF TERRAIN MODELS

Dr. Thomas Cochran

Litton Scientific Support Laboratory
Fort Ord, California

I. INTRODUCTION

The Army Aircraft Modeling and Simulation (AMSIM) Program has developed Terrain Models to support field experiments conducted at Hunter Liggett Military Reservation (HLMR) by the US Army Combat Developments Command Experimentation Command.

II. MODEL INPUTS

The Terrain Models represent terrain relief by digitized topographic elevations. The models presently use data tapes of topographic elevations collected by Stanford Research Institute (SRI) in an earlier project. SRI manually digitized a 1500-km^2 area of HLMR. Topographic elevations were recorded at Cartesian grid points spaced at 100 meters.

Vegetation effects are also treated by the models. For this purpose, a 400-km^2 vegetation area of HLMR was manually digitized on the 100-m grid. The vegetation was classified into eight categories and an appropriate height was assigned to each.

III. MODEL OUTPUTS

The Terrain Models are presently capable of providing the following outputs:

1. Sensor Coverage Diagrams (SCDs) of variable scale which show surfaces at specified absolute altitudes (i.e., areas on or above ground) that can be observed from given sensor-site locations.

2. Terrain Profiles and Terrain Masking-Envelope Profiles that display the terrain profile along a two-dimensional path drawn on a map and the profile of the altitude required in order to establish intervisibility with a fixed-site location.

3. Line-of-sight (LOS) intervisibility status between points on a three-dimensional curve (e.g., flight path) and several sensor sites.

4. Terrain profile between any two geographic locations.

IV. VALIDATION TECHNIQUES

During various stages of model development, research was conducted to determine the validity of the Terrain Models. This research included: 1)profile comparison, 2) critical angle comparison, 3) bench-mark comparison, 4) terrain model uncertainty relations, and 5) Monte Carlo error analysis. A brief description of the techniques used is given below. The results are presented in the following section.

1. Profile Comparison. The Terrain Models were checked to determine how well predictions of terrain heights would agree with the topographic maps from which digitized data were derived. The accuracy of the terrain profiles generated by the models is a function of the method used to interpolate between points in the grid of digitized topographic elevations. The profile comparison consisted of comparing profiles obtained manually from the maps with those generated by the models using various methods of interpolation. Vegetation was not treated in this analysis.

2. Critical Angle Comparison. A critical angle is defined as the complement of the vertical angle between an observer's zenith and a line from the observer to a physical terrain feature (e.g., ridgeline, tree-top, etc.) which masks other terrain features behind it from the observer's view. In Figure 1 α_1 and α_2 are positive critical angles. A comparison was made between critical angles measured optically in the field with those generated by the Terrain Model.

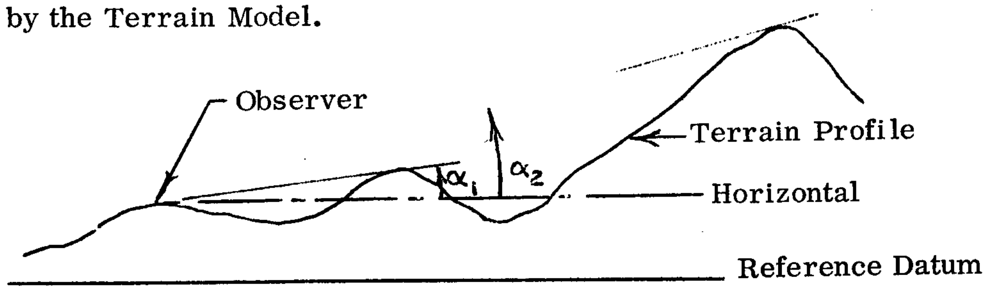


Figure 1 CRITICAL ANGLES

These results were used to compute the uncertainties in predicting peak or ridgeline elevations. It was found that the bench-mark comparison was a better method for estimating these uncertainties.

3. Bench-Mark Comparison. In order to compare the accuracy of the Terrain Models in predicting terrain elevations and peak locations, the Terrain Models were used to predict the terrain elevations of 46 bench marks at HLMR and the location of those bench marks that were on peaks or ridgelines. Since the topographic maps, from which the digitized terrain data were derived, were made before the bench marks were surveyed, the digitized data is not expected to be more accurate in the vicinity of the bench marks. The accuracies of several interpolation techniques, each with peak generation capabilities, were examined in the bench-mark comparison.

4. Terrain Model Uncertainty Relations. Uncertainties were examined in calculations used by the Terrain Models to provide sensor coverage diagrams, terrain masking envelope profiles, and intervisibility predictions. In each case, the uncertainty relation for the variable of interest was derived using standard propagation of error techniques.

5. Monte Carlo Error Analysis. A Monte Carlo sampling capability was incorporated into the Terrain Models. The models were then used to compute intervisibility for a variety of flight paths as seen from several observation points. The intervisibility calculations were repeated many times; random errors were introduced each time into the computation by sampling from distributions of the variables involved in the determination of intervisibility. These distributions were estimated from field data. In this manner, uncertainties in the intervisibility predictions were estimated.

V. VALIDATION RESULTS

1. Accuracy in Reproducing Topographic Map Data. The accuracy with which computer-generated profiles represent topographic map data can be expressed by the standard deviation of the differences between the terrain elevations along the computer-generated profiles and the respective topographic map elevations. This accuracy is 8.7 feet when the Terrain Models use a four-point cubic spline interpolation technique.* This represented a 25-percent

*An n-point cubic spline function $Z(X)$ is the function constrained to pass through n data points $[X_i, Z_i](i = 1, n)$ such that $\int_{X_1}^{X_n} \left(\frac{d^2 Z}{dX^2} \right)^2 dX = \text{minimum}$.

improvement over a linear interpolation technique with a peak generation capability. No significant improvement in accuracy was noted when the number of data points in each spline interpolation was increased from four to six.*

A comparison of computer running times revealed that the four-point spline interpolation takes roughly 2.5 times longer than the linear interpolation.

2. Accuracy of Predicting Peak Elevations. Figure 2 shows the distributions of $\overline{\Delta Z}$, where ΔZ is the difference between Z_{BM} (actual), the surveyed elevation, and Z_{BM} (predicted), the elevation predicted by the Terrain Models. Figure 2a is the distribution obtained when the Terrain Models use a linear interpolation technique with a peak generation capability. Figure 2b is the equivalent distribution obtained when the cubic spline interpolation technique is used. The means and standard deviations of the two distributions are:

$$\overline{\Delta Z} \text{ (linear)} = 5.9 \pm 6.2 \text{ feet} \qquad \sigma_{\Delta Z} \text{ (linear)} = 27.0 \text{ feet}$$

$$\overline{\Delta Z} \text{ (spline)} = 0.6 \pm 3.2 \text{ feet} \qquad \sigma_{\Delta Z} \text{ (spline)} = 15.5 \text{ feet} \qquad (1)$$

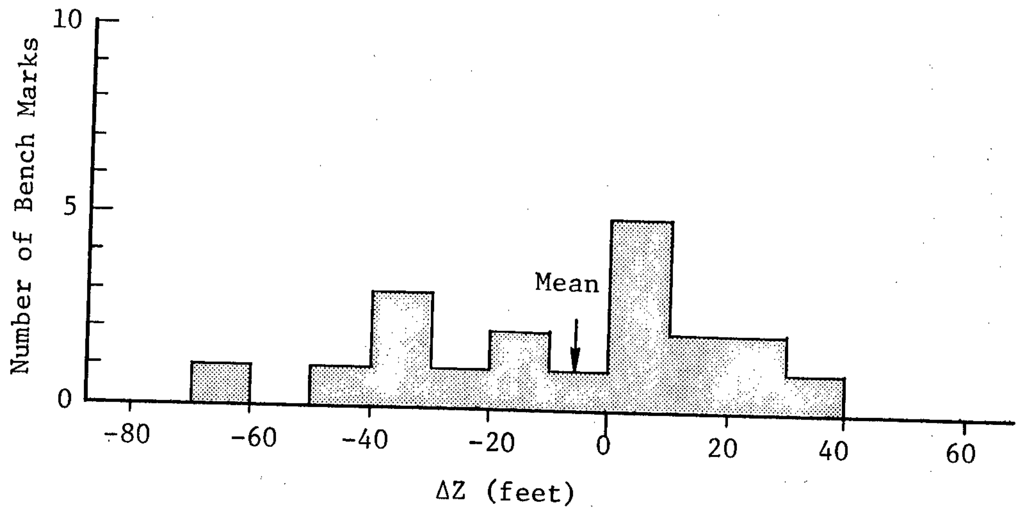
Although both means are consistent with zero (i.e., no bias in the peak generation techniques), the standard deviation of ΔZ using the cubic spline fit, represents a 40-percent improvement over the linear interpolation technique.

3. Accuracy of Predicting Peak Location. When the Terrain Models were used to predict peak elevations, they also computed the location of the generated peak along the radial through the actual bench mark position. The models were constrained to search for, or generate, the peak along the radial and within the two-radial grid-crossing intervals closest to the actual bench mark location. The actual bench mark location was within one of the two intervals.

Using linear interpolations with peak generation, 19 of the 26 bench marks located on peaks were within the interval tested for maxima. Figure 3a shows a histogram of $\Delta\rho$, the differences between the location of the actual bench marks and the generated peaks. The mean of the distribution is consistent with zero, i.e., no peak location bias.

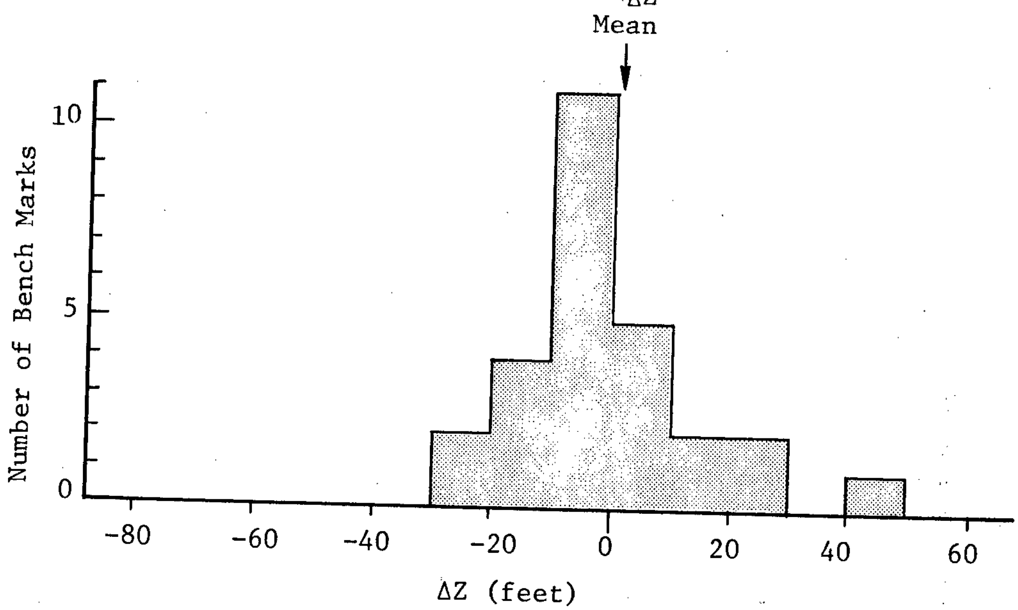
Using cubic spline interpolations, out of 26 bench marks on peaks, 24 spline function maxima were found in the same search intervals. The distri-

*Errors in reproducing the map sheets are the combined errors due to the interpolation technique and the errors in obtaining the digitized data from the original map sheets.



(a) Linear Interpolation

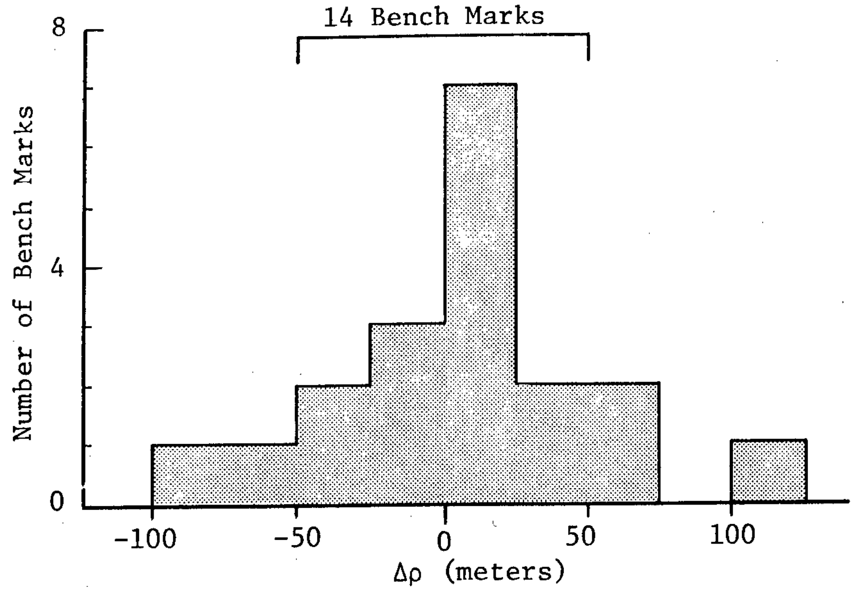
$\overline{\Delta Z} = -5.9 \pm 6.2$ feet $\quad \sigma_{\Delta Z} = 27.0$ feet



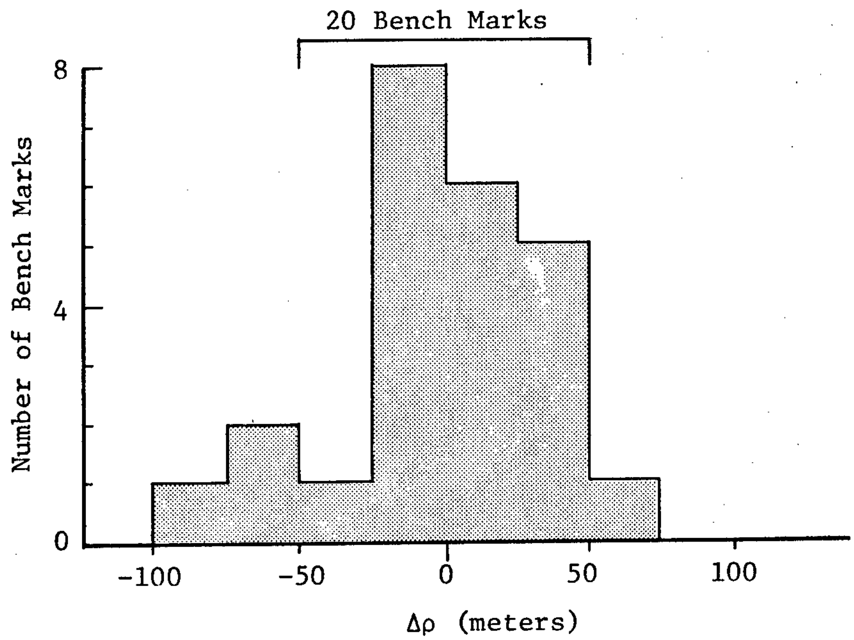
(b) Spline Interpolation

$\overline{\Delta Z} = 0.6 \pm 3.2$ feet $\quad \sigma_{\Delta Z} = 15.5$ feet

Figure 2 DIFFERENCE BETWEEN PREDICTED TERRAIN PEAK ELEVATIONS AND BENCH MARK ELEVATIONS FOR BENCH MARKS LOCATED ON THE PEAKS OR RIDGELINES. PREDICTED ELEVATIONS ARE THE ELEVATIONS AT THE LOCATION OF THE GENERATED PEAKS.
$\Delta Z = Z_{BM}$ (ACTUAL) $- Z_{BM}$ (PREDICTED)

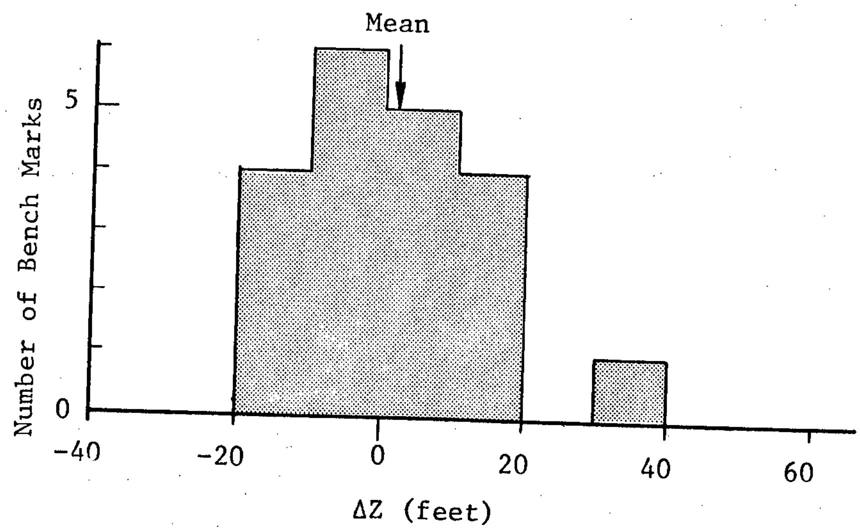


(a) Linear Interpolation
$\overline{\Delta\rho} = 0.3 \pm 18.2\text{m}; \quad \sigma_{\Delta\rho} = 68\text{m}$
7 bench marks not shown



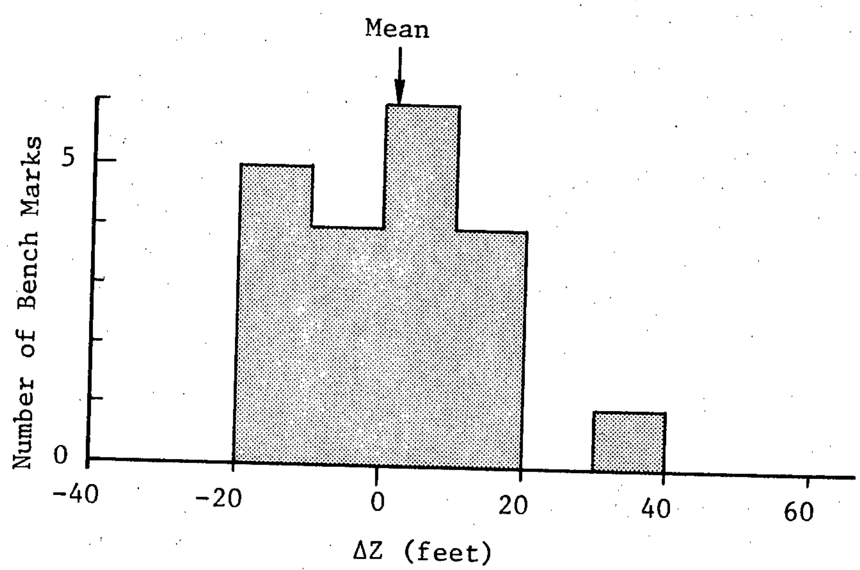
(b) Spline Interpolation
$\overline{\Delta\rho} = 4.7 \pm 9.4\text{m}; \quad \sigma_{\Delta\rho} = 42\text{m}$
2 bench marks not shown

Figure 3 DIFFERENCE BETWEEN ACTUAL AND PREDICTED BENCH MARK LOCATIONS FOR 26 BENCH MARKS LOCATED ON PEAKS. $\Delta\rho = \rho_{BM}$(ACTUAL) - ρ_{BM}(PREDICTED). BENCH MARKS NOT SHOWN HAVE $\Delta\rho > 50$ METERS, OR $\Delta\rho < -50$ METERS.



(a) Linear Interpolation

$\overline{\Delta Z} = 2.4 \pm 2.7$ feet $\sigma_{\Delta Z} = 12.0$ feet



(b) Spline Interpolation

$\overline{\Delta Z} = 1.8 \pm 2.7$ feet $\sigma_{\Delta Z} = 12.2$ feet

Figure 4 DIFFERENCE BETWEEN ACTUAL AND PREDICTED BENCH MARK ELEVATIONS FOR 20 BENCH MARKS LOCATED OTHER THAN ON PEAKS. $\Delta Z = Z_{BM}$ (ACTUAL) $- Z_{BM}$ (PREDICTED) bution of $\Delta\rho$ for these cases in shown in Figure 3b. The mean of the distribution is consistent with zero.

If it is assumed that

$$|\Delta\rho| \geq 50 \text{ meters} \qquad (2)$$

for the bench marks not shown in the figure, and a plot of $\Delta\rho$ for all bench marks on peaks is normally distributed, then the uncertainties in $\Delta\rho$ are given approximately by

$$\begin{aligned} \sigma_{\Delta\rho} \text{ (linear)} &= 68 \text{ meters} \\ \sigma_{\Delta\rho} \text{ (spline)} &= 42 \text{ meters} \end{aligned} \qquad (3)$$

4. Accuracy of Predicting Random Terrain Elevations. If the Terrain Models are used to obtain the terrain elevation of a random map location (e.g., the terrain elevation below a point along an aircraft flight path), then one should compare predictions of the Terrain Models with actual elevations using a random selection of terrain points. In general, bench marks are not randomly distributed over the terrain, but are usually located on, or very near, topographic highs. There were 20 bench marks located other than on peaks. These were analyzed using linear and cubic spline interpolations. The results are shown in Figure 4. As might be expected, the means are both consistent with zero. The accuracy of the two interpolation techniques are comparable, i.e.,

$$\begin{aligned} \sigma_{\Delta Z} \text{ (linear)} &= 12.0 \text{ feet} \\ \sigma_{\Delta Z} \text{ (spline)} &= 12.2 \text{ feet} \end{aligned} \qquad (4)$$

5. Terrain Model Uncertainties. The uncertainty relations associated with the calculations required to produce the Terrain Models' outputs were examined. In this paper, discussion is limited to the uncertainty relations associated with predicting LOS intervisibility between a sensor site and points along a curve (e.g., flight path).

When the curve is parameterized as a function of time and the points are treated sequentially, the time at which the intervisibility status changes can be determined. The precision of this measurement is dependent on the spacing of the points on the curve. By examining the terrain profiles of a typical radial from a sensor site, illustrated in Figure 5, it can be seen that a change in intervisibility status occurs when

$$Z = Z_s + \rho \cdot \frac{Z_m - Z_s}{\rho_m} \qquad (5)$$

where Z_s is the sensor altitude, Z_m and ρ_m are the altitude and radial distance to the critical masking peak, respectively, and Z and ρ are the altitude and radial distance to the point on the flight path where the intervisibility status changes. It is assumed that the earth's curvature corrections have already been applied.

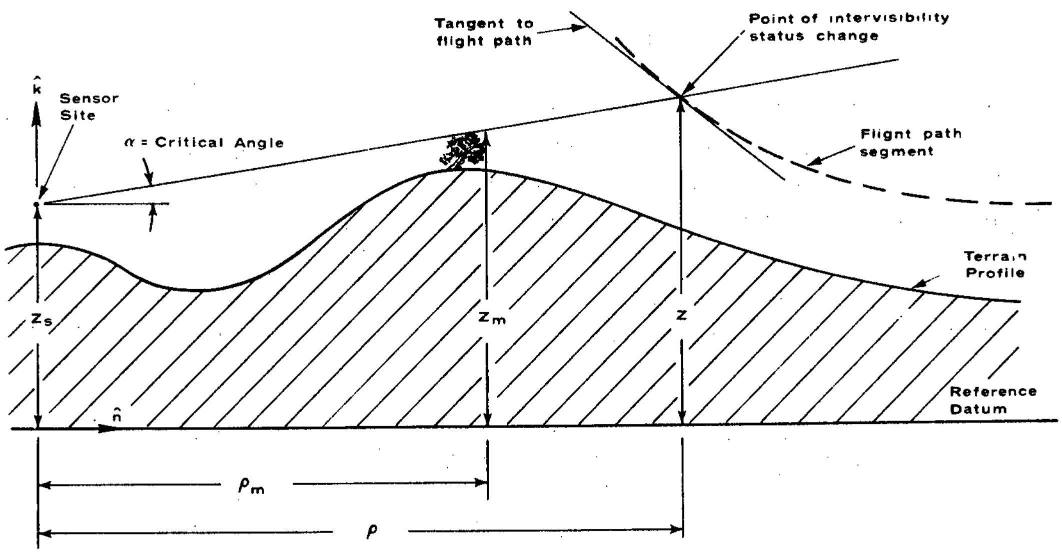


Figure 5 FLIGHT PATH AND TERRAIN PROFILE IN THE PLANE CONTAINING THE SENSOR SITE AND A POINT ON THE FLIGHT PATH WHERE THE INTERVISIBILITY STATUS CHANGES.

The variables in equation 5 are functions of time. In order to examine the uncertainty in the time at which the intervisibility status changes, equation 5 is solved explicitly for time. When this is attempted, two difficulties immediately arise. First, ρ_m and Z_m are discontinuous functions which depend on the shape of the curve. Secondly, unless the curve has a simple time dependence, it cannot be solved easily for t.

If the flight path is approximated by constant velocity segments and the analysis restricted to those segments in vertical planes containing the sensor site (i.e., ρ , Z planes), then

$$\rho = \rho_o + V_\rho t \qquad Z = Z_o + V_z t \tag{6}$$

where ρ_o, V_ρ, Z_o, and V_Z are constant over a given segment and the t solution has the form:

$$t = \frac{Z_o - Z_s - \rho \tan\alpha}{V_\rho \tan\alpha - V_Z} \tag{7}$$

where α is the critical angle and $\tan\alpha = (Z_m - Z_s)/\rho_m$.

Since each segment remains in a ρ , Z plane, ρ_m and Z_m (and therefore α) are constant over their continuous intervals. In other words, the same critical mask governs the portion of the line segment between the critical mask and the next more distant mask in the same plane.

Assuming δV and δV_Z are negligible, and Z_s, Z_m, and Z are independent (this requirement is met when ρ_m and $\Delta\rho = \rho - \rho_m$ are large), then the uncertainty in t is given by

$$\delta t(\text{peak}) = \frac{1}{|V_\rho \tan\alpha - V_Z|}\left[\left(\frac{\rho}{\rho_m}\right)^2\left(\delta Z_m^2 + \tan^2\alpha\,\delta\rho_m^2\right) + \left(\frac{\rho}{\rho_m} - 1\right)^2 \delta Z_s^2 + \delta Z^2 + \tan^2\alpha\,\delta\rho^2\right]^{\frac{1}{2}}, \ \Delta\rho \text{ large} \tag{8}$$

When $\Delta\rho$ is small, one can write $\Delta Z = Z_m - Z$ and the uncertainty in t is given by

$$\delta t(\text{peak}) = \frac{1}{|V_\rho \tan\alpha - V_Z|}\left[\left(\frac{\rho}{\rho_m}\right)^2 \tan^2\alpha\,\delta\rho_m^2 + \left(\frac{\rho}{\rho_m} - 1\right)^2\left(\delta Z_m^2 - \delta Z_s^2\right) + (\delta(\Delta Z))^2 + \tan^2\alpha\,\delta\rho^2\right]^{\frac{1}{2}}, \ \Delta\rho \text{ small} \tag{9}$$

Equations 8 and 9 do not apply when the critical angle caused by a near-in mask, (e.g., a tree near the sensor site). In this case ρ is defined by

$$Z = Z_s + \rho\tan\alpha \tag{10}$$

If equation 10 is used in place of equation 5 and the uncertainty in t is given by

$$\delta t(\text{near-in}) = \frac{1}{|V_\rho \tan\alpha - V_Z|}\left[\rho^2\sec^4\alpha\,\delta\alpha^2 + \delta Z_s^2 + \delta Z^2 + \tan^2\alpha\,\delta_\rho^2\right]^{\frac{1}{2}} \tag{11}$$

6. <u>Applications of Terrain Model Uncertainties.</u> The magnitude of the uncertainties derived in the above equations can be quantitatively examined by making appropriate assignments of dependent variable uncertainties. For example, if

$$
\begin{aligned}
\delta Z_m &= 18 \text{ feet}^* & \delta Z &= 17 \text{ feet} \\
\delta \rho_m &= 42 \text{ meters} & \delta \rho &= 10 \text{ meters} \\
\delta Z_s &= 0 & V_Z &= 120 \text{ ft/min} \\
\tan^2 \alpha &= (0.02)^{2\,**} & V_\rho &= 2
\end{aligned}
\qquad (12)
$$

then, from equation 8, δt (peak) = 6.6 seconds.

7. Monte Carlo Error Analysis. Five flight paths and four sensor sites were represented in the Monte Carlo error analysis. The flight path data were obtained from radar-tracking data recorded during five field trials at HLMR. The raw radar data were smoothed, and the aircraft's UTM coordinates were recorded at one-second intervals. Aircraft absolute altitude data, obtained from unsmoothed radar altimeter readings, were similarly recorded.

At each position along a flight path, the Terrain Models (using cubic spline interpolations) were used to compute the intervisibility status for each active sensor. The aircraft altitude, required in this calculation, was obtained by adding the recorded aircraft's absolute altitude to the terrain elevation at the respective UTM coordinates.

With the Monte Carlo capability incorporated into the Terrain Models, at each recorded flight path location the intervisibility calculations for each sensor were repeated 50 times, each time adding random errors (drawn from normal distributions) to the critical peak elevations and the flight path coordinates. As illustrated below, the shifts in the times at which the intervisibility status changed, due to the addition of these errors, provided a means of determining δt , the uncertainty in time at which the intervisibility status changed.

---

*It is assumed that the uncertainty (δh_{veg}) in the vegetation height, is nine feet. If this uncertainty is combined with the 15.5-foot uncertainty in the peak height from the bench mark study, then the overall uncertainty in Z_m is 18 feet. If vegetation were not included in the model and δh_{veg} = 32 feet, then Z_m = 36 feet.

**Typically, the critical angles vary between $\pm 4^o$. The means of the absolute value of α varies between one and two degrees ($\sim$ 0.02 radians).

Figure 6 shows a segment of one of the flight paths. The time scale has been shifted so that, with no errors introduced, the models predicted that the flight path was visible from the sensor site when $t \geq 0$ seconds and invisible when $t < 0$ seconds. With errors, the predicted intervisibility status-change occurred at t_i ($i = 1, 50$).

The uncertainty, δt, is measured by the width of the t_i distribution, which would be normal if equation 8 were valid. Rather than plot the distribution of t_i it is more convenient to plot the normalized integral of this distribution (Figure 7). It is simply the fraction of Monte Carlo runs which predict target sensor intervisibility at t as a function of time. The normalized integral is the cumulative probability that LOS intervisibility exists (or does not exist).

In Figure 7a the points are the Monte Carlo results, and the solid line is a normal distribution function with a width, $\sigma = 10$ seconds. The scatter in the data points is partially due to statistical effects (due to the limited number of Monte Carlo runs), and partially due to the scatter in the aircraft altitude data. A better fit is obtained by treating the two portions of the distribution, $t \gtrless 0$, separately. The dotted lines in Figure 7a are normal distribution functions with $\sigma = 6$ ($t < 0$) and $\sigma = 15$ seconds ($t > 0$).

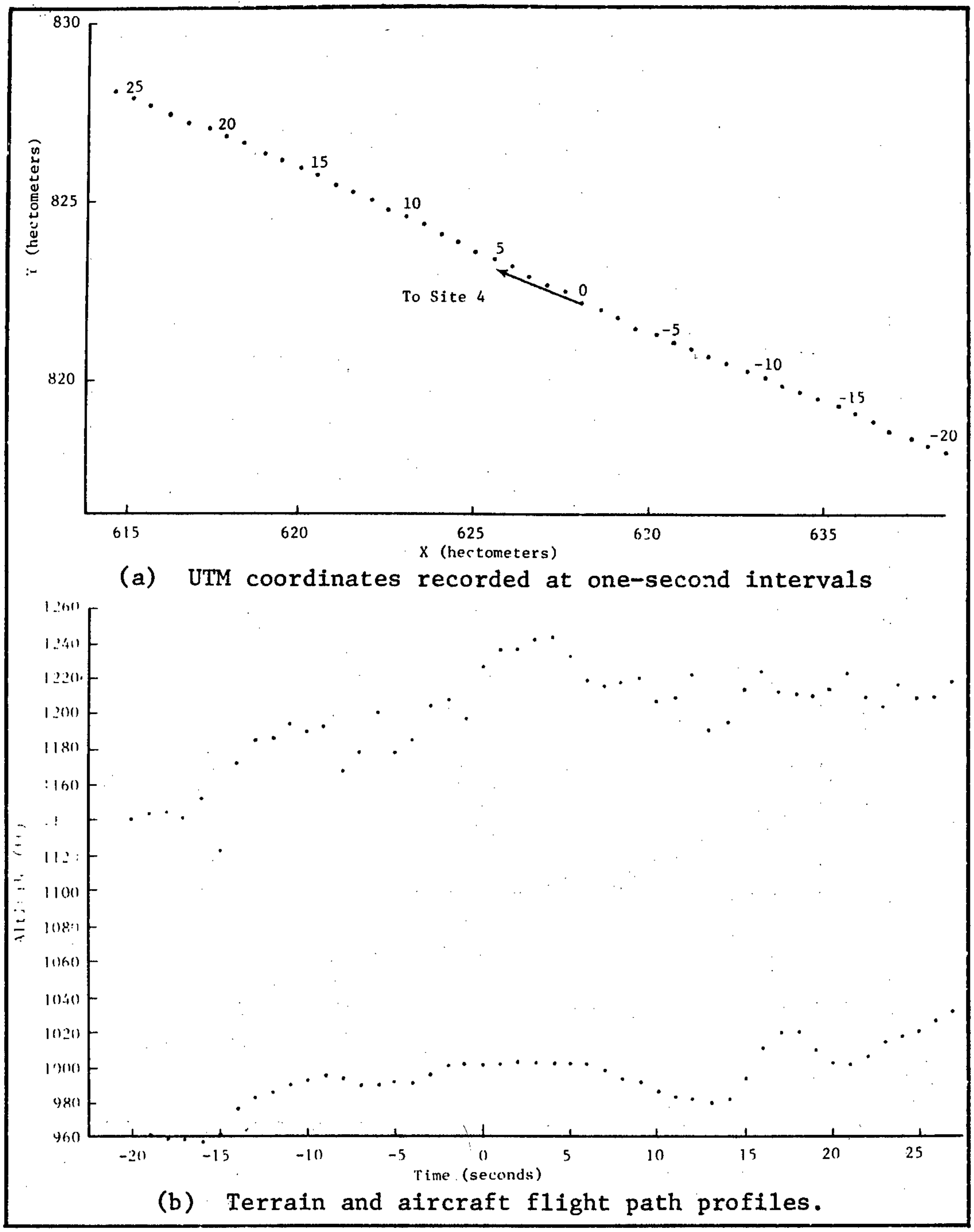
If a similar procedure is used to examine several flight paths, as seen from several sensor sites, then, as illustrated in Figure 8, a more complete picture of the accuracy of the Terrain Models can be obtained. It shows the distribution of the uncertainty in the time of the intervisibility status change for all flight path directions relative to the sensor. Two values of the critical peak height uncertainty (18 and 36 feet) are shown.

VI. APPLICATION OF RESULTS

The examination of the trade-off between the grid size (and therefore the core storage requirement) and model accuracy can be made using the validation results. Usually, it is desirable to select the maximum grid spacing (minimizing core storage) which does not significantly increase the errors of Models. The major sources of errors in the outputs of the Terrain Models are the uncertainties in the height and location of the critical peaks.

In each application of the Terrain Models, the appropriate uncertainty relationship analogous to equation 8 contains the factor

$$\left(\frac{\delta Z_m^2}{\tan^2\alpha} + \delta\rho_m^2\right) \quad , \text{ or } \quad \left(\delta Z_m^2 + \tan^2\alpha\,\delta\rho_m^2\right) . \qquad (13)$$

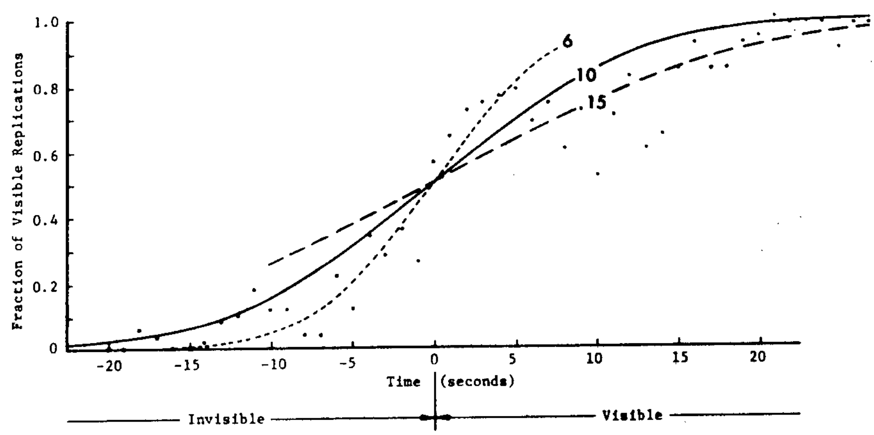


(a) UTM coordinates recorded at one-second intervals

(b) Terrain and aircraft flight path profiles.

NOTE:
The time (seconds) equals IRIG time-
22 hours, 11 minutes, .06 seconds.

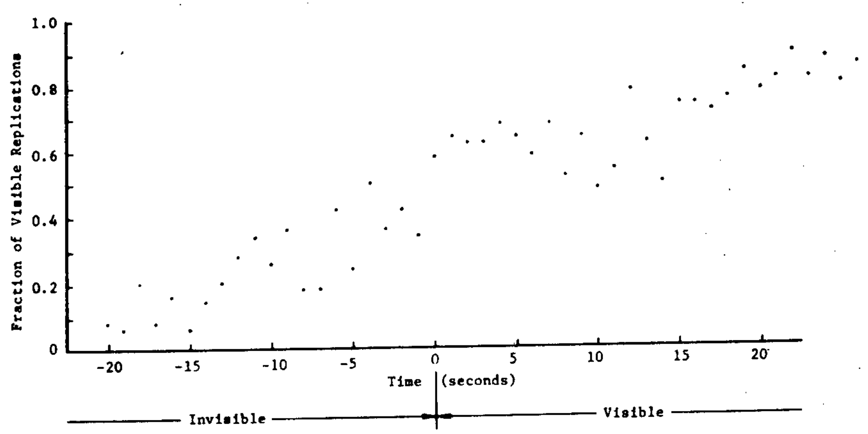
Figure 6 PORTION OF THE AIRCRAFT FLIGHT PATH DURING TRIAL 954 OF EXPERIMENT 42.8.



(a) Monte Carlo Input Uncertainties

Aircraft Location: $\sigma_x = \sigma_y$ = 9 meters; σ_z = 17 Feet

Critical Peak Height: σ_{z_m} = 18 feet



(b) Monte Carlo Input Uncertainties

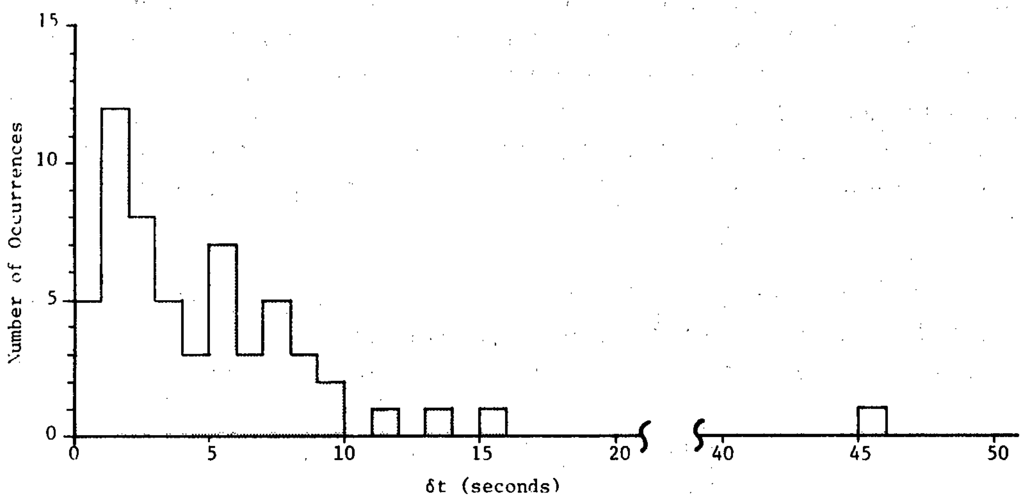
Aircraft location: $\sigma_x = \sigma_y$ = 9 meters; σ_z = 17 Feet

Critical Peak Height: σ_{z_m} = 36 feet

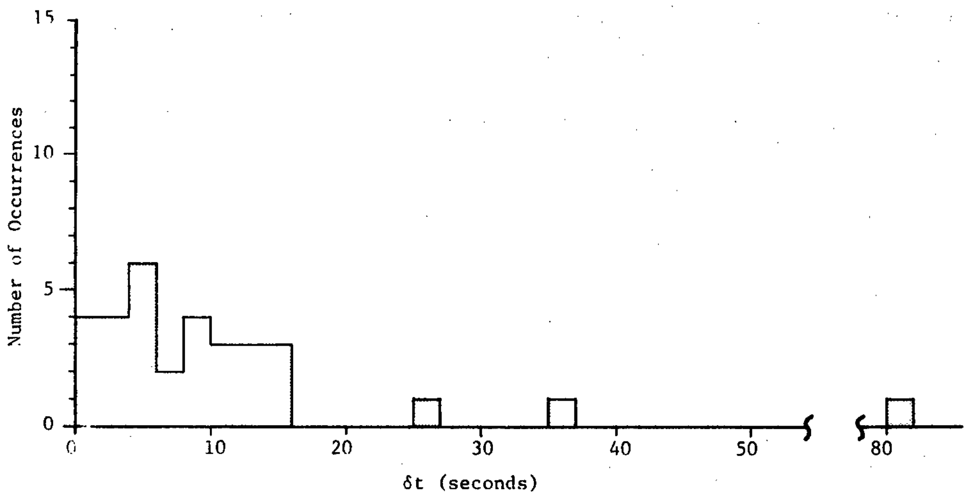
NOTE:

Intervisibility established at t=0 seconds, corresponding to IRIG time: 22hr. 11 min. .06 sec. At t=0, ρ_m = 1255m, ρ = 3887m and α = 0.163. Curves in (a) are normal probability distributions with means at t=0 and widths corresponding to 6, 10, and 15 seconds.

Figure 7 MONTE CARLO, INTERVISIBILITY PREDICTIONS (50 REPLICATIONS) FOR EXPERIMENT 42.8 FLIGHT PATH (TRIAL) 954 AS OBSERVED FROM SITE 4



(a) Critical peak height uncertainty
σ_{z_m} = 18 feet; $\overline{\delta t}$ = 5 seconds
57 events



(b) Critical peak height uncertainty
σ_{z_m} = 36 feet; $\overline{\delta t}$ = 11 seconds
32 events

Figure 8 MONTE CARLO PREDICTIONS OF THE UNCERTAINTY IN THE TIME AT WHICH THE TARGET-SENSOR INTERVISIBILITY STATUS CHANGED DURING EXPERIMENT 42.8 (SENCON). AIRCRAFT LOCATION UNCERTAINTIES: $\sigma_x = \sigma_y$ = 9 METERS; σ_z = 17 FEET.

In the validation study, δZ_m was found to be 15.5 feet when the contour interval of the topographic map from which the digitized data was extracted, was 20 feet. If δZ_m is assumed to be primarily a function of the map accuracy and is a linear function of the contour interval, then it can be approximated by $\delta Z_m = 0.25C$ meters, where C, the contour interval, is in feet. Likewise, if $\delta \rho_m$ depends primarily on the grid spacing, then it can be expressed as $\delta \rho_m = 0.4d$ meters, where d, the grid spacing, is in meters.

For a given map, C is fixed. Thus, when the relations for δZ_m and $\delta \rho_m$ are substituted into the uncertainty relations (i.e., factors 13), errors in the Terrain Models can be reduced by requiring

$$|\tan\alpha| 0.4d < 0.25C. \tag{14}$$

Because $|\alpha|$ is seldom greater than 0.06, $|\tan\alpha| \approx |\alpha|$. Hence, d should be selected so that $d < 10C$, where d is in meters and C in feet. For 1:25000-scale map with a 20-foot contour interval, d, much less than 200 meters, would not significantly reduce the factors in 13. A reduction in the grid spacing much beyond 200 meters simply increases the computer-core storage requirement without significantly reducing the errors of the Terrain Models.

AN ATTITUDE AND FLIGHT PATH PREDICTIVE MODEL FOR ROTARY WING ARMY AIRCRAFT

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I. INTRODUCTION

The Aircraft Modeling and Simulation (AMSIM) Program was designed to support field experiments conducted by the US Army Combat Developments Command Experimentation Command (USACDCEC) at Fort Ord, California. Of prime importance in this project was the development of models that could be used to simulate one-on-one engagements of Army aircraft by selected foreign forward area air defense threats. Several AMSIM Aircraft Models were developed under this effort.

To understand system elements and their interactions, models traditionally have been constructed and operated to simulate (or represent) real-world systems. For example, several sophisticated models, developed in the past several years, have simulated aerial combat between an aircraft and air-defense weapons (e.g., AFAADS gun models).[1*] The AMISM modeling effort complements, rather than supplements, these other programs. The AMSIM Aircraft Models can be used as a tool to provide additional data which can be used to enhance the execution of field experimentation. One possible application of the AMSIM Aircraft Models will be discussed in detail in Section V, Model Application, and will entail a theoretical experimentation situation.

The AMSIM Aircraft Models and associated computer programs are basically analytic predictive models. They provide detailed information on a rotary wing aircraft's flight path, kinematics, orientation,

[*] Superscript numbers denote references listed at the end of this paper.

presented shape and cross-sectional area. Two of the Aircraft Models--Flight Path Model and Attitude Model* are discussed in this paper.

II. FLIGHT PATH MODEL

This model approximates an aircraft trajectory by fitting a continuous function $\vec{r}(t)$ to a set of discrete coordinate data $[x(t_i), y(t_i), z(t_i)]$, i = 1, 2,...n specifying the aircraft's position as a function of time. Field tracking data, map coordinates or synthetically generated position coordinates may be used as input to the model.

After the investigation of several curve-fitting techniques for representing flight trajectories, cubic spline functions were found to have major advantages--accuracy and ease of computation. Spline functions can be derived from the supposition that the pilot flies (or approximately flies) so as to minimize the forces on the helicopter. Since these forces are proportional to aircraft accelerations, this suppostion is equivalent to requiring that

$$\int_{t_1}^{t_n} \left[\frac{d^2 \vec{r}}{dt^2}\right]^2 dt \qquad (1)$$

be a minimum. In practice, equation 1 is minimized independently along each coordinate direction.

In one dimension, the flight path, x(t), is derived by taking the variation in equation 1 along the x direction. Thus, for arbitrary x(t),

$$\int_{t_1}^{t_n} \ddot{x}\delta\ddot{x}dt = 0 \qquad (2)$$

*A complete description of the models and associated computer programs is contained in Project AMSIM, Volume II, Aircraft Models - An Attitude and Flight Path Predicitve Model for Rotary Wing Aircraft, D. B. Clark and N. M. Stevenson, Litton Scientific Support Laboratory, Technical Memorandum TR-71-2.

subject to the constraint $x(t_i) = x_i$ for all i. Equation 2 is solved by integrating twice by parts and using the method of La Grange multipliers. Consequently, the one-dimensional flight path becomes

$$x(t) = \frac{1}{12} \sum_{i=2}^{n-1} \lambda_i \tau_i^{\,3} \, \theta(\tau_i) + \frac{1}{6} \dddot{x}(t_1) \tau_1^{\,3} + \dot{x}(t_1) \tau_1 + x(t_1) \qquad (3)$$

where $t_i = t - t_i$, λ_i are La Grange multipliers (spline coefficients), and

$$\theta(\tau) = 1 \text{ if } \tau > 0$$
$$= 0 \text{ if } \tau < 0.$$

Similar results are obtained for the y and z trajectories. Aircraft kinematic motion is represented by velocity components ($\dot{x}$, $\dot{y}$, $\dot{z}$) and acceleration components ($\ddot{x}$, $\ddot{y}$, $\ddot{z}$).

The spline coefficients in equation 2 are generated from the n input position locations by a matrix inversion technique. The special form of the matrix is used to reduce the number of multiplications (and divisions) from n^3 to n^2 in the inversion process. These coefficients are used to regenerate the aircraft's position, velocity, and acceleration components as a function of time. Hence, complete aircraft trajectory and kinematical information is contained in a set of 3n numerical constants.

Since a finite time and distance are required for a typical aircraft maneuver (e.g., a turn), the sensitivity of fit was investigated as a function of temporal and spatial data-point intervals. In this case, sensitivity implies the model's ability to regenerate the original aircraft position, velocity, and acceleration data from a minimum number of spline coefficients. Based upon previous tracking data, a characteristic maneuver time is on the order of four to eight seconds at typical velocities (i.e., 80 to 130 knots). As was expected, the spline flight path was not seriously degraded until the input data-point temporal spacing was approximately equal to this characteristic time.

III. ATTITUDE MODEL

The Attitude Model consists essentially of a mathematical description of the aircraft's orientation and assumed shape during flight. The orientation is developed by considering the total forces and moments acting on an aircraft*. The shape is then approximated by the outline of a set of clustered ellipsoids. Relative to an observer, the ellipsoids are projected on a plane perpendicular to the observer's line-of-sight (LOS). The model requires the spline coefficient set and aircraft pitch attitude angle versus speed data.

Several basic simplifying assumptions and approximations have been employed in the model. However, sufficient flexibility is provided so that detail and accuracy can be improved if desired. Briefly, the principal approximations are:

1. Rotational motion about the rotor hub is critically damped and fully accounted for by the pitch attitude profile. Furthermore, a virtual rotor tip plane is defined to be the perpendicular to the horizon during hover and inclined forward during constant-velocity level flight. The inclination angle is just the pitch attitude angle.

2. Drag force is a) proportional to aircraft speed, b) independent of orientation, and c) directed through the origin of the aircraft set of body axes.

3. The aircraft nose vector lies in a plane defined by the rotor thrust and velocity vectors.

Orientation

The attitude of the helicopter flying at a constant velocity behaves as a pendulum hung in a wing tunnel, swinging backward

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*Only single rotary wing aircraft will be considered in this discussion. Presumably, however, the model should apply to aircraft with multiple rotary wings (e.g., CH-47) if appropriate pitch angles are included.

until the drag moment equals the weight moment.[2] Experimental data are used to determine the relationship between pitch angle and aircraft speed. Figure 1 illustrates this configuration for horizontal flight.

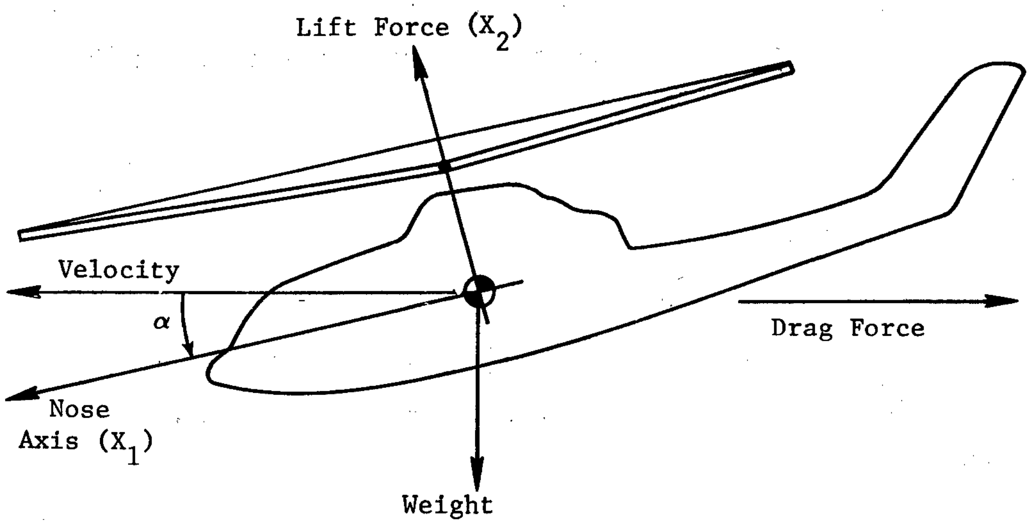

Figure 1 STEADY STATE ORIENTATION

The pitch angle, α , is the angle between the horizontal plane and the nose axis. The normal helicopter is quite complicated in its blade motion because both flapping and feathering motions exist with respect to the physical, powered shaft. Three fundamental types of rotor configurations are in general use--fully articulated, semi-rigid, and rigid. By requiring constant-velocity pitch angle data for each helicopter, the model precludes the need to distinguish between rotor types.

Under normal flight conditions, desired accelerations result in deviations from the steady state orientation. However, if helicopter pitching moment, lift, and parasitic drag are assumed independent of fuselage angle, these deviations can be treated as perturbations about the steady state condition. Without a detailed knowledge of each helicopter and its rotor system, the perturbation equations assume that the virtual rotor tip plane is rigidly attached to the fuselage. In essence, attitude for the non-steady state helicopter is constructed by considering rotational perturbations impressed on a rigid body about some instantaneous axis of rotation. The rotation angle (expressed by a rotation matrix) is derived from a consideration of lift force, weight, parasitic drag force, and linear acceleration of the body reference frame.

When the total linear momentum is constant, the forces on a helicopter are lift, weight and drag. Equilibrium requires that

$$\vec{F}_L + \vec{F}_D - mg\hat{k} = 0$$

where

$\vec{F}_L$ = total lift force

$\vec{F}_D$ = total parasitic drag force

$mg\hat{k}$ = gravitational force (weight)

Since the drag force is assumed coincident with the velocity direction*, $\hat{v}$, then

$$\vec{F}_L = |\vec{F}_D| \; \hat{v} + mg\hat{k}. \tag{4}$$

When helicopter linear accelerations, $\vec{a}$, are included, equation 4 becomes

$$\vec{F}_L = |\vec{F}_D| \; \hat{v} + mg\hat{k} + m\vec{a}.$$

Since $|\vec{F}_D|$ = mgtan α is known, the direction of $\vec{F}_L$ and, consequently, the direction of the aircraft vertical axis can be determined.

In general, there are three rotational degrees of freedom which can be controlled by the pilot: roll, pitch and yaw. However, during maneuvers aircraft roll is determined by the radius of curvature of the turn, while pitch is dependent upon the desired forward speed. Consequently, only aircraft yaw about some instantaneous axis can be independently controlled by the pilot--in effect, the pilot can fly sideways. With this consideration, the following assertion is used to constrain this independent variable. When the aircraft is performing a lateral change in position, the pilot operates the controls such that the aircraft nose axis remains coplanar with the velocity and lift vectors. This constraint does not provide an exact description of attitude changes, however, validation data have shown that the error resulting from this approximation is not significant.

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*In actual computations, the velocity is the speed and direction of the aircraft relative to the air.

The above constraint and the direction of the aircraft's lift force and velocity are used to construct a rotation matrix operator (A) which describes the helicopter orientation relative to a fixed reference frame. A second rotation matrix operator (B) specifies the orientation of the observer's LOS reference frame relative to the fixed frame. Consequently, the aircraft orientation relative to an observer is expressed by a single rotation matrix operator $R = AB^{-1}$.

Aircraft Surface

An aircraft surface may be mathematically described by constructing a set of n three-dimensional surfaces clustered in such a manner as to resemble the aircraft shape. The aircraft's presented shape and geometric cross-section, as viewed from any aspect, are described by a set of clustered ellipsoids. Much better resolution of surface features has been obtained with AMSIM modeling than is possible with the traditional shoe box. Preliminary effort has demonstrated that approximately 15 ellipsoids are necessary for an accurate surface representation. Figure 2 illustrates this method as applied to the AH-1G (Cobra).

IV. VALIDATION

Predictive accuracy (referenced to past USACDCEC field data) has been the sole criterion for evaluating the Aircraft Models' output. It should be noted that in this instance, reliance on past field data has not been sufficient to establish the range of applicability for these models. Consequently, a more extensive validation effort has been planned.

Several validation tests have been applied to each model, however, only one result will be discussed in this paper. This evaluation consisted of a comparison between the predicted line-of-sight computer-generated aircraft shapes and actual photographic images of an aircraft (AH-1G) flying a known course. Aircraft radar-tracking data collected during the course of USACDCEC experiment SENCON: Attack Helicopter (Ground-to-Air) (see Reference 3) were used in this study. The aircraft was an AH-1G helicopter flying an attack mission against a fixed target (tank). The initial tracking data (1/8-second spacing) were smoothed using a 65-point (four-second) quadratic technique before cubic spline functions were generated by the Flight Path Model. Figure 3a illustrates the portion of the flight path used for this study. A time-referenced camera was set up at the indicated sensor site. The photographic images

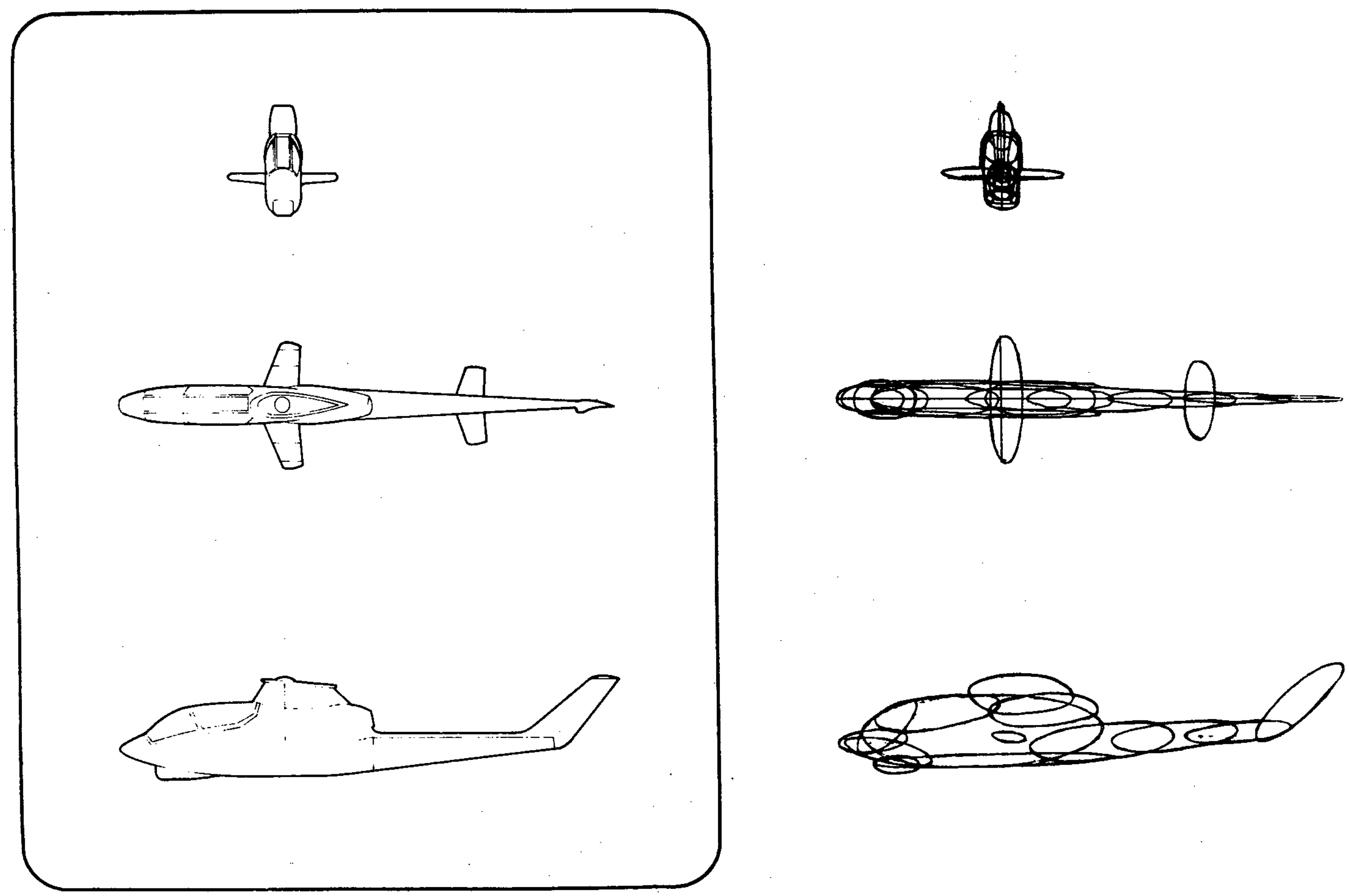
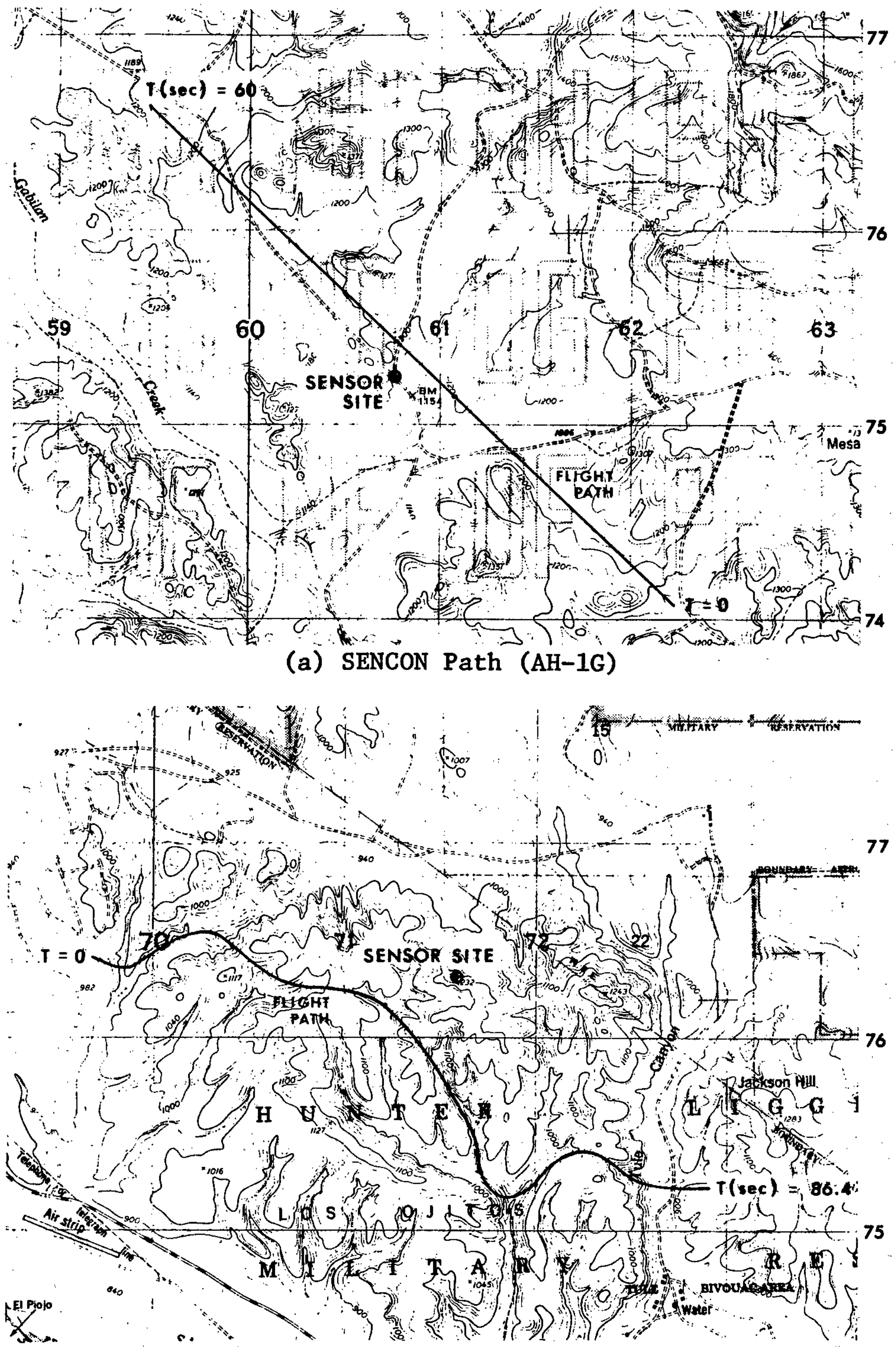


Figure 2 AMSIM MODELING PRESENTATION OF THE AH-1G (COBRA)



(a) SENCON Path (AH-1G)

(b) VISCON Path (UH-1B)

Figure 3 AIRCRAFT FLIGHT PATHS

(six were outlined and presented with computer-generated shapes so that a comparison between overall size and orientation could be made. Figure 4 illustrates the comparison for all six images. Aircraft-relative positions and orientations in the celestial hemisphere (i.e., azimuth and elevation angles) are preserved in the figure.

As is readily seen, the Attitude Model is capable of reproducing the aircraft's apparent shape. Close examination reveals small defects and inconsistencies within the set of images as a whole, however, uncertainties in the initial field data and time-referencing system are sufficient to explain these inconsistencies. For example, site-elevation uncertainty ($\pm$ 20 meters) results in an evaluation-angle error of approximately $\pm 5°$. This results in an appreciable apparent aircraft roll around the nose axis during cross-over.

For more complex flight paths, an example derived from an earlier USACDCEC experiment (VISCON) is illustrated in Figure 5. The helicopter, a UH-1B, is flying a nap-of-the-earth course through hilly terrain at approximately 70 knots. (Figure 3b illustrates its flight path and observer location.) The absence of a photographic record has precluded validation of this output.

V. MODEL APPLICATION

One difficulty encountered in aircraft survivability field experiments is obtaining realistic hit/kill assessments in real or near real time. The Aircraft Models may be able to assist in the hit decision in order to improve combat realism. One possible application of the models is described below.

It is possible to mount Direct Fire Simulators (DFS) utilizing lasers coupled to fire control systems on air-defense type weapons in an effort to simulate firing events and, hence, to obtain realistic combat hit probabilities. The DFS laser can be mounted on the gun barrel and aligned coincident with the gun sight by effectively locking out the lead corrections. Consequently, the barrel tracks the target simultaneously with the sight regardless of the target's range or velocity. If the target is being correctly tracked, a hit will be instantaneously detected by sensors attached to the target when the trigger is pulled.

One inherent limitation of this method is the treatment of the target's vulnerable area. With the utilization of a distinct sensor array on the target, two schemes are available for estimating the vulnerable target area at the projectile intercept time. In one scheme, this area is considered constant during the projectile's flight time (5 seconds, typically). In the other scheme, the gunner is required to continue smooth track for the duration of the projectile's flight time. However, both schemes lack some degree of realism. This limitation may be, at least, partially minimized by the use of a gun model, intercept model, and portions of the Aircraft Models operating on a real or near real time basis.

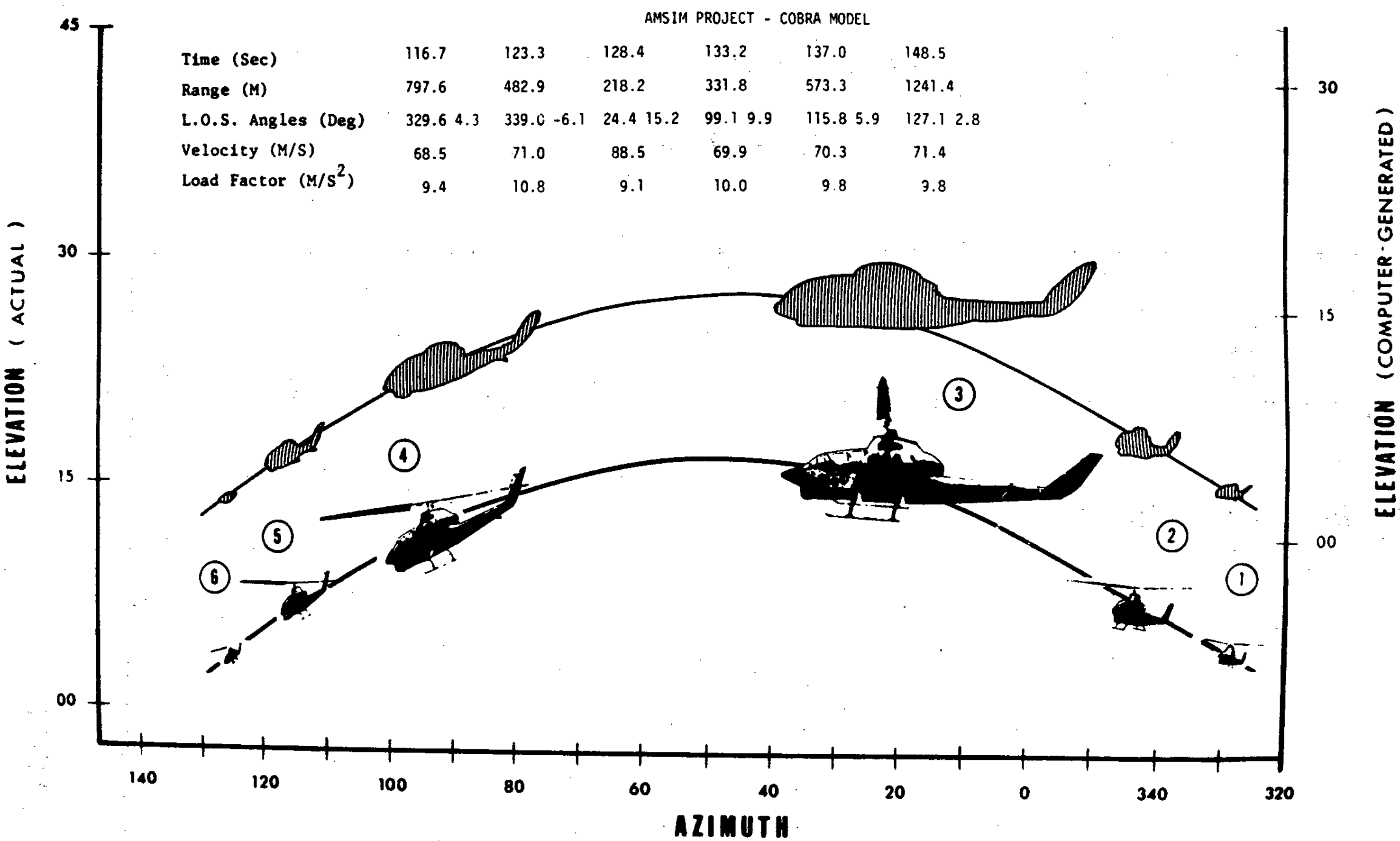
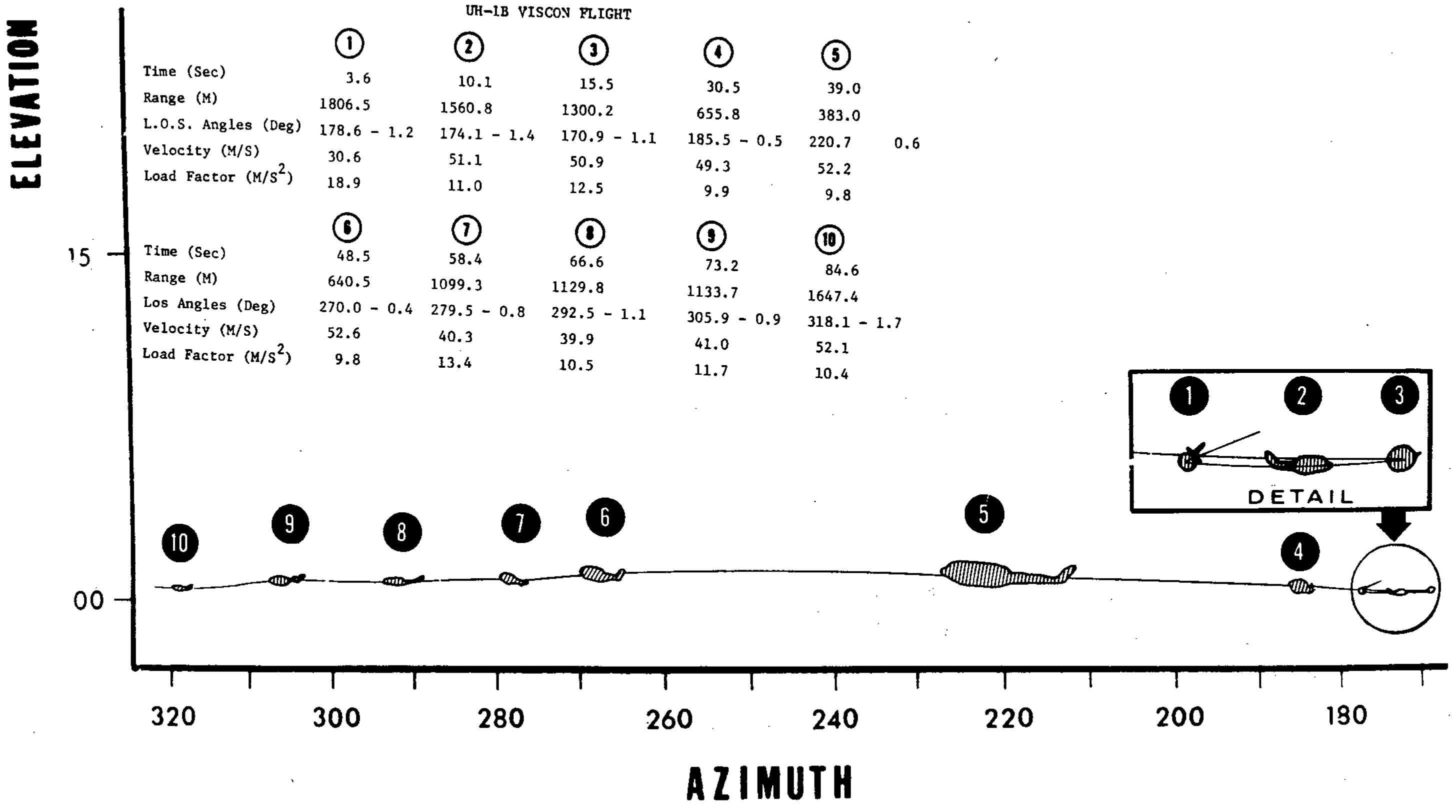


Figure 4 COMPARISON OF PHOTOGRAPHIC AND COMPUTER-GENERATED IMAGES



UH-1B VISCON FLIGHT

	1	2	3	4	5
Time (Sec)	3.6	10.1	15.5	30.5	39.0
Range (M)	1806.5	1560.8	1300.2	655.8	383.0
L.O.S. Angles (Deg)	178.6 - 1.2	174.1 - 1.4	170.9 - 1.1	185.5 - 0.5	220.7 0.6
Velocity (M/S)	30.6	51.1	50.9	49.3	52.2
Load Factor (M/S^2)	18.9	11.0	12.5	9.9	9.8

	6	7	8	9	10
Time (Sec)	48.5	58.4	66.6	73.2	84.6
Range (M)	640.5	1099.3	1129.8	1133.7	1647.4
Los Angles (Deg)	270.0 - 0.4	279.5 - 0.8	292.5 - 1.1	305.9 - 0.9	318.1 - 1.7
Velocity (M/S)	52.6	40.3	39.9	41.0	52.1
Load Factor (M/S^2)	9.8	13.4	10.5	11.7	10.4

Figure 5 UH-1B (HELICOPTER) FLYING NAP-OF-THE-EARTH COURSE

After the gunner pulls the trigger (i.e., pulses the laser), the gun and intercept models could be used to determine the actual projectile trajectory within some error distribution. The error distribution is based upon gun system and ballistic uncertainties. If the real time track of the target is used for input to the Flight Path Model, the aircraft's presented cross-sectional area (or, if desired, vulnerable area) may be calculated at projectile/target intersect time. Hit probabilities are then proportional to the ratio of the presented area to the area generated by the projectile uncertainties. For the purposes of calculation, these uncertainties can be represented by some two-dimensional normal distribution. The distribution is determined by projecting all gun and ballistic errors (range, azimuth, and elevation) onto a plane perpendicular to the line-of-sight.

With the presented area capability, aircraft tactics may be studied when an aircraft is engaging or being engaged by a ground threat. If the minimum presented area can be maintained, then the survivability of aircraft during a one-on-one engagement should be enhanced significantly.

Additionally, the capability of the Aircraft Models to provide orientation information (e.g., roll, pitch and yaw rates) obviates accelerometer requirements in experiments involving airborne missile firings. This capability is also useful in constructing the gun system errors which result from maneuvering targets.

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TECHNIQUES FOR MINIMIZING THE DEPLOYMENT COST OF HARDSITE BALLISTIC MISSILE DEFENSE SYSTEMS

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Dr. Stanley S. Dick, Keystone Computer Associates, Inc.
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INTRODUCTION

A key problem faced by the advanced weapon system planner is that of determining how improvements in weapon system technology and performance affect overall weapon system cost effectiveness. To select a technology for further development it is not enough to show that development of the technology will significantly improve the performance of a weapon system element. Rather, the value of the technology under consideration must be shown in the true system context; i.e., it must be shown that incorporation of the technology will significantly improve the overall cost effectiveness of the weapon system.

In its role as advanced hardsite defense planner, ABMDA must find a total system cost effectiveness justification for any decision to proceed with the design or development of an advanced hardsite defense component. To assist in this process ABMDA has been developing an analytical system of models and techniques which relate hardsite defense element characteristics and performances to overall system cost effectiveness. The analytical system consists of several separate but compatible computer models and simulations, each of which models one particular portion of the total defense system. For any given problem, the models are linked together in a manner which suits the particular problem requirements and provides results that clearly show the effects desired.

The problem of relating defense element characteristics to total system cost effectiveness is a particularly complex and difficult one, due to the great number of parameters which influence the result, and due to the fact that when any one defense component is altered it affects the deployment and utilization of all other defense components. The complexity of this problem was the principal reason for developing several small but compatible models rather than one large evaluation model.

For ease of modification and to give special visibility to the problem, the separate models are not linked through the computer, but are hand fed and operated. This procedure is economical and provides maximum insight and flexibility.

It should be mentioned that emphasis was placed on developing logical and consistent system flow within and between the separate models. The purpose of the component models and the integrated system is to identify and relate those factors of the defense system which drive the system costs.

The purpose of this paper is to describe the ABMDA system of evaluation models and demonstrate its application.

HARDSITE DEFENSE EVALUATION PROBLEMS

In the evaluation of hardsite defense alternatives to determine the impact of technological improvements, four types of problems arise which are solvable with the models. (See Chart I). The first problem is that of determining the cost effectiveness of a defense system whose hardware characteristics are fixed. A good measure of merit is the total deployment cost to ensure a specified number of surviving silos against a given attack. In order to form a basis for comparison to other defense systems, the minimum deployment cost is determined where the cost is minimized by the proper choice of defense system deployment parameters and defense tactics, while still ensuring that the desired number of silos will survive. For this problem the defense component characteristics are fixed; that is, the defense component characteristics are not optimized. A typical problem would be that of comparing two defense systems each of which utilizes a different radar or computer. The basis for comparison would be the minimum cost deployment for each case.

CHART I

HARDSITE DEFENSE PROBLEMS

I. DETERMINE MINIMUM COST DEPLOYMENT TO ENSURE DESIRED SILO SURVIVABILITY FOR FIXED DEFENSE HARDWARE CHARACTERISTICS

   DEPLOYMENT OPTIMIZED
   DEFENSE TACTICS OPTIMIZED

II. DETERMINE OPTIMUM DESIGN CHARACTERISTICS AND CORRESPONDING DEPLOYMENT COST TO ENSURE DESIRED SILO SURVIVABILITY

   DESIGN CHARACTERISTICS OPTIMIZED
   DEFENSE DEPLOYMENT OPTIMIZED
   DEFENSE TACTICS OPTIMIZED

III. DETERMINE EFFECT ON DEPLOYMENT COST OF RELAXING DEFENSE CHARACTERISTICS OR TECHNOLOGY

IV. DETERMINE EFFECT ON SILO SURVIVABILITY OF CHANGES IN DEFENSE OR ATTACK CHARACTERISTICS (DEFENSE AND OFFENSE REGRETS)

The second problem is the same as the first except that an added optimization is included: that of optimizing the defense hardware characteristics. For example, a typical problem would be that of finding the radar size (range and power) and the computer size (instruction rate) which minimizes overall deployment costs to ensure a desired silo survivability against a given attack. Thus, three types of optimization occur simultaneously:

optimized deployment
optimized tactics
optimized radar and computer size

For this type of problem the relationship between the cost and characteristics of the defense components must be known.

The third type of problem is that of determining how deployment costs increase when off-optimum defense characteristics are used. For example, suppose the optimum computer size is so large that its feasibility is in doubt. The question to be answered, then, is how much would the defense deployment cost be increased if the computer size were reduced. A trade off between total defense deployment cost and computer size is developed which shows the impact of decreased computer size.

The fourth type of problem is that of determining the offense and defense regrets; i.e., determining the effect on the number of survivors if the offense or the defense does not perform as intended. For example, suppose the defense optimizes for a particular discrimination altitude, but later it finds that it cannot discriminate until a lower altitude. What effect will this have on the number of survivors?

HSD EVALUATION SYSTEM AND LINKAGE

The evaluation system for analyzing the types of problems discussed above consists of four separate and independent computer models which treat separate portions of the HSD system and its performance, but which are linked through common variables and parameters so as to provide valid relationships between the overall system cost-effectiveness and component characteristics. (See Chart II). The overall deployment costs are determined by the capabilities and unit costs of four defense components: radar, computer, interceptor, and interceptor farm. The four models are concerned with determining the total number of these four defense components which will provide a specified number of MM silos surviving. By looping or iterating over the critical independent variables, the system configuration which minimizes the total deployment cost is determined.

In general, the evaluation is performed by initially assuming values for the two independent deployment parameters: the number of MM silos covered by the defense and the number of silos covered by an interceptor farm. The Interceptor Inventory Requirements Model (SIRM) determines the number of interceptors required to ensure the specified silo survivability. In this model the offense chooses the attack distribution which maximizes the number of silos killed and the defense chooses the salvo size and number of silos defended per interceptor battery which minimizes the number of silos killed so that a minimax solution is obtained. The number of interceptor farms is computed by simply dividing the initially assumed values of the number of MM silos covered by the number of silos covered per interceptor farm.

For the specified interceptor battery size (silos covered per interceptor farm) the Radar and Interceptor Coverage Model (TACM) determines the number of silos that can be defended by the radar, considering its range, and field of view, and the interceptor flyout characteristics. The total number of radars required is then computed by simply dividing the initially assumed value of total MM silos covered by the number of silos covered per radar.

Using the attack and defense tactics as defined by (SIRM) and the radar battery size and commitment altitudes as defined by TACM, the Traffic Handling Requirements Model (TRAM) determines the maximum instruction rates and radar power characteristics necessary to handle the threat under an assumed attack rate and attack geometry. This model is a time-stepped simulation which computes instruction rate, average power and time occupancy requirements as a function of time.

The Deployment and Cost Model (DECM) computes the system deployment cost based upon assumed unit costs and the numbers of interceptors, radars, computers, and farms obtained from the other models. If fixed values of radar and computing capacity are assumed and the requirements exceed the available capacity, then the number of silos per radar is reduced to meet the constraint which, in turn, increases the number of radars required. To determine minimum costs the initially assumed deployment parameters; i.e., the number of MM silos covered and the number of silos covered by an interceptor farm, are systematically varied and the entire problem rerun for each variation. Likewise, if a defense characteristic is being optimized, the characteristic is varied along with its unit cost and the deployment is optimized for each variation to find the minimum cost value of the characteristic.

There are many ways this system of models can be linked to show different effects depending upon which parameters are taken as constraints and which are assumed to be variables. It is this feature of problem flexibility that makes this modular system of models so useful in evaluating defense alternatives and constraints.

INTERCEPTOR INVENTORY REQUIREMENTS MODEL (SIRM)

SIRM is a minimax model which determines for each defense tactic and for a given number of interceptors, the attack structure which maximizes the number of silos killed, and then finds the defense tactic which is the minimum of the maximums. By iteration the number of interceptors that ensures a given survivability is determined.

Chart III shows a typical result of SIRM where the number of interceptors are plotted as a function of the two principal deployment parameters: the number of silos covered and the number of silos per interceptor battery. The attack is optimized on the number of silos attacked and the split of RV's between covered and uncovered silos. The defense is optimized on salvo size and number of silos defended per interceptor battery.

Chart III shows typical results for silo attack only. When radar attack is considered, the number of silos per radar is required as an additional input. This value is obtained from TACM.

RADAR AND INTERCEPTOR COVERAGE MODEL (TACM)

TACM considers the geometry of the attack and defense and determines the number of silos a given radar can defend as a function of the number of silos covered by an interceptor battery. As the number of silos per interceptor battery increases, so does the flyout time. This results in increasing the required acquisition range for a fixed number of silos covered by the radar. Consequently, for a fixed acquisition range (and field-of-view), the number of silos that can be defended is reduced as the number of silos per interceptor battery increases.

The model optimizes the site location for each interceptor battery. The optimum site is that which results in either (1) the minimum radar range or (2) the minimum interceptor commitment altitude required to protect all the silos covered by the battery against attacks occurring on the most difficult trajectories.

The various inputs to the model are listed in Chart IV. The model gives a systematic method of determining radar coverage as a function of threat and defense characteristics.

An intermediate output of TACM is shown in Chart V. This chart is a representation of a silo field where each block of three numbers represents a group of MM silos covered by a given interceptor farm. Each group contains the same number of silos. This number of silos per interceptor farm is one of the deployment parameters used in the analysis. The three values give the acquisition range, acquisition altitude and commit altitude required of the radar (located as shown) in order to defend all the silos in the group. For any given radar, its coverage capability can be determined by determining all such groups of MM silos that require less range than the radar. Also, other interceptor battery requirements, such as commit altitude or field-of-view can be included. These data can be filtered as shown to determine radar coverage as a function of any set of radar constraints.

Chart VI is a typical output of TACM which is generated by a number of individual runs. It shows radar battery coverage as a function of the range of the radar. Parametric data such as this is used for evaluating many deployments with fixed component characteristics. The dotted line gives the trade-off between interceptor and radar coverage for a fixed radar range.

TRAFFIC HANDLING REQUIREMENTS MODEL (TRAM)

The Traffic Handling Requirements Model determines the instruction rate (MIPS), average radar power and time occupancy required to handle the traffic as a function of time. It is a time-stepped simulation which generates the attack according to the attack rates and directions as listed in Chart VII. The radar field-of-view is divided into several zones (as shown) which correspond to the various radar traffic handling functions. The simulation counts up the number of different types of objects in each zone at a particular time. It then determines the total instruction rate and average power by multiplying the number of objects per region by the required instruction rate and average power per objects appropriate to the radar function, object type and region. Time occupancy is the fraction of time spent by the radar in transmitting and receiving pulses, assuming a pulse cannot be transmitted until the previous pulse is received. The maximum instruction rate, average power requirements and time occupancy are determined by performing the simulation for several times and selecting the maximum values.

The type of results produced by a TRAM run are depicted in Chart VIII. TRAM will show the individual contributions of the various radar functions as well as the cumulative total traffic handling requirements as a function of time. Also, the division of traffic handling requirements between threatening and nonthreatening objects can be determined. (Threatening objects are those directed towards defended silos).

Chart IX gives some typical results of a series of TRAM runs in which the inputs were all made compatible to a fixed number of silos surviving. The figure gives instruction rate required as a function of the number of silos covered per radar for various values of total number of silos covered. The interceptor and RV attack density inputs are obtained from the SIRM model where the number of silos surviving is kept constant as the silo coverage is varied.

The results show a strong dependency of computer requirements on silo coverage. The need for making computations in a systems context is illustrated by the figure. For the lower total numbers of silos covered, the MIPS increase drastically due to the increase in the numbers of interceptors and RV's per silo required for a fixed number of surviving silos.

DEPLOYMENT AND COST MODEL (DECM)

DECM is an often changing model which does the costing of each deployment and chooses the deployment of minimum cost. For each set of independent parameters DECM sums the costs of interceptors, radars, data processors and farms to obtain the total deployment cost.

For a defense system of fixed hardware, the relationship between number of silos covered by an interceptor farm and the number of silos covered by a radar is the tradeoff of most interest in determining the minimum cost deployment. This relationship is a direct output of the radar/interceptor coverage model (TACM) with the exception that it is constrained by the traffic handling requirements as determined from TRAM, and the attack and defense allocations as determined from the survivability model, SIRM. Chart X shows the traffic handling requirements (i.e., instruction rates) superimposed on the TACM data presented in Chart VI. The dashed curves are iso-MIPS (Millions of Instructions Per Second) contours. A given iso-MIPS contour defines all values of interceptor battery coverage and corresponding radar battery coverage which require instruction rates equal to the MIPS value on the contour line. The instruction rate overlays on the coverage data are a function of RV's per silo and interceptors per RV. Since these values are outputs from SIRM, which vary with total number of silos covered (for fixed survivors), each value of total silos covered requires another overlay of MIPS.

Consider a defense system with radar range of R and an instruction rate capacity of M. For any value of interceptor battery coverage, the radar battery coverage possible would be constrained to the shaded region bounded by the iso-range curve R and the iso-MIPS curve M. This region then defines the allowable deployments (interceptor battery coverage and radar battery coverage) which are compatible with the above hardware requirements on radar range and instruction rate. To make maximum use of the hardware the defense would consider only those deployments which lie on the bounding curve (i.e., maximum allowable radar battery coverage for a given interceptor battery coverage).

Using this relationship the component and total deployment costs can be readily computed as a function of interceptor battery coverage as shown in Chart XI. The farm costs and interceptor costs decrease as interceptor silo coverage increases. The radar costs, on the other hand, increase with the interceptor coverage. This results in a characteristic "bucket" which defines a clear minimum cost value of silos per interceptor battery and the corresponding value of silos per radar. By determining the minimum cost deployment for each value of total silos covered by the defense, the value of the total coverage which results in an overall minimum deployment cost can be determined as shown in Chart XII.

We can now see how to determine the impact on cost effectiveness of variations in computer technology. Referring to Chart X, we can imagine that the computer can have any value of instruction rate. By systematically varying the instruction rate, a series of the bounded curves (relationships between interceptor battery coverage and radar battery coverage) are obtained. For each value of instruction rate assumed, the minimum cost deployment can be determined as before, assuming that the unit computer cost is a function of instruction rate.

The final relationship between minimum deployment cost and instruction rate is shown in Chart XIII. This curve shows a minimum cost value of computing capacity. However, the most interesting message from this curve is the great reduction in the required instruction rate technology that can be purchased for only a slight increase in deployment costs.

By following a procedure similar to that described above, it is possible to independently or collectively optimize any number of defense characteristics. Chart XIV shows a typical example wherein both computer capacity and radar-acquisition range are varied taking into account the changes in unit cost. In this case interceptor battery coverage, radar battery coverage and the number of silos covered with a defense are taken as independent variables. The range and MIPS required for each combination of independent values is determined from data like that shown in Figure X. The unit costs for the radar and computer are then determined from component cost versus performance data. For each set of independent deployment parameters the total deployment cost is computed. Chart XIV shows the deployment cost variation with all three of the independent deployment parameters. Also, the required MIPS and acquisition range are noted for various cases. The examination of those values in relation to the overall deployment cost will show the impact of relaxing either instruction rate or acquisition range or both.

SUMMARY

The hardsite defense evaluation system has been used successfully in evaluating radar range and computer instruction rate requirements against various threats. The system is continually being modified and expanded to examine other defense characteristics.

The system of techniques has proven to be highly valuable as a means of isolating key HSD system parameters, to identify the optimum operating range and to show the impact of off-optimum values. The description of the defense system characteristics is simple, but it is this feature which enables the system picture to be shown clearly so that the driving factors which govern HSD cost effectiveness can be determined.

CHART II

HSD SYSTEM MODELS AND LINKAGE

Deployment Inputs:
① Total Number of Silos Covered by Defense
② Silos Covered by an Interceptor Farm

Threat Inputs:
③ Number of RV's plus Decoys
④ Trajectories plus Discrimination Altitudes
⑤ Attack Rates

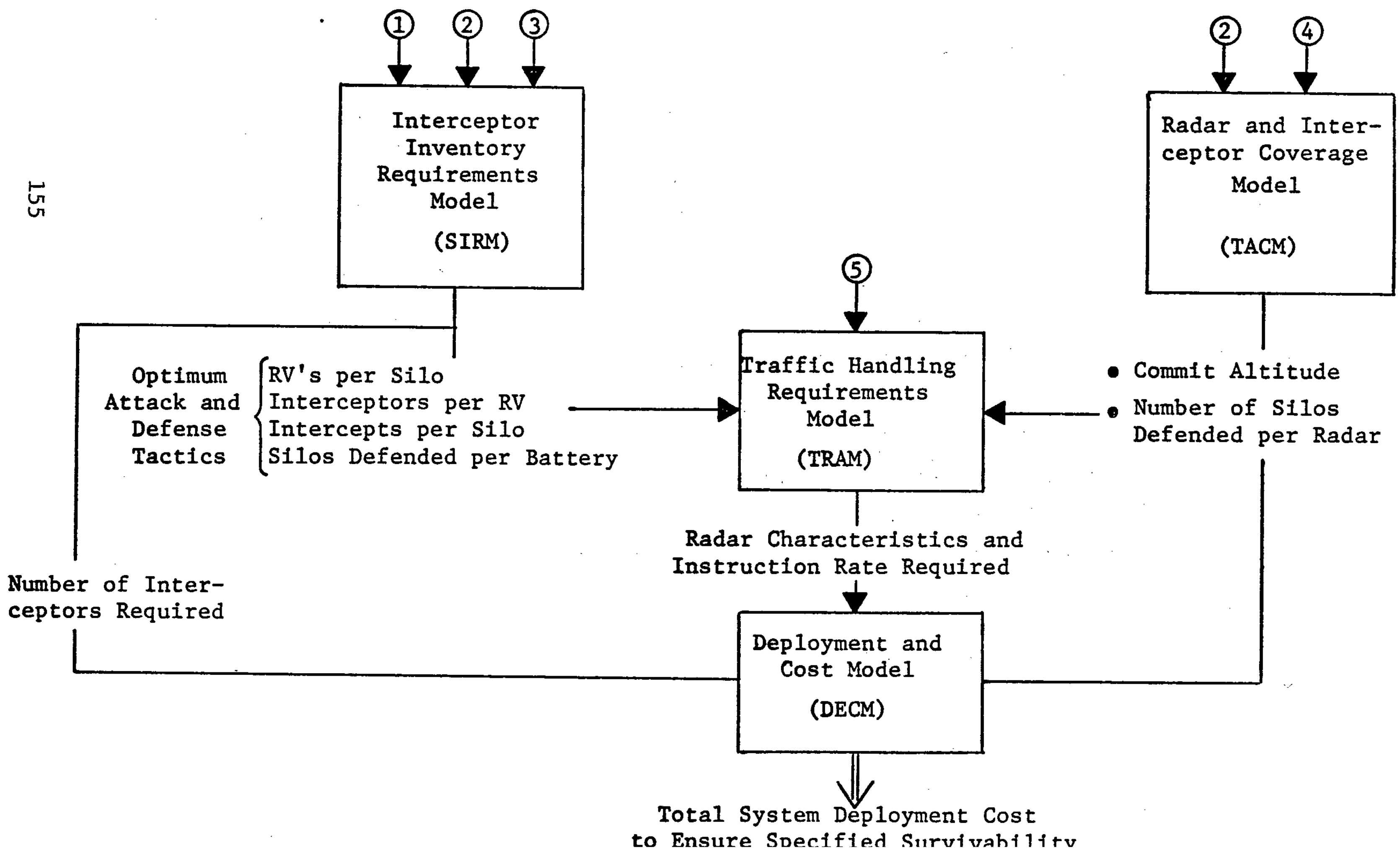


CHART III
INTERCEPTOR INVENTORY REQUIREMENTS MODEL (SIRM)

- Computes number of interceptors required to ensure given silo survivability
- Determines optimum attack and defense factors

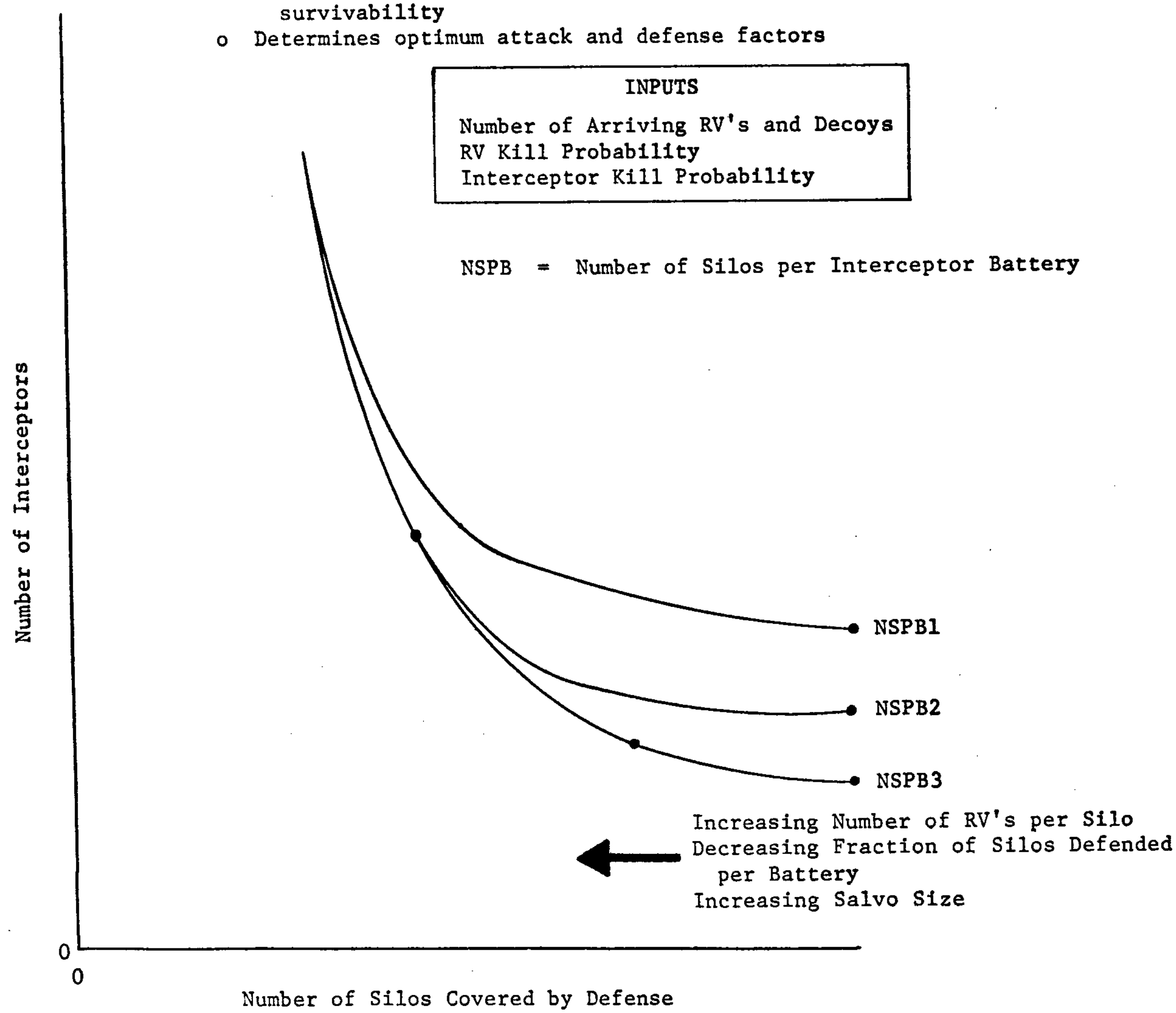


CHART IV

RADAR/INTERCEPTOR COVERAGE MODEL (TACM)

FOR GIVEN RADAR COVERAGE (SILOS PER RADAR), MODEL COMPUTES RADAR RANGE AND FIELD OF VIEW REQUIREMENTS

FOR GIVEN RADAR CHARACTERISTICS, MODEL COMPUTES MAXIMUM NUMBER OF SILOS COVERED BY RADAR (OPTIMUM INTERCEPTOR SITING)

INPUTS

RADAR	RADAR AZIMUTH GATE RADAR ELEVATION GATE CLUTTER ANGLE PRETRACK DURATION
INTERCEPTOR	NO. OF SILOS PER INT. BATTERY INTERCEPTOR FLYOUT PERFORMANCE
TARGET	KEEPOUT RADIUS SILO SPACING BATTLE SPACE REQUIRED
ATTACK	REENTRY ANGLE BALLISTIC COEFFICIENT AZIMUTH ATTACK DIRECTIONS

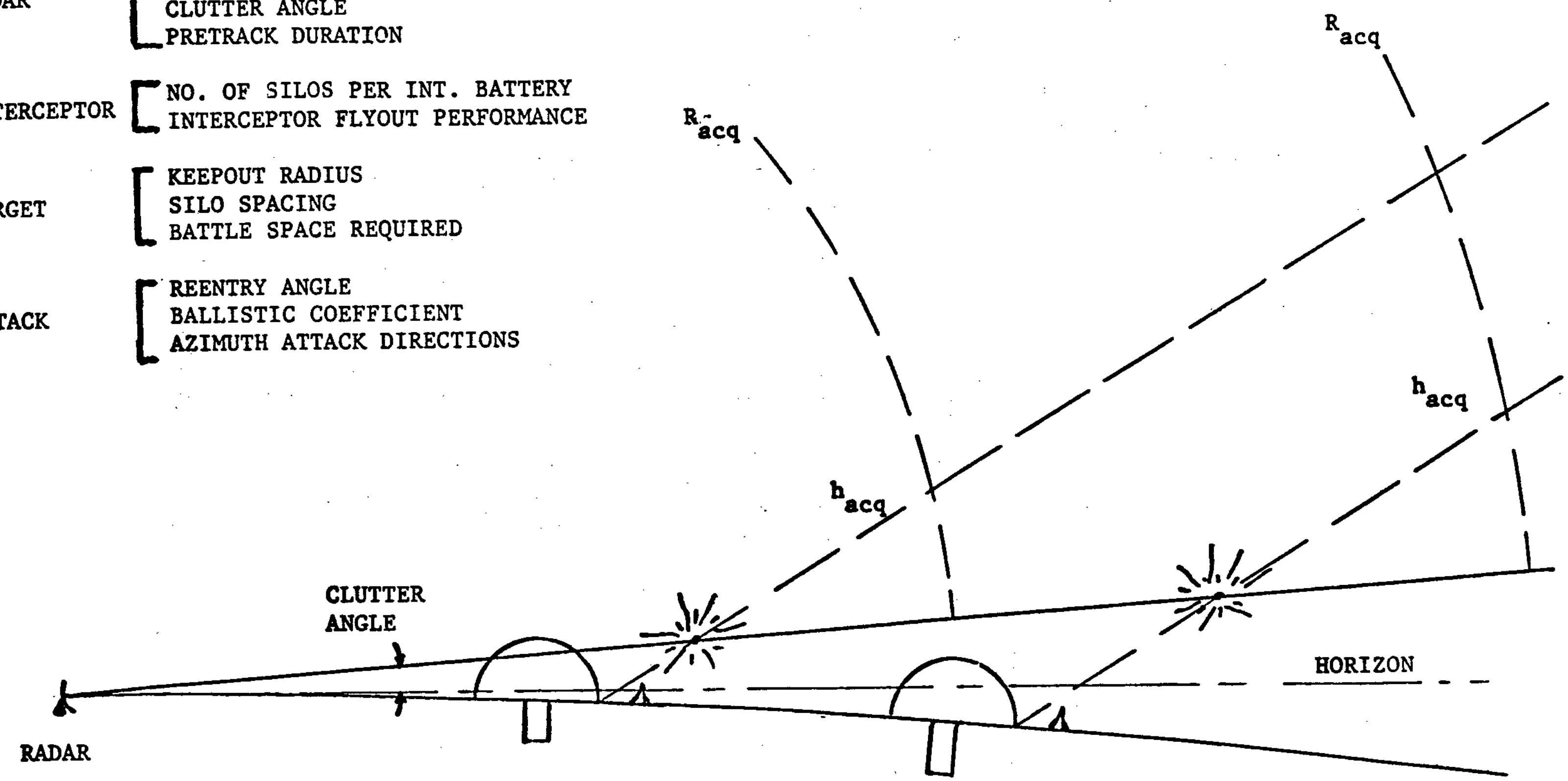
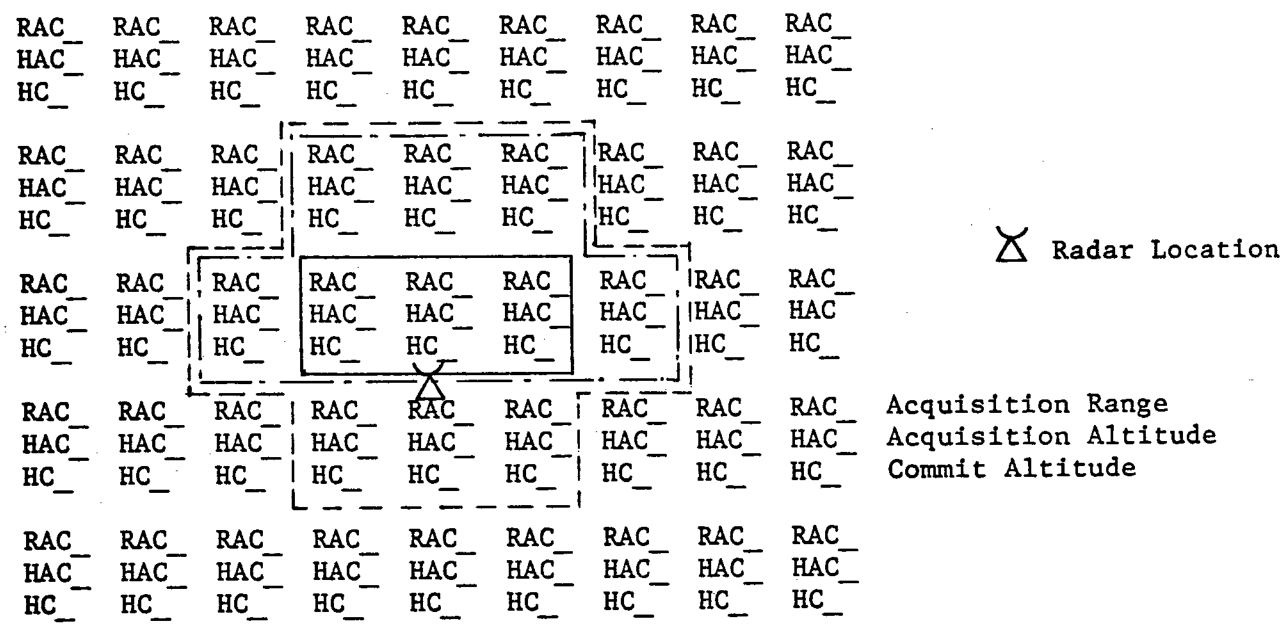


CHART V

RADAR COVERAGE DATA (TACM)

Silos per Farm = -



——— Silos Requiring ≤ R_1 NM Acquisition Range
— — — Silos Requiring ≤ R_2 NM Acquisition Range
— · — Silos Requiring ≤ C^2 KFT Commit Altitude

CHART VI
RADAR COVERAGE REQUIREMENTS

TGT Field Attacked TGT Spacing Keep out Radius Radar Site Radar AZ	INPUTS	Radar EL Interceptor Attack AZ Reentry Angle Battle Space

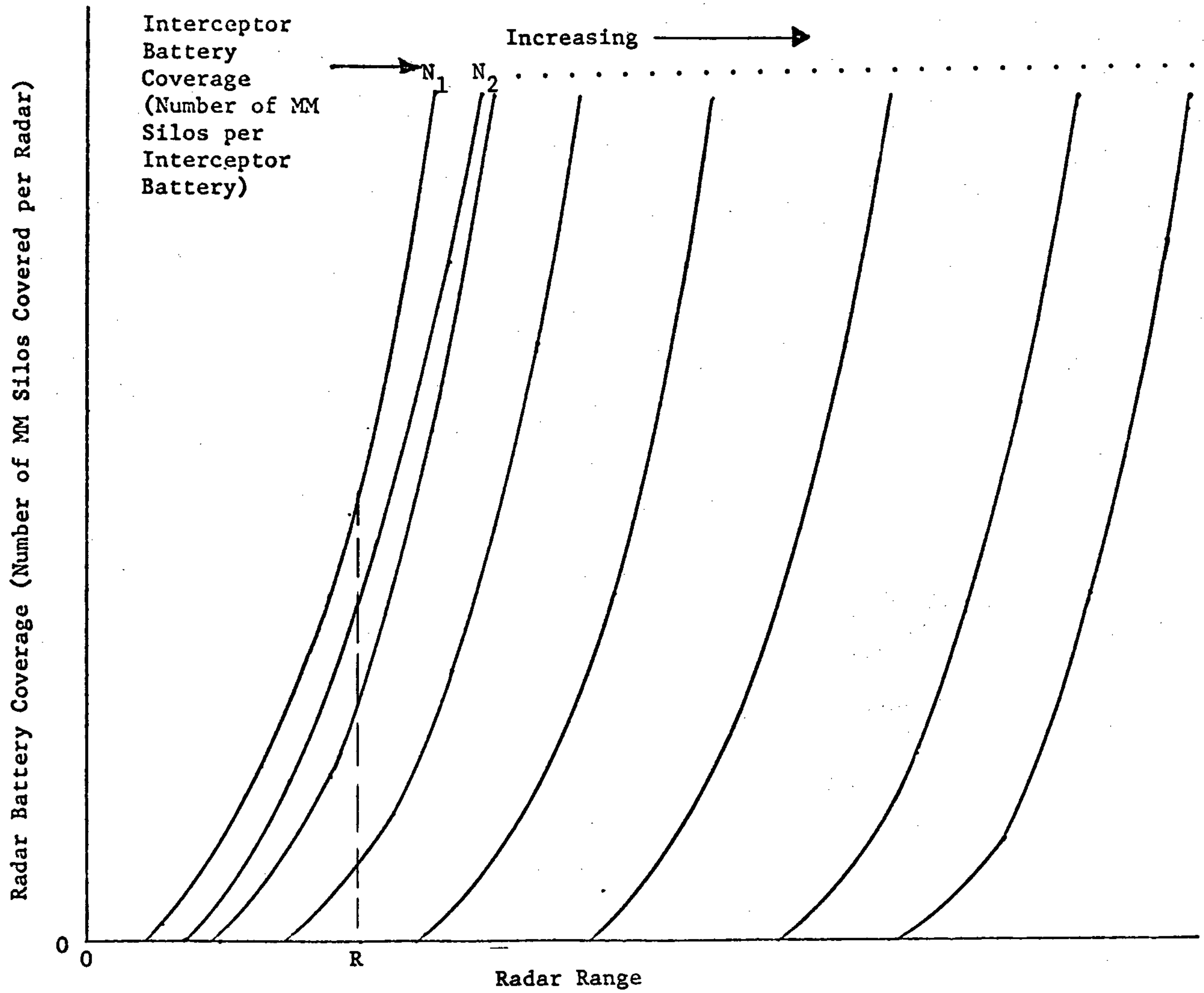


CHART VII

TRAFFIC HANDLING REQUIREMENTS MODEL

(TRAM)

INPUTS

DEFENDED AREA
- o SIZE OF SILO FIELD
- o SILO SPACING
- o LOCATION OF RADARS
- o SILOS DEFENDED BY RADARS
- o SILOS ATTACKED

PAYLOAD
- o NO. OF RV's, DECOYS & JUNK PER PAYLOAD
- o PAYLOAD OBJECT SPACING
- o NO. OF RV's & DECOYS PER SILO

ATTACK
- o INTER OBJECT TIME SPACING ON SILO
- o INTER SILO TIME SPACING
- o ATTACK DIRECTIONS & ELEVATIONS

RADAR, INTERCEPTOR, DATA PROCESSOR CONSTRAINTS
- o EFFECTIVE NO. OF INT. PER THREATENING OBJECT
- o RADAR AZ, EL GATES
- o DATA PROCESSING FACTORS
- o ACQ. & COMMIT RANGES & ALT.

OUTPUTS

- o NUMBER OF OBJECTS VERSUS TIME BY TYPE & REGION
- o REQUIRED MIPS VERSUS TIME
- o REQUIRED PEAK POWER
- o REQUIRED AVERAGE POWER VERSUS TIME
- o REQUIRED TIME OCCUPANCY VERSUS TIME

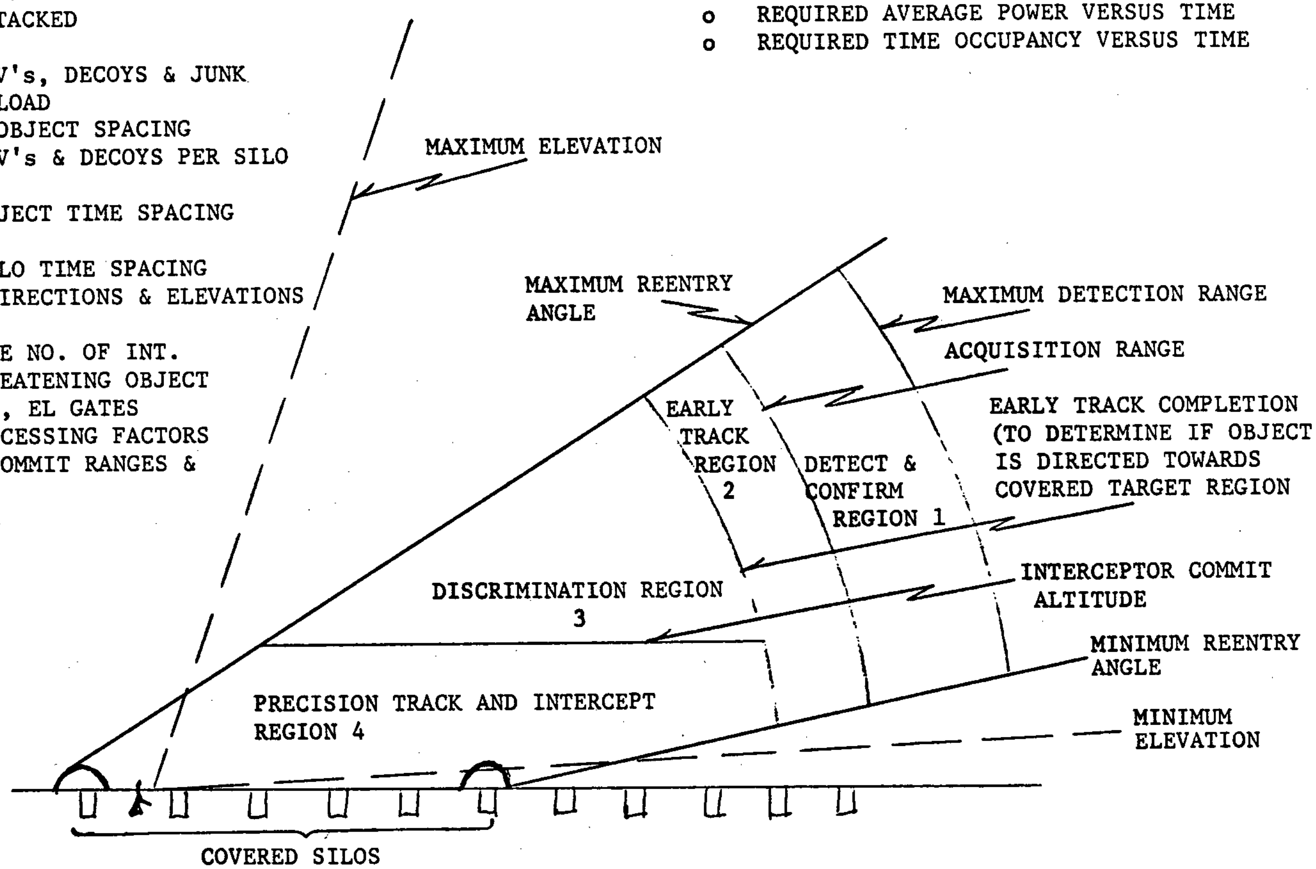


CHART VIII

RELATIVE IMPORTANCE OF THE VARIOUS TRAFFIC HANDLING FUNCTIONS (TRAM)

GIVEN: Deployment; i.e., silos defended per interceptor battery and silos per radar
Attack Characteristics

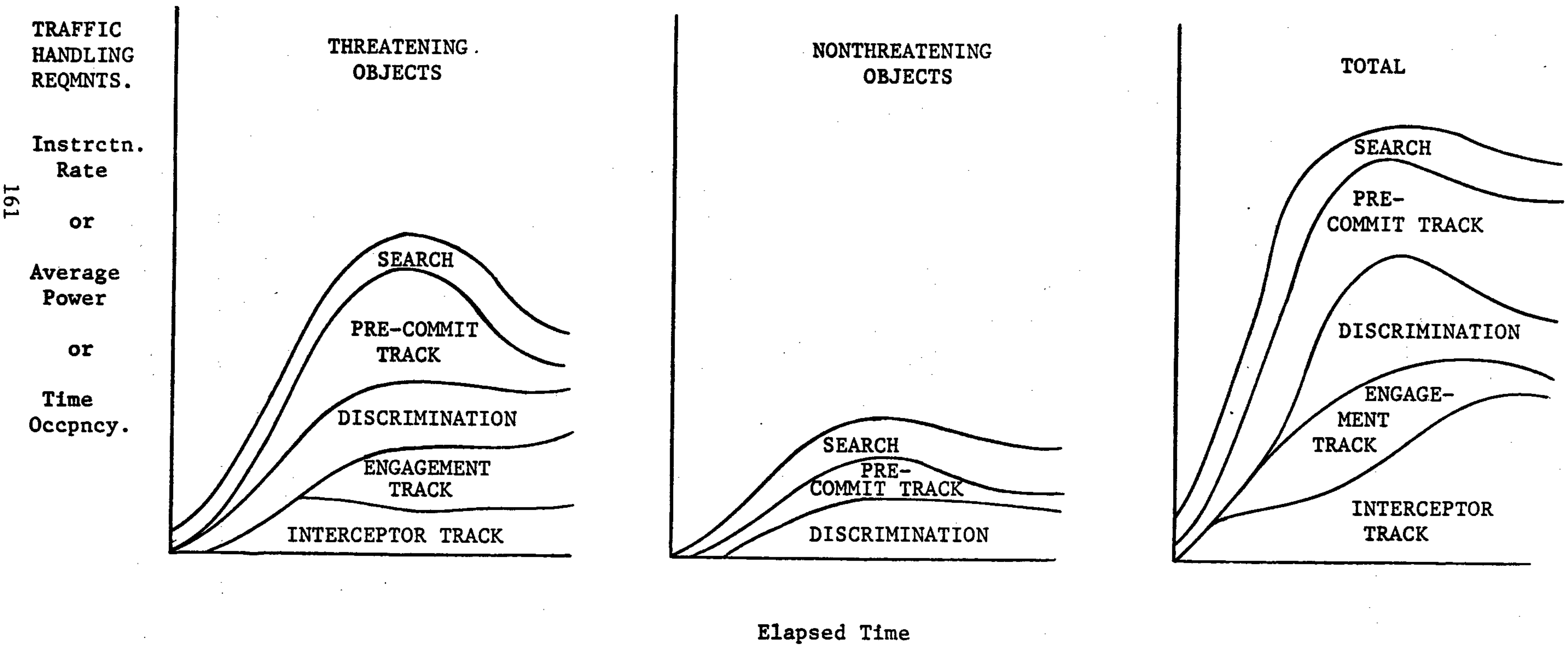


CHART IX

INSTRUCTION RATE REQUIRED TO
MAINTAIN A FIXED NUMBER OF SURVIVORS

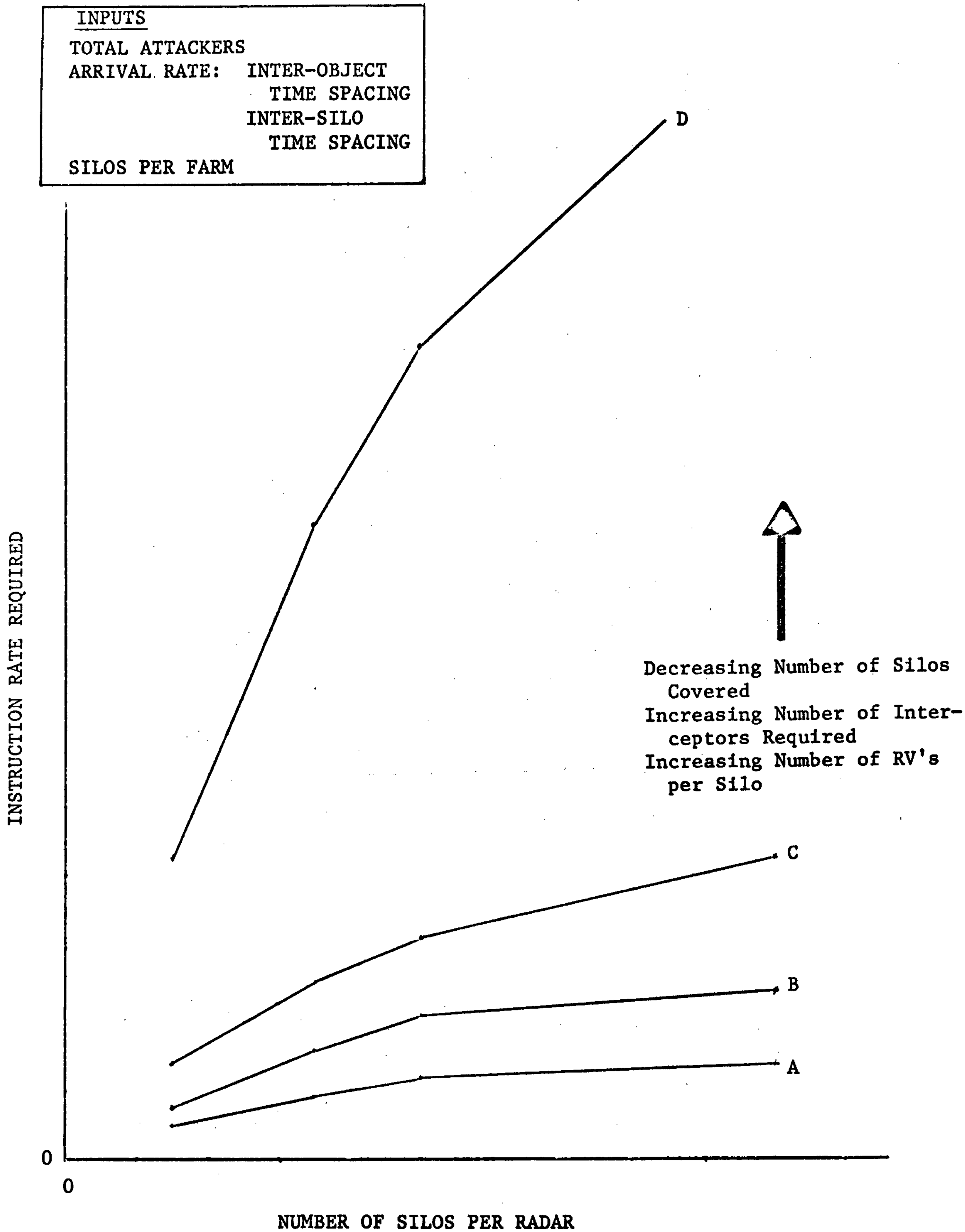


CHART X

RADAR BATTERY COVERAGE AS CONSTRAINED BY INSTRUCTION RATE AND ACQUISITION RANGE

TGT Field Attacked TGT Spacing Keep out Radius Radar Site Radar AZ Battle Space	INPUTS	Radar EL Interceptor Attack AZ Reentry Angle RV Attack Rate RV's per Silo Interceptors per RV

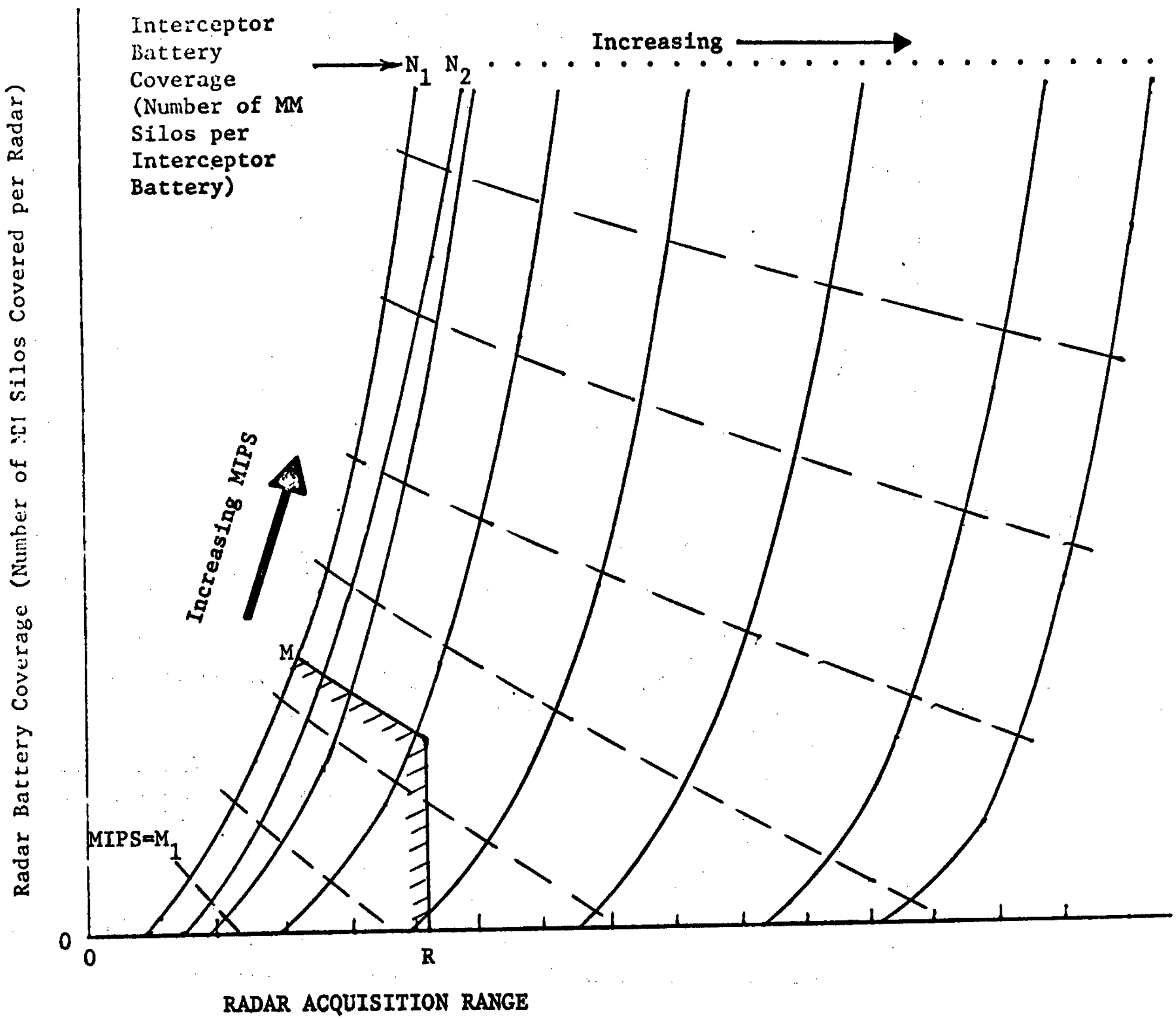


CHART XI

DEPLOYMENT COST OPTIMIZATION
FOR DEFENSE OF FIXED CHARACTERISTICS

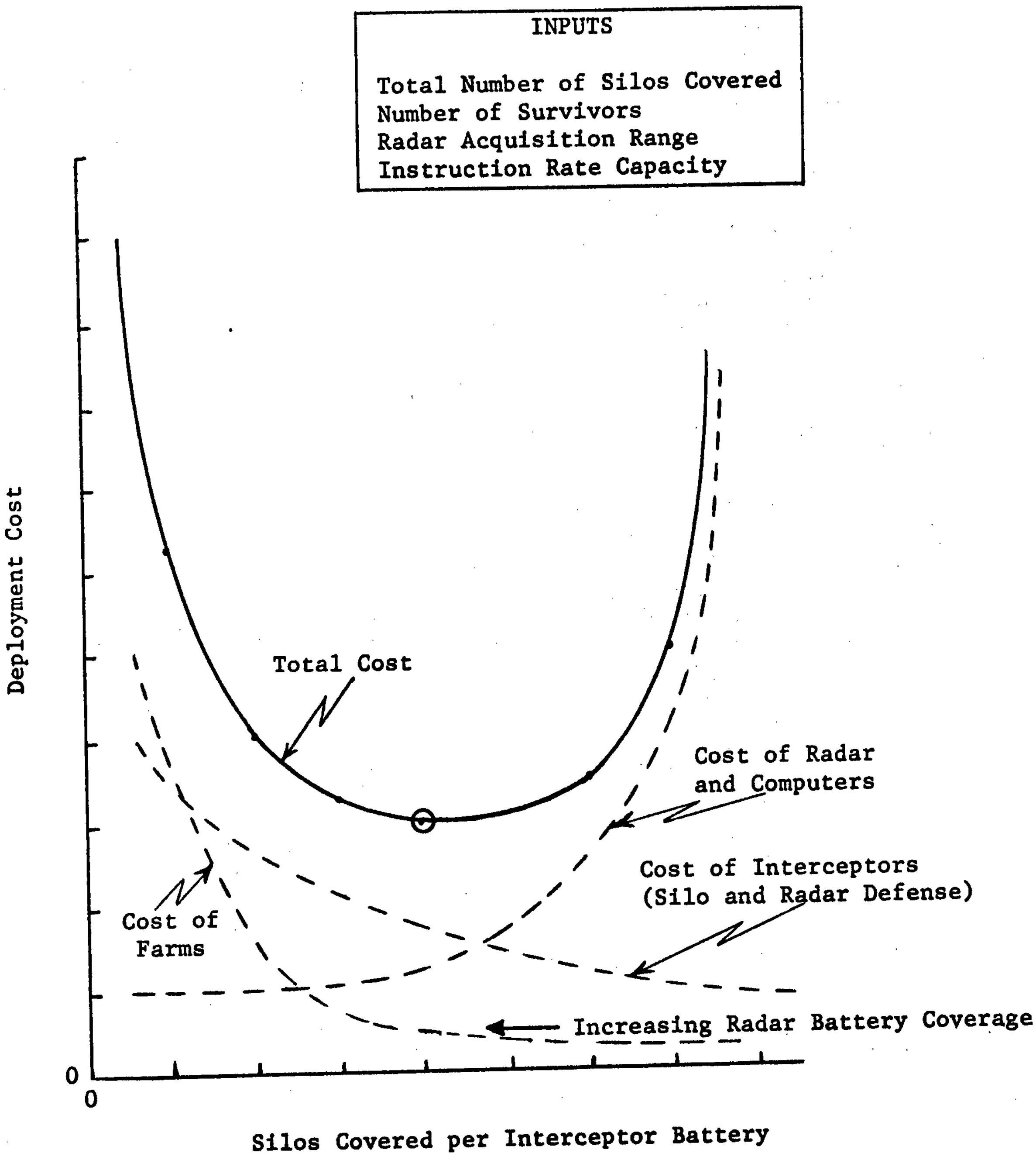


CHART XII
EFFECT ON MINIMUM DEPLOYMENT COST OF TOTAL NUMBER OF SILOS COVERED

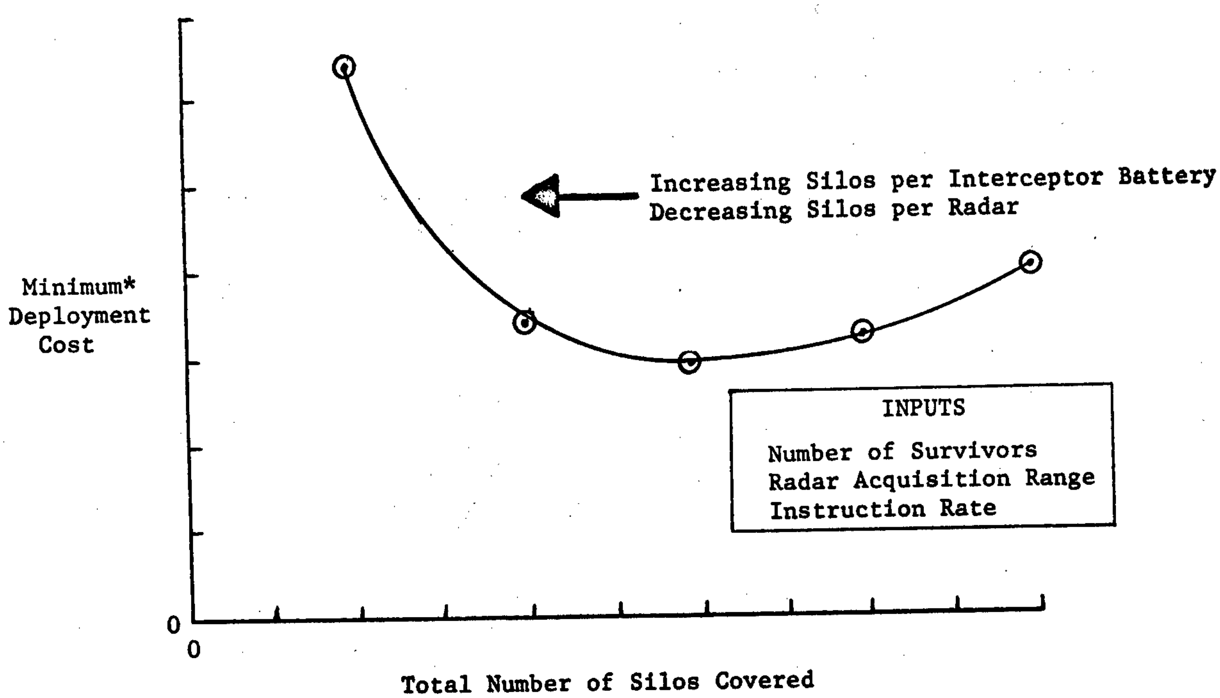


CHART XIII
EFFECT OF INSTRUCTION RATE CAPACITY ON DEPLOYMENT COSTS

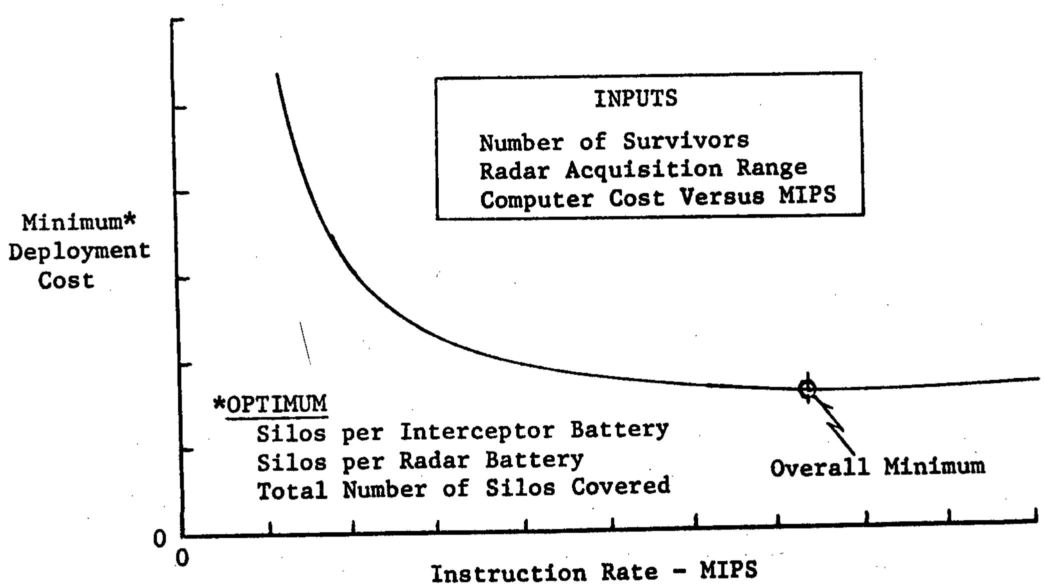


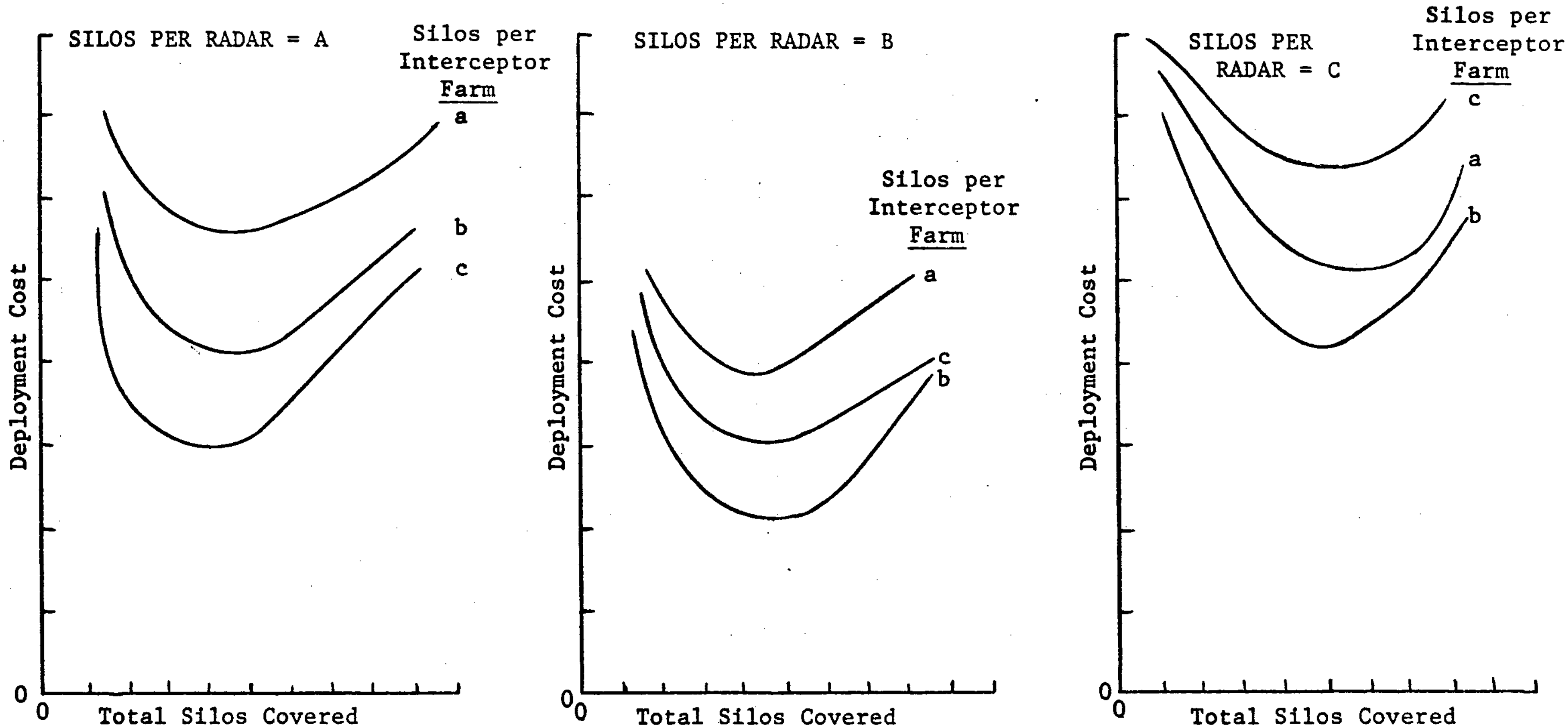
CHART XIV

OPTIMIZATION OF ACQUISITION RANGE AND INSTRUCTION RATE

INPUTS

Silos Surviving
Attack Characteristics
Radar Cost Versus Acquisition Range
Computer Cost Versus MIPS

Instruction Rate and Acquisition Range Optimized for Each Point



CHALLENGES IN MILITARY OR IN THE 70'S

Dr. Clive G. Whittenbury, Vice President
Research Analysis Corporation
McLean, Virginia

In the next few minutes I am going to make a few observations, raise a few issues, and offer a suggestion or two. The purpose is to raise questions in your own minds about future directions in Army operations research, both how it will be done and in what areas. I must warn you that this handful of comments are offered to provoke your thoughts, and are not collected from a learned study of the profession.

When we refer nowadays to operations research, we tend to stretch our view to cover a large variety of logical and systematic procedures, some of them involving advanced mathematics, but many involving only simple arithmetic, which are applied to solving many different kinds of problems in military planning and decision making. It is this view that I will be referring to today and that I would like to disect.

The challenges to military OR in the next decade fall in two areas: challenges to the profession itself and challenges posed by military problems.

These challenges arise from the changes in skills, their practice and in the institutions as well as from some fundamental changes in the defense environment.

We have entered a maturing period for the profession, in which the practitioner must decide clearly what services he is providing and the client must commit himself to what he wants. Otherwise there will be serious questions about both the market and the capabilities to serve the market. We are really talking about three kinds of services: one in which special OR techniques are applied to quantitatively defined problems, another in which the professional services overlap the clients responsibilities (for instance in systems evaluation and management) and a third in which significant and not well-defined problems are posed, analyzed and solved. In the first and second kinds, specific disciplines or techniques qualify the professional. While these capabilities were once unique or specialized enough to justify separate groups or independent centers to which clients went for most of their needs, they have now been assimilated alongside the many other capabilities required to solve the normal problems of planning and management within the client organization. The challenge to the professional here is to reexamine and determine his role under these changing circumstances.

The third kind of service, so called problem solving, is the main feature of many of the established OR groups. Paradoxically, although they started on specific types of problems and developed methodology or analytical techniques for solution, the resulting mathematical techniques comparising OR now play only a secondary, and usually a minor, role in their work. Rather, it is necessary to rely on an experience and sustained high performance solving problems earlier as a part of the client community or through an apprenticeship in the profession. The challenge to the profession here lies in the relationship with the client and the basis for contracting services. First, there is a significant overlap with the functions and responsibilities of the client: thus, if the client is not basically committed to this service it has no chance of succeeding, and projects conducted like an adversary proceeding do no one any good. The practitioner must meet the challenge of differentiating between the logical need for his objective, outward-looking service and the practicality of encouraging the market and then performing in it. Second, the problem-solving service must be differentiated from the technical service, since the former deals with undefined problems and sells experience and track record in applying this experience while the latter (technical services) sells specific testable capabilities on defined problems. The challenge here is to develop a performance award method of competition to be followed by negotiation of price, instead of the classical bid exercise which is usually appropriate for well-defined technical services. One shouldn't attempt to buy new ideas through a low bid, any more than one goes to the cheapest lawyer in town. On the other hand, while quality costs money there must be a way of ensuring that you get quality. An important accompanying challenge is the code of ethics approach to quality control, which has not been practiced in OR and related management consulting as it has been in the other professions. Such a code of ethics or its equivalent would simplify the contracting procedures referred to.

Before leaving the challenge to the profession itself, it might be useful to clarify what was meant by the maturing period for the profession.

From a well-defined set of activities in a limited number of places, the practice of OR has experienced widespread growth in technical scope and application since WWII. This has been accompanied by a general confusion of terminology used to describe what people have been doing, as well as by uncertainty concerning the specific qualifications of people working in the area. The "systems approach" became a substitute for specific technical capabilities in taking on a problem: in fact a pinch of jargon paraded under the heading "systems analysis" almost became a license to invade other professions. We all know what sort of problems that led to in the past. All of this has taken place in a period, particularly during the early and mid-sixties, in which budgets and attitudes were sufficient to underwrite all kinds of experimentation. This experimentation in support of management was directed toward efficiency in the use of funds and toward making objective and rational decisions, for example through system evaluation and various analytic management techniques. In recent years we have begun to see a weeding of these activities, because of the discipline of tightening budgets and the sharpening test of operations research and related services against well understood technical needs and the importance of actual results.

We are moving then, over the next decade, into a period when the challenge to military OR will be met by a set of capabilities which have matured, from the point of view of the practitioner and the client, into quite specific classes of activities.

Military problems which arise from fundamental changes in the defense environment pose the most important challenges to military OR. These problems arise from two main sources: the deteriorated attitude toward the military (its activities and institutions) as expressed by the media and some publicly represented opinion; the shrunk budget for defense, particularly research and development. As a handful of key problems are indicated in the remainder of this brief talk, you will see the connection to these two sources of difficulties.

Attitudes expressed toward defense through declining funding will limit the purchase of new weapon systems and constrain the base for research and development. Improvements in operational performance and successful products from R&D must come on the first attempt and have a significant impact on our military capability. This means that innovation, not just in hardware but in operational concepts, doctrine and organization, must be solicited, encouraged, and experimented with. Some of you may protest that this isn't a problem and that we do well, but others may feel that chloroform rather than encouragement is the commodity in most plentiful supply when a new idea raises its head. It would be interesting to hear your views.

The path to innovation is not easy, because it upsets existing knowledge, experience, training, organization and the totem poles which surround accepted hardware. It may be the only route to achieving high operational performance and an edge over the enemy--weapon system performance will be critical under low budgets. We are going to find out a few years from now what a deadly serious business innovation in national security capabilities will have become. It is in the area of innovation that we may find the most critical application of systematic analysis using OR techniques. Where experience is lacking because of a new concept, such analysis provides the only way of representing future operations, testing alternative ideas and planning field experiments.

Attitudes toward defense, concern for our own people and, once again, costs, lead us toward capital-intensive, or at least less people-intensive systems. This applies all the way from administrative and logistics systems to combat. The challenge to, and utility of, OR and related activities in most of these areas is straight forward, but in combat systems specifically we must keep trying hard to unravel some of the fine structure of close combat. One of the most challenging problems to OR will continue to be the analysis of close combat or its possible replacement in terms of the purpose of the participants, measures of their success, how they achieve success and how the terrain and other environmental characteristics influence the whole operation, in general and in high resolution with all its subtleties. Since land warfare is built around this set of central issues and the role of the individual, maybe a major effort is in order on several fronts. We experiment in each war and find out the individuals role, and some imaginative things can be done quickly. For example, when the going gets rough, we try replacing him with a planted sensor. Where are the efforts which take a broader and an early enough look at this critical problem?

As a last challenge, we face the possibilities of our forces being deployed in CONUS rather than being deployed overseas. How do we meet the readiness problem for the Army in being? This will pose a renewed set of problems for practical OR.

Finally, lets return to the relationship between the military and society at large. Challenges to military OR in the seventies will often be synonymous with challenges to the military. Some of the traditional support and help from civilian institutions, including universities, individuals, foundations, have come into jeopardy, although we are moving into a time when this help will be needed most. However in the OR community you have technical qualifications, you have experience which tracks with your own, you have understanding, sympathy and an attitude that your problems are consequential; but most important you have a motivation alongside this problem-solving capability which could go a long way to helping meet this challenge to the Army of the 70's.

CHALLENGES IN MILITARY OR IN THE 70'S

Mr. David C. Hardison
Headquarters, US Army Combat Developments Command

Thank you Mr. Chairman. In order to save most of our time for Panel discussion of points of the most general interest, I will be quite brief and proceed almost immediately to the several specific near-term challenges to military OR that I wish to mention. Some of the challenges involve mainly matters of military substance, some involve mainly OR tools, and some involve the military OR profession, but most involve all three, so let's go directly to the several specific challenges which I want to table.

CHALLENGE 1: DEVELOP AN ARITHMETIC OF INFORMATION SYSTEMS.

Our ability to accomplish the fire, movement and support functions of land combat, on the whole, exceeds our abilities to accomplish the intelligence and control functions. Technological advances in solid state electronics, sensors, communication devices, and computers offer promise of major advances in information systems. Our knowledge of how to appraise the performance of information systems is poor and our experience in testing such systems is limited and not altogether satisfactory. We must develop a better way for assessing the performance of intelligence and control systems and determining the relation of performance to combat effectiveness. We are now committing substantial resources to buy hardware for these areas and even greater expenditures are forecast. The military OR challenge is apparent.

CHALLENGE 2: UNDERSTANDING THE MAIN WAYS IN WHICH NIGHT OPERATIONS DIFFER FROM DAY OPERATIONS.

The past decade has seen an increase in night operations. The next decade promises even more. Military OR has contributed too little to the understanding of differences between night operations and operations conducted during periods of light. OR studies, for example, typically have assumed that differences will be primarily in ranges at which targets can be acquired for engagement with direct fire systems. Thus these studies have looked not at night fights but mainly at night sights. Control, movement, support, and human factors at night may be quite different from daylight. We need to understand the nature of these differences. And we must consider them in the design and employment of those elements of our forces which are to fight continuously, or mainly during periods of darkness.

CHALLENGE 3: IDENTIFY THE BEST BALANCE OF AIR MOBILE AND GROUND MOBILE FORCES TO OPPOSE A MODERN ARMORED FORMATION.

Much has been learned in Vietnam regarding the use of air mobile forces in low intensity warfare. Controversy remains however as regards the application of the principles and tools of air mobility to the European battlefield. Questions often arise concerning: aircraft survivability when opposed by forward deployed air defense missiles and radar directed automatic weapons; aircraft dependibility during periods of darkness and adverse weather, and; economic feasibility of fielding major air mobile forces. Some persons at times appear to propose programs which would result in all forces being air mobile while other persons seem to resist any air mobility. Neither extreme view will obtain and participation in the determination of the best balance offers many OR challenges. Experiments with the Air Cavalry Combat Brigade and the TRICAP divisions will be very important, and military OR analysts can play a challenging role and make significant contributions to the understanding of this important matter.

CHALLENGE 4: DEVELOP IMPROVED UNDERSTANDING OF THE ROBUSTNESS OF HIGH ORDER SYSTEMS.

Compared to systems of earlier times, modern military systems are not only more sophisticated but also of a higher order. Elements of forces have become more interdependent and less capable of efficient autonomous operation. Concern for vulnerability of key control elements increases. The power brown-out of N.E. USA a few years back is an illustration of a failure of a massive network of interconnected systems resulting from failure of a relatively small part which was not decoupled in a timely manner. TACFIRE, CS3, TOS, REMBASS and IBCS remind us of the need for a better way to assess the vulnerability of complex systems and a better rationale for robustness of design to counter catastrophic failure of the whole as a result of loss of a part.

CHALLENGE 5: BUILD AND USE A MORE WIDELY ACCEPTED FRAMEWORK FOR ORGANIZING AND EXTENDING OUR KNOWLEDGE OF MILITARY SYSTEMS AND OPERATIONS.

During the past two decades, the number of persons practicing military OR has grown quite remarkably. It is easy to cite examples of OR work done at a particular time which failed to reach the level of understanding previously attained by earlier researchers. To learn what is known and what is unknown in a particular area, one first usually must find who did what and where he now is. Our knowledge storage and retrieval schemes need much improvement and a better taxonomy well might be a good starting point.

CHALLENGE 6: DEVELOP A LANGUAGE AND LOGIC FOR DESCRIBING METASYSTEMS AND, CONSISTENT THEREWITH, BUILD AN INTEGRATED HIERARCHIAL SET OF MODELS OF A THEATER LAND FORCE AND ITS SUBORDINATE DIVISIONS, UNITS, ELEMENTS, AND ITEMS.

We need a language for common use in the study of forces, divisions, units, elements, items, and components of the land combat systems. And we need a coherent plan to develop (perhaps evolve is more descriptive) models of all parts of the land combat system. The need includes models which range from a single wide scope, low-resolution representation of theater land forces to several small-scope (but high-resolution) models of units and items. The several high resolution models should produce outputs suitable for use as the main inputs for the higher level models.

CHALLENGE 7: PRACTICAL MEANS FOR EVALUATING A WIDE RANGE OF OPTIONS FOR A VERY LARGE SCALE SYSTEM.

We have no fully satisfactory way to examine a wide range of design options for large scale systems. This is especially the case for conceptual system designs which differ from traditional ones in fundamental ways. Large scale systems (such as an Army division) can be examined empirically, but the resources required to test them are so great that the number of options which can be tested are few, typically just one. Divisions can be modeled analytically but with low credibility. Computer played simulation models of large scale systems often are so cumbersome as to be useless or, alternatively, they smooth over the fine grain differences which are thought to be of critical consequence. The continuing challenge to the OR community is to increase our capacity to preserve important detail even while extending the scope of matters treated as a system.

CHALLENGE 8: ACQUIRE REQUISITE PROCESS KNOWLEDGE OF MILITARY OPERATIONS.

One still sees evidence that some of us think we can model processes which we do not understand. The previous comments regarding night operations offer a specific example of this. Many others can be suggested - target acquisition, personnel suppression, decision processes, etc. The need to return to empirical observation to formulate process theories suitable for independent and empirical validation or refutation is hardly new, but it will always be a noteworthy challenge in military OR.

CHALLENGE 9: DEVELOP A DISCIPLINED SET OF MEASURES OF EFFECTIVENESS (MOE) APPLICABLE TO ARMY SYSTEMS.

Goals, objectives, tasks, characteristics, performance, costs, effectiveness, efficiency, and criteria are important - but different - notions. Perhaps no single matter in military OR deserves more clear thinking, and few receive less. Without adequate analysis of mission, "faster" is taken as "better" and the familiar circular route to "costlier," to "too few," to "austere," to "ineffective," to "improved" to "faster," to.... It's time to get our MOE house squared away. If you're not already keenly aware of this problem you won't catch up as a result of a few remarks so let's just drop this one without further comment.

CHALLENGE 10: EXPAND THE USE OF PEER CRITIQUES AND FEEDBACK FROM SERVICE USE OF ARMY SYSTEMS TO CHALLENGE OR THEORIES, AND DISSIMINATE NEW KNOWLEDGE TO MILITARY OR COMMUNITY.

An important characteristic of all science has been openness to challenge by peers. Due in part to security practices, military OR suffers from overcompartmentalization and lack of technical scrutiny. Many rules - those concerning 30% casualties, FEBA movement rates, proper support to combat force ratio, etc. - appear to have migrated from precept to tradition through countless unchallenged generations of quotes, footnotes and use. Some have become almost "laws" of military operations. Validation checks using combat records and field experiments are not as widely sought as laymen would suspect and, where new insights are gained, dissimination is sluggish.

CHALLENGE 11: PURGE THE ANALYTIC QUACKS, EARN CREDIBILITY, AND TRANSITION TO REALITY.

Military OR has more than its fair share of incompetents. It lacks adequate professional standards for analysts. It uses military "experts" by assignment who attempt both to supervise OR and serve as its client. Its practitioners include too many persons who have much not very recent military experience and low ability to cope with abstractions or change. No novel suggestions here, only the observation that one important challenge to military OR is the elevation of its professional standards to exclude the analytic quacks. Without this, military OR will not be able to bring its promises and its products into substantial agreement.

CHALLENGE 12: USE MILITARY OR RESOURCES MORE EFFICIENTLY, ESPECIALLY USE COMPUTERS MORE EFFICIENTLY.

It's time for the military OR community to grow up, to better manage itself, and to tell the sponsor what it can and cannot now do for him. Better internal management of OR, better definition and acceptance of the limits of current OR, and more open communication with the sponsor seem simple challenges. Their attainment is by no means certain so they deserve inclusion as a reminder to us all.

CHALLENGES IN MILITARY OR IN THE 70'S

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Prior to about 1960, military operations research studies were concerned primarily with determining the effectiveness of military systems. Studies were performed to determine the effectiveness of small scale systems, such as individual types of weapons, as well as large scale systems, such as division-size military forces. Late in the 1950's, there began to be an interest in cost, as it relates to effectiveness. One of the first applications that I can recall of what has come to be known as cost-effectiveness was in the area of nuclear warhead technology. Fissionable material was relatively scarce and expensive. The defense community became interested not only in the yield of the nuclear warhead, but in how many kilotons of yield could be obtained for each kilogram of fissionable material expended. This kind of rudimentary cost-effectiveness study has developed over the last ten or so years into what we have now -- the firm and obvious requirement to investigate not only the benefits of proposed alternate military systems and courses of action, but also the economic penalties associated with these alternatives.

Now what about the next ten years. Of course we all have heard of risk analyses. The techniques for performing risk analyses will certainly be refined over the next few years, for the desirability of assessing the economic and technical risks associated with competing courses of action cannot be questioned. There also will be developed improved techniques for conducting economic analyses of military systems. However, the greatest technical challenge, as I see it, lies in the area of system effectiveness, where the whole thing started twenty or more years ago.

For many military systems, adequate measures of effectiveness simply do not exist, with performance measures being quoted as though they were effectiveness measures. For example, a communication system capable of handling x number of messages per unit of time may be called more effective than one capable of handling only half that many. The fallacy is that the comparison is being made on performance and not effectiveness. The number of messages that can be handled per unit of time is a performance characteristic. In order to look at the effectiveness of a communication system, one would have to know something about the number of messages that <u>need</u> to be handled by the communication system when that system is employed in the situation for which it is being recommended. It may be, for example, that either system can more than adequately handle all the messages that need to be handled, so both are equally effective in handling that particular mission. The concept of a mission, then, is of paramount importance in measuring the effectiveness of a system. Without a definition of what mission a system is expected to perform, it is impossible to measure the effectiveness of that system.

Now you will say that this is obvious; that everyone knows this already; that this represents no new challenge. But look at all the cases in which performance is still measured and reported as effectiveness. We still hear that a certain steel helmet is more effective than another because a certain fragment must impact it at a higher velocity in order to perforate it. The appropriate measure of effectiveness for a helmet must be in terms of the likelihood that a soldier will become incapacitated when in a battlefield environment. This requires an examination of the spectrum of fragments and their velocities that one encounters on the battlefield, as well as an examination of the residual wounding potential of a fragment that does perforate the helmet. Briefly stated, the real mission of an infantry-man's helmet is to afford increased protection to the wearer in a battlefield environment; it is not to stop just a narrow spectrum of fragments.

Other examples of this type of thing are found in nearly all areas of military OR. QMR-type documents have for years been filled with performance specifications which only incidentally related to effectiveness. One example that comes to mind occurred a number of years ago relative to the air-burst fuzing system for the Honest John rocket with nuclear warhead. The QMR required that no more than a certain small percentage of bursts should be allowed to occur above a specified height. The only fuze available at that time that could satisfy this requirement was one for which the distribution of range to burst had such a large variance that the target was infrequently hit. Here a certain type of performance had been asked for, instead of a certain level of effectiveness.

Thus I feel that the real challenge in the next few years lies not so much in the exciting area of new concepts and philosophies, although these certainly present a challenge, but in the more mundane areas of sharpening up in some of the things that may have been taken for granted up until now.

CHALLENGES IN MILITARY OR IN THE 70'S

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The emphasis and reliance on military operations research applied to land warfare by top level decision-makers could well increase in the next decade. There are several reasons for this.

First, it appears that the Defense budget will be highly constrained in the foreseeable future. Increasing pressure for greater federal expenditures in the non-Defense segment of our economy will place a high premium on improving our allocation of resources for defense.

Secondly, at the same time manpower is expected to take an increasingly larger share of the total military dollar. Thus, there will be a high premium on getting the most for our dollar from our new weapon and support systems - a job for operations research.

Thirdly, we are shifting to a policy of a credible, conventional deterrent capability in Europe. As a result, there will be more emphasis on tactical warfare systems and capabilities (as opposed to strategic systems). Tactical warfare is much more complex than strategic warfare, and military OR can contribute heavily to sorting out these complex problems.

Finally, advances in computer equipment and the lessons learned in OR methodology in the last decade provide a basis for improving the quality of military operations research and therefore the willingness of decision-makers to trust its results.

To capitalize on the opportunities in the 70's, some improvements in OR are needed. Our effectiveness models and war games need to be made much more valuable in providing the information needed to make good decisions on weapon design, weapon acquisition, force sizing, and force composition.

Some of the more serious problems with current models and war games are:

. Too often the complexity of our models is not compatible with the availability of data. For example, there are serious data voids in the areas of target detection and acquisition and in weapon degradation in combat. Also, we really don't understand how the actions of human beings are influenced by events in combat. Even for relatively straightforward things, such as the hit probability of tank guns against moving targets, our data base is incredibly poor. It's not clear that it makes sense to construct a complex simulation when the input data required to make it work is so poor.

In spite of the shortcomings of the data base and the large uncertainties associated therewith, too often models are not constructed to permit comprehensive analysis of the sensitivity of output values to changes in input values. A lot of lip service is given to sensitivity analysis, but most OR studies of weapons systems place very little emphasis on it. In my view, an understanding of how changes in key parameters influence the results is probably the most important thing we get out of systems analyses.

War games use static measures of effectiveness called firepower scores. These measures are intended to be rough indicators of combat capability, but the way they are derived and used often leads to either incorrect or misleading results.

Another problem is that too often a model is expected to do too many things. For example, in a recent study, a complex simulation model dealing with battalion-size forces was expected to produce answers on the relative effectiveness of individual weapons, of weapon mixes, of force organizations, and even the influence of design changes on the individual weapons systems. It is probably unreasonable to ask one model to do all these jobs.

There are some of our problems -- but what can be done about them?

First of all, it appears to me that we can do a much better job in estimating weapon system or force effectiveness if we attempt to do this with a <u>family of models</u> rather than a single model. The models of such a family would be tied together and each would deal with a different level of aggregation.

I would like to describe briefly the type of models that might comprise a family. Duel models are very useful for determining how changes in a particular system's characteristics affect its capability in a one-on-one situation. Unfortunately, duel models do not treat important effects relating to the interaction of weapons and often they cannot treat some important characteristics of a weapon. For example, in a tank-versus-tank duel model, it's difficult to treat mobility properly. Despite its limitations, I think the duel model is a good starting point. I think we could learn a lot from small engagement models which include up to perhaps five units on the side. This type of model would not only be useful in gaining an understanding of a subsystem's contributions to weapon effectiveness, it would also permit some interplay among different types of systems, albeit on a very limited scale.

The small engagement model could provide a basis for constructing another model which would be designed to simulate engagements of larger forces, for example, company-size or battalion-size forces. This second type of model could be constructed and used better if it were based on the results of a small engagement model. A company or battalion-size simulation would be useful for determining how different weapon systems performed individually and in combination with other weapon systems.

One of the problems with such simulation models is that a large number of computations has to be made for each battle sequence, and, if it is a Monte Carlo model, each sequence has to be replicated enough times to produce a valid result from a statistical standpoint. Thus, a complex simulation of this type does not lend itself to comprehensive sensitivity analyses because each run takes a lot of expensive computer time.

An approach that has a lot of appeal is to use such a simulation in combination with an analytic model consisting of a series of differential equations which, for example, deals with killing rates for each weapon system under different conditions. A model of this type will be described by Professor Bonder and Dr. Hoening later in this symposium. The analytic model would be tied directly to the results of the Monte Carlo simulations. It would be simple and inexpensive to conduct sensitivity analyses with this type of analytic model.

Division, corps, or army size conflicts would be treated in a larger-scale model or war game. The war game would use the results of battalion and company-size engagements derived from the battalion-size Monte Carlo simulation as a basis for computing the outcomes of engagements by larger forces. The large-scale model would focus on the relative effectiveness of specific organizational units such as tank battalions, infantry companies, etc., in different situations.

With respect to large-scale war games and models, we need to develop better indicators of force effectiveness. The effectiveness of a weapon or an organizational unit is closely related to the specific tactical situation within which it is employed. Using firepower scores, which are independent of the tactical situations, is simply not adequate.

I realize this is very sketchy, but the point is that there is a great deal of payoff in using a family of models rather than one model. Each model would be used for a different purpose, but each would provide the basis for the next level of aggregation. This is not a new idea. The Research Analysis Corporation is presently doing a study for the Army called, the "Equal Cost Firepower Study" in which they are using two models which deal with different aggregation levels to evaluate the payoff of trading artillery out of our Europe-deployed forces for equal cost antitank forces. I believe that this family approach to modeling has tremendous potential for the future.

A few words about data. The data problem continues to limit the usefulness of military OR. What can be done about it? I think there are a couple of possible approaches for improving the data situation.

First, we can get the various training commands to collect data in formats which are useful for weapons systems analysis. This requires better liaison between the training community and the operations research community.

In addition, we need to perform more realistic testing and collect the data such testing provides. A great deal has been said about realistic operational testing in recent months, and I am very hopeful that current planning will result in a large improvement in this area. A series of two-sided tests on the Maverick missile are being planned for early 1972. The objective of these tests will be to determine how Maverick's effectiveness is influenced by various environments, terrains, and enemy countermeasures. Similar tests are being planned for TOW, Dragon, and Shillelagh. Hopefully, this type of testing will be applied to all new weapon systems. This type of testing provides an excellent opportunity to get more useful data, if the operations research community gets involved in test planning and specifies the type of data needed to analyze system effectiveness.

In summary, I believe that we can do a better job in analyzing both weapon and force effectiveness by using a family-of-models approach which encompasses small unit engagement models at one end of the spectrum and large-scale corps/army models at the other end of the spectrum. Because of the poor data base and the inherent uncertainties in tactical warfare, sensitivity analyses will continue to be of prime importance. I think the next few years will provide some improvements in the data base; however, the extent to which this materializes is probably strongly related to the degree to which the operations research community can insert itself into the training and operational testing processes.

SESSION IV - DISCUSSION

Comment:
I can't let the panel go by without my adding some comments to it. I find the panels comments interesting, valuable, and truthful. I find an underlining paradox among all the comments. You say there are two things that are required. One is the measure of problem solving capability, to help solve problems which require an analyst with a great deal of creativity and experience. You also say what is needed is a great deal of basic research, experimental activities, and basic science--understanding the processes. Dave said night operations, how our units operate together. Joe said more data. All very fine words, I think. Except we're lacking the resources to do both. I see no utilization of the OR analyst in the problem solving mode or an ability to give them experience in doing so. The Army trains lots of people, lots of military officers in OR and then lets them review studies, as opposed to giving them experience, as you claim, Dr. Whittenbury, to help solve problems. You need assistance on both sides, both the sponsor and the consultant. The second activity in terms of basic research has no input resource, that is, money to do basic research. I see a large scarcity of resources to do a lot of what the panel said is needed and I agree is needed. Would anyone care to comment on where the too scarce resources are going to come from, the money to do the basic research and the time and the analytical capability due to problem solving.

On the area of testing, it's clear we are willing to put more of our scarce resources into this operational testing area. These two new inititives that were started last fall which cover about twelve million dollars a year, for both these two test programs I described, for about two years is evidence of this. I think we are going to see more of this. Something's got to give as a result but I think it is money well spent. I don't know about research.

Comment:
Let me add something on the matter of research. I pointed out this problem of helmets. Had someone looked at this analytically beforehand, one would have recognized that this was poorly spent money. I think the OR community owes the research community its information on sensitivity. A good deal of our research is laissez faire research. Now you speak about resources in OR, I think AMC has about one hundred-fifty thousand people or so. I find out that in the Tank and Automotive Command, there are seven people in the OR group. So there is a matter of re-establishing priorities. This is a problem. In fact, I hope to meet with the so called SAGS, Systems Analysis Groups, of AMC next week on this very matter.

Comment:
I don't challenge your statement that some aren't using their OR trained people well. I'm sad to learn that other commands are still doing this.

I guess I share your interest in the question of resources to do this sort of work and I'm not in a position to answer it. On the other hand, I go back to the comment that I made about the need, not only for the clients, but for the people doing the work themselves to differentiate between creating knowledge and creating something that is going to have an impact on an operational system or a management system or an administrative system or whatever it is. There is the old comment that it's not what you know that is important, it's what you do about it. And I think the profession necessarily over a long period of time, has spent a great deal of effort on the first part. And now I think there is perhaps an education behind us. We are concerned about a much better working relationship between where the action is and what an outside professional can contribute so that the profession really has a payoff and it is very very critical, it's not something that you automatically buy as a service because it comes in a bigger package. Those days are gone, I'm sure.

Question:
What we're really talking about is operations engineering. If I talk about engineering, I'm talking about analysis, design and testing. In other words, the whole cycle. Operations engineering, where we put little emphasis on the hardware any longer, but more on doctrine and organizational changes. The reason is, how do you know whether you've got improvements unless you can describe what you have now. Most of the problems, about half and half of our speeches today, have been interwoven between the so called decisions for, alternatives for decision-makers and actually hardware technology. So, do we need to go back where OR started in the early days and say well, we can forget military systems and look at operations engineering?

Answer:
I'll just make a quick reaction to that. I think there is a very significant point that people have had a devil of a time defining operations research, systems analysis, systems engineering, etc., etc. I don't think there is any clever, simple, hidden meaning under all of that that we haven't quite found yet. We're really describing something that has taken on a great deal more sophistication than it ever warranted, and it is basically made up of a lot of different kinds of packages to which systems engineers can make a contribution. Then, when they drift out of the area of their speciality and get involved with "problem solving", they suddenly become a member of this community and then they spend the rest of their life trying to figure out what it is. So, I won't take the position that one cannot adopt any more nomenclature. I'd like to be specific about those things that are accepted capabilities and distinguish them from classes of problems that very capable people who have never gone near an OR course can solve just as well as anybody else who calls himself a system analyst. And there are plenty throughout the Army--throughout all time. I guess BRL was doing systems analysis before the war. They call it something else and so on and so on. So I'm not sure I'm really answering your question, Dr. Callahan, but I'm certainly not supporting the idea.

Comment:

I've tried from time to time to think of some way to clarify the nomenclature problem that obviously faces us. We call ourselves by different things at different times, fashions ebb and flow. Perhaps as Clive says, we are entering a maturing phase, then it will be more nearly possible to describe what we are, in terms of what we characteristically do, but at least, so far in the history of military OR in this country, I have found it more fun to do than describe.

Question:

Dr. Bryson: I'd like to address my question primarily to Dave Hardison. When he was asked to chair this panel, I was disappointed when he was also asked who he would like to have on it and he didn't immediately say, I want you on it, but now he's got me anyway. I think that one of the things most of the panelists missed is the thought that General Norton mentioned this morning when he said, "let's do ORSA on ORSA". That is the challenge that was thrown out to us this afternoon by these gentlemen. These challenges pretty much, not universally, but pretty much were this kind of challenge-here's where we are now and here's the direction in which you should be going. But very few times, did I hear them say here's where you're going to end up or here's where you should end up. You know in an OR study, the first thing you do, or one of the first things you do is set the objectives for the goals the study is suppose to accomplish. Now this little speech leads up to my question. If indeed we can define the goal, the objective of the challenge, this objective very likely is going to be a variable objective and it is going to be moving away from you possibly faster than you're moving towards it, or moving in the correct direction. But in any event, a great many of these thirteen that Mr. Hardison mentioned, I think will result in the next ten years and us being farther from the objective than we are today. Some of them not. The question is, which of those do you feel, Mr. Hardison, are the ones where we can make the most progress towards this elusive objective which I have mentioned, and which ones do you really feel, based on your twenty years experience, that we really can't do very much with?

Answer:

Mr. Hardison: Dr. Bryson, I guess I would agree with the idea that many of these that I tossed off will be farther from the objective at some time later than now. Perhaps we won't be as far from the objective as we would have been had we not started now trying to keep even from it leaving us even faster. I think we are basically, in many cases on a down escalator trying to get upstairs. We're going like all get-out to try to keep from getting in the basement. I expect to see returning to the substance. I expect to see some significant changes made in the next five or ten years in our understanding of the effect of better information systems on the effectiveness of Land Combat Systems. I think the time is right, technologically, for the equipment to become available; I think the organizations are sort of in exsistence now and there is a spirit of test and try. So I think that the first challenge I threw out to develop an arithmetic of information systems is likely to evolve in some advances in the next ten years. I think that in the night operations bit, it's just certain that we'll do experiments and we'll do studies to get a better understanding of the structure of night combat and the ways in which it differs from day combat. So, I don't believe that the objective there is receding as fast as our advances will be made. I think that we will find our preferred balance between air-mobile and ground-mobile forces. I think it will be a very dynamic thing, moving incidentally to a higher fraction of air-mobility, but I think that we will make advances in that particular area. I think that we will not do very much in the robustness of a high order of systems. I think that we will not do very much in improving our information storage and retrieval systems, because it is too defuse. You can't get agreement on words, you can't get agreement on taxonomies. I think that is more of a hand wringing type of, wouldn't it be better if we could, but I don't expect to see anything very useful happen in that area. I believe we will make some advances in our abilities to evaluate larger-scale systems analytically than we have had before. There is no denying the fact that the computers are getting larger and better and faster and cheaper and people are learning better how to use them. I think that our ability to model systems today has come a long way in the last twenty years since people were playing with some of the very early computers. So there have been advances in the simulation models in that period and I think that we will continue to see additional ones. The notion that we should have an integrated set or nested set of models throughout the Army, I just don't know. I rather doubt that, because it seems to me to be one of those goals or objectives which requires a concensus of too many people, most of whom don't understand why or are not willing to make a long enough and sufficiently dedicated commitment. The length of time required to pull it off is two or three generations of author assignments--a couple of generations of computers. I, at one time, thought that it made sense to really go gung ho in that direction as most groups of people who study this problem concluded that we should do it, but now I'm not so sure. Maybe we ought to be improving the air defense model and improving the tank model and the infantry model and the communications model and wringing our hands, if nothing more. On the ethics of the profession, I just don't know, I listened to what Clive said and I think we really have a problem now in trying to obtain help from non-government practitioners of OR. I don't know where that's all going, I don't know to set up any ethical standards which could be applied, but I surely sense that there is a problem there, that it's getting worse or greater, and I don't see anything happening which is likely to remove any substantial parts of it. I think we're starting to get the structure for MOE sorted out to the point that one can think in terms of the measures of performance of systems at a given level feeding into systems at a higher level. I think it makes sense to put some effort in that area and I think we will make some clear progress in that area. Particularly in areas other than in firepower and mobility where there's been a lot of work done already, I think we will make some progress. In fact, I'd go one step beyond that and say I think we have made, in the last six months, some substantial progress in our own shop in there.

Comment:

I would like to add a couple more points to the data problem you raised. One is that I believe that the people who do studies in many cases do not take enough trouble to look for all the available data, fully realizing that we don't really have a good system for disseminating the existing good data, but I'm not sure whether people really try hard enough. The second part is that we do have a challenge in the future for the data gathering community, wherever it is, to be more responsive to the needs of the modelers to get the data in the manner that the modeler needs it and the kind of data that he needs. And we do have a challenge there in making the data gathering more responsive and this is not necessarily a CDC problem, but it's a task, as Don mentioned, in Europe or anywhere else where we can get data.

Comment:

Certainly it has occured to some of you that a substantial fraction of these problems are simple problems of scale. I sit here and look over this audience of nearly 200 people and it suddenly occurs to me that in my own lifetime in the profession there was a time when an audience of 200 would have included not only every Army Operations Analyst in existence, but most of their families.

Comment:

I would like to ask a question about operational testing. Dr. Frederickson said that there is a willingness to put resources into this business and I have heard a number of people question whether it is possible to have operational testing for such expensive large-scale items as a new tank or a new helicopter or a new aircraft, because there is no possible way to turn it down. Also I wonder who is going to do this. If it is going to be done under the same leadership as the people who develop these things, and if that is to be the case, I think that's an invitation to foregone acceptance to most of these things. Perhaps that might give you something to start on.

Comment:

We certainly don't want the judge and jury and the prosecutor to be the same person, so they will be separated. The tests on Dragon, TOW, and Shillelagh, for example, are not going to be done by the R&D community. Some of us in the R&D community are interested, will have a chance to comment on any test plan that's produced, but will not be the ones conducting the test or judging the outcome or planning the test. Your first point was, how can we afford to test major systems like MBT-70, for example. We don't have to test divisions of MBT-70, we can test just a few units and I think we have to do that. We've got to know what we're buying.

Question:

The question was, can you reject the MBT-70 at this late date and say it's not satisfactory and go back to the drawing board?

Answer:

I think a fair probability that it will be rejected at the moment. We're still at least three years away from producing them. I guess that's hyperoptomistic, it's more like five. Let's take a system that is further along. Your point's still, I think, a valid one. Supposing we find that there is a serious flaw in one of our guided missile systems. For example, supposing we find that it is very easy to counter-measure, very easy to react. I'm not saying it is, let's just say we find them. It's not clear that we have to junk the whole system. It may be that we can develop either tactics or equipment or both which will minimize those shortcomings and still give it a reasonable level of effectiveness. It could be the case that we convince ourselves that it is absolutely worthless. I think that is sort of unlikely, but if that were true, it is good to find it out before the war starts.

Question:
I have a question. I am confused now. You said I was bouyed by the fact that you said there is money going into testing, you know, operational experiments, and now I find this to find out whether a piece of equipment is a good piece or not. I had in mind doing operational experiments to find out and learn something about the prophecies that Dave was talking about and maybe then getting better predictive methods. Can you tell me how we can integrate both of these things? I don't see why we can't do both. What mechanism are we going to use to do this? I find one is an opposite of operational troops out in the field running tanks around and I don't see where the so-called egghead scientists are around to produce the knowledge from the data.

Answer:
This is what I was alluding when I said operational engineering. The original VISTA report that set up combat developments. Combat developments should be worrying about operational organizations and not hardware. Now if you have a hundred unknown varibles, and say 50 of them are dealing with hardware, and 50 of them are dealing with operations, what I really meant was, how can you separate the two? Say you take standard M-1 rifles or M-16, or whatever you have, and all you do is trade around to fit the operations variable, that could be a problem. So when you start mixing the whole hundred unknowns at one time, you've got a real problem.

First of all, these tests on reliance haven't been laid on for these things, so let me guess what they might be like. The test for TOW will probably consist of like company size defenses set up against larger size tank forces. The tank forces will have as their objective taking certain grounds. They won't know the positions of the defending units. The test will be instrumented to some extent. They may have, for example, lasers in place of guns, gun cameras, and so forth to record. The tankers themselves, will plan the tactics. Perhaps there will be suggestions made up on tactics. They will be trying their best to minimize, for one example, their exposure time to certain suspected defended positions. A tanker usually follows the low ground and tries to keep his tank in as much defilade as he can while he is approaching the target. Perhaps he'll use a smoke detachment, a motor detachment with smoke rounds to augment their approach. On the other hand, the defenders are going to be trying to maximize their effectiveness, perhaps by firing in salvos, or perhaps firing only at certain approaches. I think the key is the fact that they are two-sided, rather than a set of sterile tests, which I am just trying to establish, whether or not the systems has its performance requirements.

Question:
I understand that, and I think that's a "realistic" examination of the system. But how does that tie in with the models that CDC has which are being used to determine, for example, how many TOWS one should have. Where are they tying into the actual predictive mechanisms that these people are using?

Answer:
Hopefully, you might be able to get exchange ratios, or ranges of exchange ratios that you could expect under different types of situations.

Question:
Wouldn't we be a lot wiser doing the thinking about that problem beforehand and integrating both objectives?

Answer:
Let me comment on this one. They can't really be separated, but I'll do it anyway. Talking about two types of tests, the expanded service test and the intensified confirmatory troop test. The former concerns itself with the question: does the equipment performance turn out as intended and designed? The second, addressing the broader question of: does the equipment which performs like this do good things for the Army in the field? Both of these cases are receiving much expanded interest at the moment and some institutional changes are taking place in the Army to better carry out them both. Now, let me give you an illustration of the type of thing you have talked about in the attack helicopter field. I talked about the balance between air mobility and ground mobility. We've been doing simulation studies of attack helicopters for quite some time. Within the last few years, we've had the opportunity at CDEC to be doing some field experiments. We've gone to fairly great pains to be sure that the simulation models are being used not only to simulate the war that will be fought in some future time period, but also using the equipment that has been tested to simulate the battles that have been played at CDEC as a means of validating whether the analytic model gives results that are at all close to the empirical model. So, I think there is a deliberate effort being made to expand the operational testing and to obtain data in a form to be used in the simulation work and not permitting the simulation work to go unchallenged unless there is some evidence that a careful effort has been made to see whether the results are in agreement.

I might add one last point on your question. The decisive influence in what the content and procedures of this test will be is pretty well in the hands of people who generated the need for said tasks and those people generate the need because of perceived deficiencies in CDC models and their input data and any of a number of other sources of that sort. So indeed quite considerable emphasis will be given in tasks to filling the void that we perceived to be critical in our past efforts, and to analytically represent these systems.

One thing that's going to be done for example, is a review of Project Pin Point.

Comment:
I'd like to make one statement. In the specific cases that I have knowledge of where we have done experiments and have compared the results with the models, the results were more closely in agreement than you would have expected. I'll kick-off three specific examples. In the accuracy work on the M-60 tank and the accuracy work on the Shillelagh missile, and on the comparison of target acquisition information from attack helicopter as measured in SENCON and as predicted in the global models. The results are much better than you would have thought the models were. I believe the results were not circular. That is, the results of the test weren't being used to predict the results of the test.

Question:
Tom Cochran from Litton. You've probably just answered my question. I wanted to address the problem of the question about these one-on-one duel models, the tactical models, and the war-gaming models. It seems to me that there are two things you can get out of these models. Two results - one set of results have to do with survivability calculations, exchange ratios and so forth, and the other things you get out of them are what the interesting variables are in the models, and so forth. From my limited experience, I find that some of these air defense models are wholly inadequate for computing any of the answers you would like to catagorize in the survivability group. In other words, the exchange ratios are probabilities of occurrance and so forth. The main reason to me seems to be that the detection models are completely inadequate and also you cannot play the human factor variables adequately. I don't see much improvement in this area over the next decade and yet you point to the fact that SENCON experimental data seems to agree with the global data. I find that probably just by chance or it's something very strange happening. I find it very hard to believe. I would even extend my analysis to include large-scale experiments, like we conducted at CDEC. The 4280 experiment, the 431 experiment, 435, 6, 7, or however how high you want to go. I find it very

difficult to believe that you can make fair decisions on equipment and materials and doctrine and so forth, based on the survivability calculation in these type of experiments.

Answer:
That you find it hard to believe is understood. I am not saying that the results of the SENCON experiment are the same as the results that one would predict for a different war and a different area. Rather, the modeler was given the situation of the SENCON experiment and he modeled that and his model gave results which were not in disagreement with that which you measured on the ground. Now that's a simple assertion of what I have been told was fact. I know that I have been told that it was fact. I believe it because the people that did the work are reputable people in this particular field.

Question:
I'm not an OR, but after having heard the questions, I don't hesitate to speak. I strongly suspect that you can revise your prior probabilities and come up with an estimate of slightly less than 200 for those people who really are. I was intrigued, Dr. Whittenbury, by what I suspect was not a casual comment at the use of the word anthropology. If there's any particular branch of science which I think has made the greatest stride in the last 20 years, I would think that perhaps that has. If I hear the reference to land combat and we have learned in the last few years that man is sort of a pair-bonding nonarena, territorial type animal. Was your use of the word "anthropology" casual, did you just pull it out of the air, or do you feel that OR will eventually begin to incorporate the man within the system?

Answer:
As a matter a fact, it wasn't a casual comment, but I hesitate to explain why I used it. I think one of the first things that came into my head was what would an anthropologist say about all of this, was the problem that I had stewed about and I think you read into some of the comments I made about the difficulty of institutions to absorb innovation. And presumably that is something that is pretty fundamental to the way instutions are being created and organizations to go with them to protect either the status quo or something that seems to be a pretty good thing and let's not make a wave. I think that's a problem for an anthropologist. That was why it wasn't a casual comment. If you'd like me to go even further than that, I will but that's why I brought it up. I think your comments about what do we do in defending territory and why do we need line-of-sight with the guy with the rifle also has something to do with that. Did I answer your question. I think it is a very important thing. It's got everything to do with, I think, the immovability of some of the doctrinal questions the problem of learning-how to do something new. It's one thing

to talk about taking on a new piece of equipment and increasing your performance overnight. There's a tremendous amount of difficulty in absorbing an innovation, training for it, and turning it into something that will really make a difference in a living doctrine not just something that is in an intellectual's head. So I think this is a very very significant point, and I wonder, while I'm on the subject, how many people in the OR business have really had a profound influence in changing doctrine. I suspect the answer is zero, or pretty close to it. I think that is a very serious matter.

Comment:
If I may, I would like to add to the previous comment. Although you didn't say it specifically, Dr. Whittenbury, at least by implication you included the sociologist, first cousin of the anthropologist, and the behavioral scientists as potential, fruitful, and useful members of the OR team.

Comment:
I would like to translate your comment, Dr. Whittenbury, into one further challenge, then, that I think you have been talking about. The same challenge we heard General Norton mention this morning and that may well be, let's establish as a challenge the marketing of the considerable skills that we have assembled in this room and in the organizations that we have back home. Rather than just leave it there, I suggest perhaps we should attempt to define some measure of utility of what we do and thereby convince these people that we are marketing our skill to or with that, yet there is value in this new management science and during the next ten years we will help them reach these objectives that Dr. Bryson claims are eluding us and Mr. Hardison says we are in fast pursuit of. As the anthropologists and the others have had their say, perhaps a businessman might say, "let's attempt to market this skill that we have here".

Comment:
We are rapidily approaching the witching hour. If anyone has one absolutely burning finger that he just can't wait for---what a polite group.

NOTE: The comment included in this section is not necessarily complete. It was necessary to delete some remarks as they were unitelligible on the recording.

FRAMEWORK OF ARMY PLANNING

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OVERVIEW OF DEFENSE MANAGEMENT

The Blue Ribbon Defense Panel found that many of the difficulties of the Department of Defense (DOD) result from the structure of the DOD itself, which almost inevitably leads people into adversary relationships rather than toward cooperation in the interests of the Department. It also leads to reliance on the workings of the bureaucracy, rather than individual initiative.

Despite the authority given the Secretary of Defense by the National Security Act of 1947 the tools available to the Secretary for effective management of the Department have not developed. The changes in Defense organization since 1947 have not reduced the difficulties arising from the fact that the division of roles and missions among the Military Departments is still based fundamentaly on distinctions between land, sea and air forces. This results in continued adversary relations between the Military Services which severely inhibit the achievement of economy and effectiveness required for adequate defense in a constrained economy. The continuing interservice competition degrades any decision making process through submerging of issues and alternatives.

The results of such parochialism are reflected in:

1. The development of aircraft by both the Air Force and the Army capable of close air support missions.

2. The lack of enthusiasm for airlift expenditures by the Air Force and the sealift program by the Navy, both intended to support the Army.

3. The continuing failure to resolve the issue of the best balance between land and carrier based tactical air support missions.

Similar problems have faced Defense managers for many years. Over the years, these Defense managers have devised different methods of best matching available resources to the established needs, in the face of Service pressures, Congressional scrutiny and human failings. The job is always difficult, and there are many ways to do it.

In the 1950's the job of balancing needed forces within budgetary constraints was done largely by the individual Military Departments. The system worked like this. Each year the Joint Chiefs of Staff gave the Secretary of Defense written recommendations on the number of divisions, ships, aircraft, ballistic missiles and other forces and support that he ought to buy. These proposals were packaged in a document called JSOP, The Joint Strategic Objectives Plan.

However, the Chiefs did not attempt to balance defense needs and resources. Therefore, their recommendations always cost substantially more than the Department had to spend. The Secretary of Defense had to match the two. He needed help and he got it from the Service Secretaries and from a system that left much of the balancing up to individual Services.

The Secretary of Defense allocated a share of the total budget to each Service. Often, the Services were given about the same share of the budget they had the year before. Next, the Secretaries of the Army, Navy and Air Force allocated their shares of the budget among their own programs, largely setting their own priorities. These priorities were based upon each Service Secretary's interpretation of National Security policy, the United States' international defense commitments, Service desires, and, of course, expected Congressional reaction to Service programs.

Since the Service Secretaries were doing the balancing of needs and resources, the process resulted in a balance based more on Service priorities than on Defense Department or national priorities. This is not surprising because even today it is hard for a Service Secretary to deal with the complexities of balancing forces across Service lines. The institutional problems were even greater in the 1950's.

In 1961, the new Secretary of Defense, Robert S. McNamara, was given the responsbility, in effect, to set his own budget ceilings. His objective was to plan for military capability to satisfy our national strategy objectives and our international commitments and then buy and operate this capability at the lowest practical cost -- a self-imposed ceiling.

Mr. McNamara -- with the help of his personal staff -- took on the job of balancing needs and resources. He made this balancing job a process of his choosing among alternative ways of doing his interpretation of the Defense Department's job.

Where did the Secretary get his alternatives? He got some from the Joint Chiefs, some from the Service Secretaries and others from his personal staff. The Joint Chiefs, for example, provided one set in the JSOP. People on his staff often came up with other options based on their own analysis. The Secretary of Defense was then faced with the task of evaluating these choices.

The Joint Chiefs and the Service Secretaries were asked to comment on the Secretary's tentative position. The Secretary reviewed these comments, had his staff analyze them and then made "final decisions" based on the facts and analyses he had seen. The Secretary's decisions then became part of his approved overall defense plan.

This plan had a price tag, but the price tag was not used as a ceiling for the Service Secretaries' October budget requests. Their guidance was the number of men or ships or planes or tanks the Secretary had approved during the spring and summer.

In their budget request, the Service Secretaries were supposed to focus their attention on making the best estimate of next year's cost of this approved plan. But in addition, the Service Secretaries were usually allowed to ask for money to finance new programs the Secretary had not previously addressed, and they were sometimes allowed to repeat requests for money which the Secretary of Defense had previously turned down.

This particular practice weakened the link between the Secretary of Defense's approved program and the budget. It caused, in November and December, major reshuffling and rebalancing of the program that had taken nine months to put together. For example, in 1968 the Service Secretaries put together a $100 billion FY 70 budget for the Secretary of Defense's program and their own requests. The Secretary of Defense then cut this $100 billion budget to about $83 billion. The new administration and Congress later cut this to $77 billion.

This management method worked better at the time than the method of the 1950's. The Secretary of Defense had for the first time the formal, structured means to take a well analyzed initiative in responding to the Joint Chiefs' proposals. The system helped to show the Secretary of Defense alternative ways of doing a job. Also, the switch from looking at Defense needs and constraints from a Service viewpoint to that of a Department-wide viewpoint helped the Secretary to understand what capability the Defense budget was buying.

Under Secretary Laird, the Defense Department management methods have continued to evolve. President Nixon has revitalized the National Security Council (NSC). He has also set up the undersecretary level NSC Defense Program Review Committee. This permanent committee, the DPRC, reviews major policy and program issues in relation to overall national priorities. The President, with the help of the Council and the DPRC, gives the Defense Department broad strategy guidance. This strategy guidance states the objectives of our military forces. In addition, the President, with the help of the Council and the DPRC, gives the Defense Department limits on planned Defense expenditures.

In response to this Presidential guidance the Secretary of Defense spells out what forces he plans to buy over the planning period to meet the President's strategy guidelines. The Secretary also shows that the cost of his plan does not exceed the President's expenditure ceilings.

To respond to these external changes and to inject their own ideas into internal Defense Management, Secretary Laird and Deputy Secretary Packard initiated several basic improvements on past methods of making hard choices. The Laird-Packard approach was to build upon and improve existing management methods.

First, after reviewing the Joint Chiefs' JSOP strategy interpretation, the Secretary of Defense gives the Joint Chiefs of Staff and the Services his explicit interpretation of the President's broad statement on defense strategy. This document provides specific policy guidelines on the way the Defense Department should plan to meet national defense objectives in the light of the defense commitments between the United States and 45 other nations. Second, the Secretary gives each Service and Defense Agency a tentative five-year budget ceiling for planning along with guidance on how to allocate that budget among various Defense-wide missions. These tentative ceilings are based upon total Defense expenditure targets set by the President.

Mr. Laird expects the Service Secretaries and the Joint Chiefs to work with him and Mr. Packard to put these guidelines together. After the guidelines are issued the Service Secretaries and the Joint Chiefs of Staff use them for detailed force planning. The Service Secretaries and the Joint Chiefs of Staff lay out detailed five-year plans for ships, planes, missiles and the like to fill out the framework of the Secretary of Defense guidelines. There are exceptions to this -- like some strategic programs and the national intelligence program -- for which much of the detailed planning is done by the Secretary of Defense staff or the Defense Agencies.

Although the Secretary is going back to the use of specific budget ceilings for planning, he is now giving five-year guidance and he is giving the Services more than just total ceilings. He is maintaining a Defense-wide balance of needs and resources by giving guidance within the Service totals.

Thus, Mr. Laird and Mr. Packard have turned over to the Service Secretaries and the Joint Chiefs of Staff the initiative for developing good detailed plans within strategy and financial guidance -- but the Secretary and the Deputy Secretary are keeping their staff's capability to review and evaluate what the Services and the Joint Chiefs of Staff say -- and come up with new alternatives themselves if necessary.

With this brief overview of the evolution of Defense management over the last twenty years, let us look at how the system operated within the Army during the calendar year 1970 cycle.

HOW THE SYSTEM WORKED

Shortly after President Nixon took office, the Department of Defense was directed to study alternative national defense strategies. During the summer of 1969, a report was made to the President and the NSC which outlined alternatives to the then current U.S. Defense strategy. Each of the alternatives contained the forces, procurement programs and required support of allies needed to implement the strategy. This report was the result of many alternatives considered not only by the Department of Defense, but by other organizations of the Federal Government.

In the fall of 1969, the President's decision as to strategy and tentative budget levels for the FY 72-76 time period was transmitted to the Defense Department.

Based on the strategy chosen by the President and the given fiscal constraints the OSD staff put together the Tentative Fiscal Guidance Memorandum (FGM) for fiscal years 1972-76 in early January 1970. After a series of exchanges between the Secretary of Defense and the Service Secretaries, the final FGM was issued in March 1970. It was now up to the Army, and other Services, to put together a total force, support and procurement program within the limits of the FGM.

Within the limited amount of dollars that was available to the Army, there was competition within and between the Army appropriations. This resulted from the need for the Army to provide a force to meet the national objectives and priorities, coupled with the need to equip, train, support and maintain this same force and to do all of this within the dollar constraints of the FGM.

Internally, the Army had to take a hard look at its structure -- and particularly the balance between development, investment, and operating costs. For example -- if the budget is to be "force structure" heavy -- after stripping out SAFEGUARD and Military Assistance Service Funded (MASF) -- then the current upward trends in pay raises and other personnel and operating costs would take an increasing share of the budget at the expense of investment. As an example of what personnel costs mean already to the Army -- between FY 69 and the end of FY 71, Army military manpower falls 404,000 or a decrease of 27%. During this same period the military payroll dropped only $434 million or 4.8% while all other costs fell $4 billion or 32%. In the FY 71 budget nearly 60% of the total is for pay of military and civilian personnel.

If on the other hand we consider a budget that emphasizes modernization, one in which the current development programs are completed and the forces are modernly equipped, then the investment portion of the budget grows considerably while the operating portion will decline. This would provide a considerably reduced force in terms of personnel but with such things as the Main Battle Tank, SAM-D, Cheyenne, and other items under development and testing.

Basically, under fiscal constraints after directed national programs are accounted for, it boils down to a question of balancing force structure, investment, and standard of living. The responsibility to use available resources judiciously has meant that difficult decisions were required and frequently at the expense of highly desirable, but prioritywise less urgently required programs. In May of 1970 the Army's Program Objective Memorandum (POM) was forwarded to OSD.

During the summer of 1970, the condition of the economy was anything but helpful to the DOD planning cycle. Inflation had increased at a higher rate than was expected, Congress had enacted an unexpected pay raise and the President had approved the Volunteer Service concept. In addition, federal revenues were lower than had been projected a year earlier. Because of all these things, the DOD was again asked to review strategy and budget levels.

Doing this for the second time was much easier because of the tremendous effort that had gone on a year earlier. In August 1970, the DOD was given a revised set of fiscal constraints for FY 72-77. This guidance was less in FY 72 than the total of the Service POM's. Ideally, the FGM and POM cycle should have been repeated. However, since the Service budgets were due to OSD and OMB on October 1 the decision was made to submit the budget based on the original fiscal guidance.

THE FY 1972 BUDGET

After approximately eight months of analysis and review, the proposed FY 1972 Service budgets were submitted to OSD and OMB at a total level that was known to be higher than the latest Presidential guidance. However, the process of reducing the proposed budgets was much different and orderly than reducing the Service proposals by the $20 billion that was done a few years earlier.

Using the FY 72 budget as an example let us examine the makeup of this program. Recall my earlier remarks concerning the tradeoffs within the Army staff on force structure versus modernization. A way of looking at the FY 72 budget would be as follows:

TABLE 1

FY 1972

PRESIDENT'S BUDGET

Pay Operations	70%
Construction	3%
Research and Development	9%
Procurement	18%
TOTAL	100%

Note that over two-thirds of the budget is for pay and related personnel expenses to clothe, maintain, and feed the forces. The next largest item in the budget is procurement. However, to obtain a more realistic view of the procurement dollars available for new systems let us examine in more detail the FY 72 PEMA program.

TABLE 2

FY 1972 PEMA PROGRAM

	DOLLARS	PERCENTAGE
TOTAL	3,819	100%
- SAFEGUARD	675	18%
- Ammunition	1,566	41%
- Production Base Support	254	7%
Remaining	1,324	34%
Annual Consumption, Fill AAO's, etc.	(700)	(18%)
Major Weapons	(624)	(16%)

As you can see from the table the dollars available in the budget for new major weapon systems once the directed and fixed programs are eliminated is actually quite small. In reality only 3 percent of the total FY 72 Army budget will be used for hardware items. It is hoped that in the outyears this amount will increase through reductions in some of the directed programs and increases in the total PEMA dollars. The resources for new weapon systems must increase if the Army is to have CHEYENNE, UTTAS, HLH, SAM-D, MBT-70, STANO and other systems or equal cost trades for forces will have to be made.

UNIT COST OF DEFENSE

The cost analyst and force planner finds himself caught in the middle of several ambitious forces.

1. Total dollar resources are limited.

2. Forces must be sufficient to meet the strategy.

3. Personnel costs are increasing.

4. Modernization equipment costs many multiples of the equipment it will replace.

A review of the ever increasing unit cost of defense may be helpful at this time. It is interesting to examine the price paid for different items of materiel that the DOD has purchased over time to perform the same fundamental mission. Even though the new equipment has more capability than the old, its cost has increased even greater than the increase in capability.

TABLE 3

UNIT COST OF DEFENSE

TROOP AND CARGO TRANSPORT AIRCRAFT

C-47	$ .1 million
C-119	.8 million
C-130	2.7 million
C-141	6.3 million
C-5	25.0 million

TROOP AND CARGO TRANSPORT HELICOPTER

CH-21	$ .4 million
CH-47	1.5 million

ATTACK AIRCRAFT

A-1	$ .4 million
A-7	1.9 million

OBSERVATION HELICOPTER

OH-13	$ .06 million
OH-6	.09 million

MAIN BATTLE TANK

M-48	$ .10 million
M-60	.26 million
MBT	.5 - .7 million

ATTACK CARRIER

SHANGRI LA	$ 50.0 million
JFK	280.0 million
EISENHOWER	600.0 million

All of these cost increases have been taking place during a time when the total funds available to Defense have been decreasing. It should be noted that from FY 1968 to FY 1971 the change in Defense spending was $-3.5 billion. At the same time non-defense spending was increasing by approximately $30 billion. In terms of percentage of the total federal budget, Defense decreased from 42.5 persent in FY 1968 to 33.9 percent in FY 1971. In terms of GNP, Defense decreased from 9.5 percent in FY 1968 to 7.4 percent in FY 1971.

OUTSIDE COMPETITION

The Defense planner is working in an environment of competition. Within Defense there is competition for the available funds. Influences external to DOD are competing for these same funds. In the final determination it is the President who must decide on the allocation of monies. Earlier it was explained how this was done twice within the last year and one-half for the DOD. The following compares the competition for dollars between Defense and non-defense programs.

1. 2 million dollars will buy a heavy helicopter or it is the cost of constructing centers for preventive and corrective health treatment to service 100,000 children in low income areas.

2. 8 million dollars will buy a fighter aircraft or it is the combined federal and state cost of supplying 300,000 school children a year with free breakfast under the Pilot School Breakfast program.

3. 64 million dollars will buy a Guided Missile ship or it is the money needed to provide treatment for all drug addicts in the U.S. within Community Narcotic Addiction Treatment Centers.

4. 600 million will buy an attack carrier or maintain 880,000 children in the Head Start Program.

5. 2,000 million will buy a new tank program or it is the capital investment required in public water supply facilities for replacement of obsolete facilities to accommodate current personnel expansion.

It is obvious that there are many programs in direct competition with the DOD for funds.

In summary, planning is done within a system. This is the system by which the DOD is managed. While the perfect management system has not been devised, the DOD management system has actually been working for a long time. The funds available to the DOD and the Army are not unlimited. There is competition between the Services for DOD funds. There is competition within the Army for funds for operations, development and procurement. In addition other government agencies are competing with the DOD for a share of the federal budget.

It is within these constraints -- both internal and external to the Army that Army planning must be done.

Mr. Rex Brugh
USACDC Institute of Systems Analysis

CONCEPTUAL DESIGN FOR THE ARMY IN THE FIELD

Resource Constraint Implications. Economists have, for years, distinguished between "panic" - periods of extreme inflation - and recession. Only recently has there been serious consideration of combining the two economic disasters. Yet we have proof that such a combination is not only possible, it is a real threat.

Much of the reasoning applicable to the cause and effect analysis of today's economic problem applies to planning for the Army of the future. There are internal problems within the overall management of the government which inevitably impact on the Army. There is a growing number of needs for the tax dollar. Urban renewal, revenue sharing, aid to education and many other claimants to the tax dollar appear, grow and reach maturity at a speed hardly visualized 10 years ago. These programs, along with the continuation of older activities, mean a declining percentage of the total budget for the Army.

Coupled with this declining percentage are two other factors which act as a composite multiplier on the net effect on the Army's future: First, real income of the military and civilian employees is increasing; and secondly, inflation applies to the items procured for modernizing the Army or for replenishment of Army inventory. Consequently, in real dollars it is almost certainly true that less will be available for manning, training and equipping an Army in the future. This is, of course, based upon an assumption that the tax "bite" on the producing elements of the economy cannot be substantially increased.

The above is a highly summarized view of a more extensive analysis recently completed, and now being reworked. The implications are far reaching. If the conclusions prove valid, the responsibilities placed on planners as supported by cost and economic analysis reach even more staggering proportions than currently exist.

Before continuing this discussion of implications of resource constraints on planning, it may be prudent to attempt to place the total effort in context. It is assumed that the responsibility of the Army continues. It is also apparent that worldwide threat is not declining. Therefore, the planners for the Army must determine that each dollar expended is judiciously applied. This implies much more that "bigger bang for the buck"; it means, in addition, that the need for the bang must be established in terms of threat and risk. In other words, cost/effectiveness studies as we have known them are but the first step in an involved process in total planning. For an example, there are many items now in development which have been evaluated and accepted as cost effective. Yet the projected budget is not adequate to procure a large part of potential requirements.

One additional thought needs to be added to complete the background. If reduced forces and reduction in numbers of different items would suffice, meeting budget constraints would be simple a matter of scheduling. However, is it not possible that buying smaller quantities of several additional items might pay huge dividends? First, one might obtain "hot" or at least warm, bases so that production could be expanded if a need arose; second, effectiveness balance could be maintained; and third, we would not be perpetuating obsolescence. The costs are, of course, higher unit prices, increased logistics problems, and proliferation of designs with reverberation in organization and training programs. These are not simple decisions, and they are not new. Resource constraints increase the number and complexity of the decisions necessary to create plans for the Army of the future.

The Army staff has evolved a planning process which, although wonderously involved, is remarkably successful. Nevertheless, the problems of facing potential budget reductions are such that it was decided to re-examine the relationship of Army design recommendations and force planning activities. (There are, of course, other reasons for the examination.) Accordingly, a major study known as conceptual design for the Army in the field (CONAF) was initiated. The following description concerns some of the cost and economic problems encountered in this study. The discussion is provided to illustrate the need for increasing the integration of costing efforts of the several Army costing activities.

Cost Analysis Functions in Force Design Activities. This discussion will cover the elements of force design of the Army in the field from the viewpoint of economic and cost analysis; the relationship of these elements to the total Army, the role of combat developments and the relationship of combat developments to force planning activities of the Army Staff.

The focus of this discussion is on the problems and the tentative conclusions formulated concerning economic and cost analysis. It may be of interest that the major emphasis of the methodology is on adapting rather than creating. That is, using the information available from the cost analysis network of the Army, conceptual designs and force designs are being analyzed and costed through models currently in use by the force planners.

To assure that we have a mutual agreement on what a force design is, let us examine the planning structure for the Army.

For planning purposes the Army is divided into these major elements. Divisional Forces, General Support Forces, and Special Mission Forces. These forces include both active Army and the reserve components. A force design is a structure created by the Combat Developments Command (CDC) for the Army in the field. Consequently, it is essential that the Army in the field be identified.

For this study a definition of the Army in the field has been prepared. This definition includes in the Army in the field all units - active and reserve - assigned to, or designed to be assigned to, a theater Army. Therefore, the Army in the field is a composite of Divisional Forces plus parts of Special Mission and General Support Forces.

Inasmuch as the DA staff planners assign resources to the entire Army, recommendations for the Army in the field must be expressed in terms that support allocation of resources to all elements. Trade offs among components must be supported within dollar and manpower constraints with consideration of all needs for scarce resources. Unfortunately, it is possible that these constraints may serve to create disagreement among Army claimants for resources as these become more critical.

Because economic and cost analyses must be used in several ways, the output results must be structured to provide recommendations concerning both appropriation and the budget, or the total obligation authority. At the same time, the outputs must be used to support choices among alternative systems, organizations and designs. Consequently, outputs must also be formatted in the usual cost/benefit manner. It should be noted that this does not imply that costs will be aggregated to budget and program levels. Specifically, the intent is to use the same data for the different uses.

At this point, it is re-emphasized that this study adapts and integrates cost analysis from many Army activities. Therefore, this effort is planned to assist in establishing a plateau from which a new series of cost analysis efforts can emanate. Progress to this time demonstrates that current models, data collection efforts and estimating relationships can be combined to create necessary links between costs and the Planning, Programming, Budgeting System; between combat developments and force planning; and between designs and between plans and programs.

Therefore, you will perceive a study which deliberately attempts to use existing models, data and procedures by developing connecting procedures and improving forecasting techniques. There will be an equally obvious attempt to concern this segment with problem identification and sequence. This discussion deliberately avoids the mathematical dissertations on solutions to individual problems.

1. Develop methodology for cost analysis

2. Calculate all appropriation category costs

3. Determine costs for reserve components as well as active Army

4. Conduct of trade-off analysis between appropriations

5. Compate costs of current representative force with preferred type force

6. Determine resource implications of design recommendations

7. Determine possible materiel trade offs

8. Recommend preferred conceptual design and identify priority tasks for implementation

9. Develop rationale indicating the effectiveness, risks and resource implications of preferred design

10. Recommend goals and priorities for planning and programming activities of DA Staff

Figure 1 - Economic and cost analysis tasks associated with developing force design recommendations

The cost and economic analysis tasks concerned with conceptual designs are considered to be those shown in Figure 1. Some of these tasks are explicitly assigned and others are implicit interpretations. You will notice that the derived tasks go far into application of costs to the DA staff decision process. The intent is to provide to the decision makers a complete picutre of the resource implications of the force design recommendations concerning organizing, equipping and deploying Army in the field units.

Methodology. With this background we can examine the overall methodology which has been developed for the study. Figure 2 is a highly summarized view of the action sequence visualized for the force designs. It is presented to keep the description in context. Experience has revealed that discussion of the many facets of cost and economic analysis leads to the conclusions by the reader that there is no overall plan. Therefore, it seems important that the sequence be presented with the thought that you may refer to the chart as the various elements of the methodology are discussed.

The designer develops alternate designs for the Army in the field. Each design is divided into packages* appropriate to deployment plans provided by the DA staff (See block 1 of Figure 2.) The designs are prepared using materiel, personnel and dollars which are projected by DA guidance or by the Economic and Cost Analysis team. The total resource utilization of each design is then examined (Block 2). If constraints are exceeded, the design is reshaped by the designer. If the constraints are not exceeded, the designs are costed for several purposes: first, to assure that approximately equal forces are evaluated; second, to compare the initial and operating costs of alternate designs; third, to assist in the evaluation of logistics and deployment requirements of alternate designs; and finally, to assist in preparing recommended resource plans for materiel procurement and organizational changes.

The designs are then evaluated for combat effectiveness and "fine" adjustments of designs are applied and costed. During the entire process there are continuing interchanges between the designer and costing community as costs, resources, or constraints are changed. The result of the entire effort is to produce a preferred design for any concept.

*In this narrative, a force package is intended to mean a specific part of a proposed Army in the field design. Thus, a proposed Pacific force is a force package. A design, then is the sum of all "packages" for the proposed Army in the field.

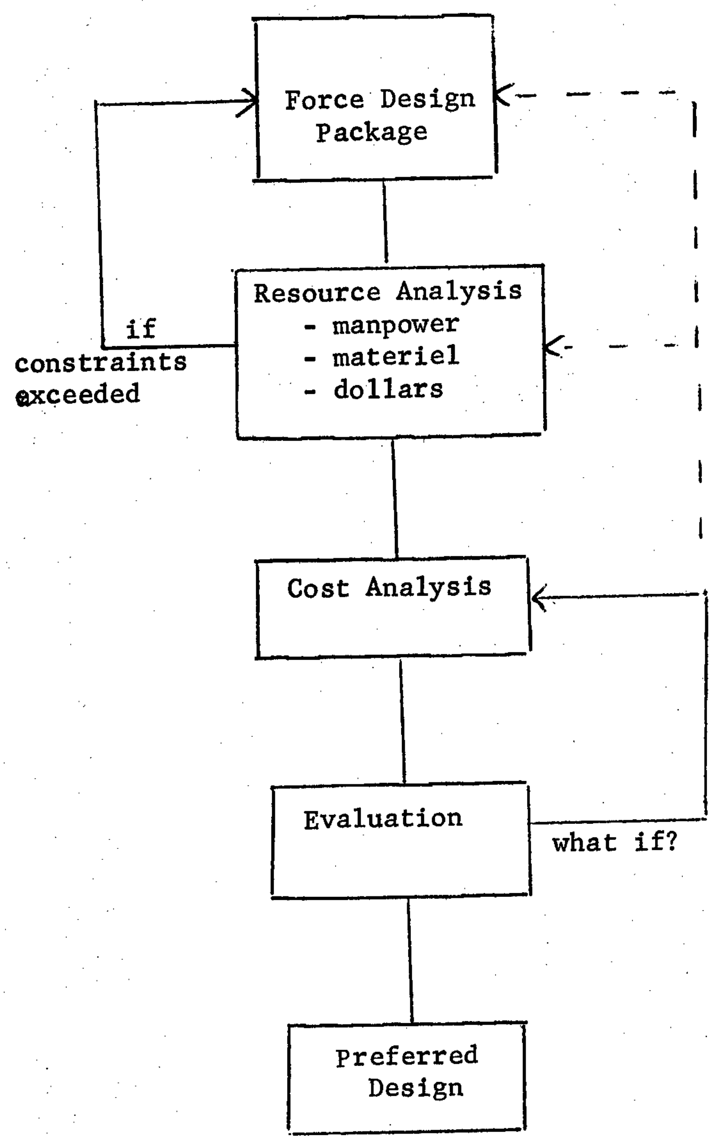

Figure 2 - Summarized chart of Design preparation, costing and evaluation

Resource Analysis. It is axiomatic that acceptable alternate force designs are alternate mixes of men and materiel which can be procured distributed and supported within the available money resources. Then, if manpower limits are established and if materiel availability can be predicted, the major resource task is to establish realistic estimates of fund availability by year. This is, of course, an oversimplification, but, on the whole, manpower authorization and materiel availability can be estimated. However, in the past, budgets and procurement have not been projected with any great accuracy. Concequently, the first tasks undertaken were to estimate manpower authorizations and materiel availability.

Manpower authorizations are essentially established by national policy. Accordingly, these numbers were furnished as guidance. These manpower ceilings were used as a needed constant to establish a starting point for the study.

The materiel resource must be analyzed in terms of both modernization items and items currently in the Army inventory. First of all, in considering the current inventory it was felt that it would be impossible to analyze each of the separate line items of equipment that make up the total Army inventory. When one analyzes this list of materiel items, it becomes apparent that the only items of interest to the force designer are the high cost items which make up the bulk of the inventory when considered from the standpoint of total dollar value.

A log normal analysis was accomplished on those major items of materiel reportable under AR 711-5. Based on this analysis, it was determined that by considering only those line item numbers (LIN's) with a total inventory value of 7.5 million dollars or more, the total materiel list could be reduced to approximately 320 line items, which represent 70% of the total dollar value of the Army inventory.

The advantages of using such a reduced list for costing and constraint analysis should be obvious provided such an analysis could be verified. This was accomplished by costing a type field Army in Europe using the reduced list and comparing it with a total dollar value of the entire inventory of reportable items within this force. The results are shown in Figure 3.

You will notice that although the largest percentage of LIN's picked up in any one of the forces is 23%, we have accounted for a minimum of 71% of the theater Army package and a much higher percentage of the rest of the elements making up the force. If this sample proves to be useful, it will be recommended that the data base for DA models, such as COSTALS, be amended to incorporate this sample.

ELEMENT	% LIN COVERED	% INV COVERED
INF DIV BASE	23%	88%
INF DIV SPT	15%	88%
MECH DIV BASE	22%	92%
MECH DIV SPT	15%	86%
ABN DIV BASE	22%	86%
ABN DIV SPT	15%	87%
AMBL DIV BASE	17%	93%
AMBL DIV SPT	15%	80%
ARMD DIV BASE	23%	92%
ARMD DIV SPT	14%	86%
CORPS PACKAGE	15%	84%
FIELD ARMY PACKAGE	12%	76%
THEATER ARMY PACKAGE	15%	71%

Figure 3 - Validation of selected item list

The master equipment authorization listing maintained at CDC includes all of the items authorized by TOE for all of the current units, as well as many of the new organizations which are currently under development. A computer program has been developed which applies the current SB 700-20 prices to this master authorization list and sums the total PEMA initial issue cost by unit. By running this program again using only those items included on the selected list, an accurate ratio is obtained of the PEMA cost based on the sample listing to the total PEMA initial issue cost by type unit. Once these ratios have been determined, accurate PEMA costs for new units may be determined by considering only those items included in the sample and expanding the total value by the indicated ratio.

In order to apply constraint analysis to the selected items list, we determined the total inventory and a ratio of initial issue for the Army in the field to the Authorized Acquisition Objective (AAO) for each item on the sample listing. By adding expected receipts for the 1972-73 budgets to this inventory and attriting the total, year by year, through 1982 and applying the appropriate ratio of initial issue to total AAO, the number of each of the selected items of materiel which will be available to the Army in the field in 1982 was determined.

In considering the modernization items there was included only those major items which have sufficient interest and potential that they may be incorporated into procurement schedules and be available by the 1982 time frame. In addition to those items providing entirely new capabilities, high cost modifications to current equipment are included in the modernization category.

There are more than 1100 items under various stages of research and development which are presently included in the CDC data bank. This number had to be reduced to a workable quantity since a great deal of data had to be collected on the modernization items. Beginning with the items included in the current Army Force Development Plan (AFDP) items were added when there appeared to be sufficient interest that development might be accelerated sufficiently to allow procurement during the CONAF time period. The list of new materiel items presently includes approximately 84 modernization items. Costing and production data has been requested on these items from the Army Materiel Command. This list will be changed from time to time as the study progresses, since new items and modifications to old items would be introduced into procurement plans and other items are type classified Standard A and procured in sufficient quantities that they may be deleted from the modernization list and included on the list of selected items.

The requirements for each force design are then compared with the available inventory, and the shortages which must be made up through the expenditure of PEMA funds are calculated. The total dollars required to procure items from the selected high value lists may then be expanded to determine the total dollar value of all inventory which must be procured to field the conceptual designs. Funds will be examined in an order of priority established by the designer. The amount of money available for procurement is, of course, constrained to projected budget levels.

The baseline force is the AFDP 73-83 force provided by the ACSFOR as of 1 July 1975, which has been projected on to 1982.

As part of this projection it was necessary to modernize this force. There are many ways to accomplish this modernization. We looked at several and developed an arbitrary modernization plan with which to test procedures. However, a department of the Army staffed and approved modernization scheme for the baseline force has been requested. This is extremely important since this will be the standard against which designs will be compared for costs and effectiveness.

Modernization was accomplished utilizing current Department of the Army plans projected under the same dollar constraints that are applied to the conceptual force designs. Only those items included in the current AFDP were considered for modernizing the baseline force. With the previously mentioned constraints on the dollars available for modernization, it was not possible to fulfill all the plans outlined in the current AFDP. For this reason, it was necessary to establish priorities for procurement.

Once this priority ranking had been established it was still necessary to analyze which items of equipment would be procured under each of the major weapons systems categories and to rank them in order of the priorities established by the DA staff. These steps resulted in an ordered listing of 35 items included in the AFDP which may be considered "big eight" items. The remaining items from the AFDP were listed in the priority established by the DA staff.

One the priority listing was established, the AFDP was analyzed year by year for PEMA expenditures and cumulative assets. Then the PEMA expenditures were summed each year beginning with the item at priority number 1 and adding items in order of their priority until the PEMA constraint had been reached. No attempt was made to tailor the selection by picking only certain items from each big eight category. We simply worked out way down from priority number 1 through our priority listing of materiel items until we ran out of money and then went on to the next year. As a result of this procedure we ended up modernizing the baseline force for testing costing procedures.

The number of each of the new items that would be available for issue to the Army in the field was determined by comparing the initial issue quantity of each item to its AAO, and using the ratio to convert force requirements to total acquisition objective. These available for issue quantities were applied first to the Euroepan Baseline Force, and anything remaining was allocated to the other forces in the base. Actual BOI's were utilized where they had been established and wherever the quantities available for issue would permit. An equitable reduced BOI was prepared in the other cases where procurement was not complete or availability was low.

This a good place to introduce the idea of micro and macro analyses required for a study of this scope. It is obvious that for force planning and for program and budget activities, total quantities are required. However, the force designer is not interested in totals or in dollars; he must know precisely the number, by type, of self-propelled howitzers, trucks, observation aircraft and similar items that are, and will be, available. The cost analyst must be able to treat both requirements.

The sample list of major items, mentioned above, provides predictable relationships with world wide assets, total inventory by National Inventory Control Point (NICP), total assets by type division and total requirements by force block or force design.

With this sample the force designer specifies major items. Checking through the sample the cost analyst can estimate total dollar value of materiel requirements for the force design or force design segment. These are important in estimating both procurement requirements and OMA requirements.

Several methods of projecting OMA requirements are available. However, at this point no satisfactory proof exists that any one is either accurate or inaccurate as organizational concepts change and as materiel and manpower mixes change.

Several conclusions have been reached. It is not safe to assume a constant level budget; provision must be made for real as well as inflationary changes; and the interrelationships of appropriations within the budget must be established. It is, or will soon be, apparent that appropriation relationships are affected by inflation.

The next procedure was to project a total budget at an expected upper limit and an expected lower limit as a fraction of the Gross National Product. Initially real growth for the GNP was calculated at 3.5% annually. We estimated from history and current programs the relationships of appropriations. Fortunately, there was firm guidance on military and civilian strengths. Consequently, the effects of real growth in income were applied. The DA staff provided current factors for pay and allowances. A real growth rate of about 2% was applied to military pay; about 1% to OMA and about 1.5% to reserve components appropriation to account for real pay growth.

At this stage of the study, no effort has been made to estimate RDT&E or MCA requirements. Instead the planned level was simply projected on a straight line as a percent of the total obligation authority (budget). Reserve components appropriations are primarily pay and allowances and OMA. These, too, are based on a constant manpower level.

The total predicted budget was then projected by summing the individual appropriations. Note that although no mention has been made of fixed costs, these were included in the appropriation analyses and projections.

These projections produced upper and lower levels for total budget and an approximation of total MPA,OMA and reserve component requirements. Figure 4 is an imaginary illustration showing RDT&E and MCA as constant percentages of the budget which is indicated at the lower projected limit. When growth rates are applied to manpower cost factors, the appropriations, within a fixed budget, change about as indicated. (For security reasons, proportions, percentage and rates are imaginary.) The remainder of the budget then is the amount available for materiel procurement. Several significant conclusions are apparent. First, as materiel capabilities and complexity are increasing, dollars are less available. Second, once a design is initiated, little or no opportunity exists to change the concept regardless of change in threat.

A similar analysis was made at various levels of the projected budget. This effort identified for the designer all resources - men, money and materiel - available during the planning period.

Alternate designs were created under each of several concepts. These are now being received and analyzed to assure that all are within expected resource levels.

Cost Analysis Activities. Figure 5 is a list of the elements of cost or economic analysis. Some are rather obvious, while others may not be quite self explanatory. Each will be briefly described.

Resource requirements. This effort is simply an accumulation of materiel (PEMA) and personnel (MPA) requirements for each design and calculation of operations and maintenance factors. The latter factors are now being projected on three different bases.

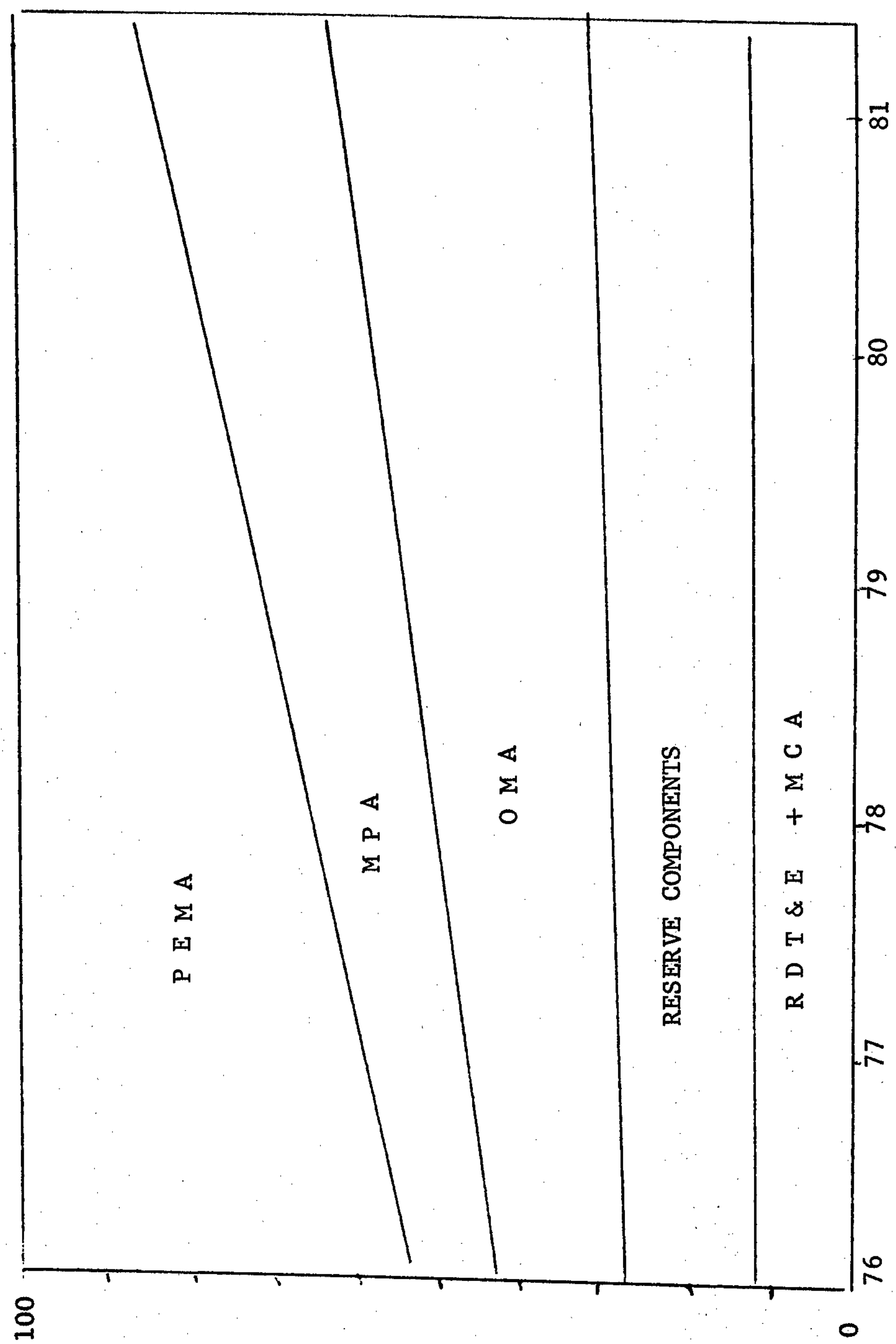

Figure 4 - Projection at lower limit of budget

Resource requirements

Equal Cost forces

Comparative costing

Resource plans

Transition plans

Cost/benefit studies supporting trades

Figure 5 - Plans for cost analysis

First, manpower factors plus constant.

Second, manpower plus materiel operating factors.

Third, pro rata share by force element.

Equal Cost Designs for Evaluation. The concept of equal cost forces presents an interesting problem. If all designs are created within projected budgets with similar materiel and manpower limits, it seems that unequal costs could hardly be achieved. However the objective of "equal costing" is to assure that evaluation is not designed to prove that "more is better than less." Consequently, equal cost forces are currently defined as equal resources applied to a threat. The cost of a representative force selected from the Army Force Development Plan is used as a base. The costs of alternate designs are compared with those of the "baseline." A second challenging problem is emerging and there seems to be no obvious answer. This problem will arise if some designs underestimate logistics requirements. The question then is, "Shall assumed additional costs of maintaining an acceptable readiness posture be added?" In whatever manner this question is answered, the appropriate initial and operating costs must be determined. At this point, forces would be equal in resources and costs.

Comparative Costing. It is planned that each design will then be costed through a model known as COSTALS. The data bank must be adjusted to the new organizational concept for both manpower and materiel, specifically from the G and H series of TOE's to the projected new series. In addition, new materiel, bases of issue and issue priorities must also be added. The major complication here is to develop procedures for adjustment of the data to proposed new series of TOE's. Initially the procedure will provide rather gross comparisons. Costing refinements will be added as combat effectiveness appraisals are improved.

The COSTALS Model is used to compare the costs of the baseline force and the conceptual designs for CONAF. This model contains both a unit cost program and a force cost program. The unit cost program provides a cost estimate for each unit identified by its Standard Requirements Code (SRC). The data base for the unit cost program currently includes approximately 600 units by SRC number and serves not only as the basis for the force costing program in the COSTALS Model, but also as a primary cost data base for two other force planning models, the "Battalion Slice" and the FOREWON Model. If all the units in the CONAF study were included in the COSTAL data base, it would be relatively simple to cost these units. However, this is not the case. Many estimates outside of the model must be made to calculate a total force cost. Naturally, no attempt was made to modify the actual Department of the Army COSTALS data base; however, a separate data base was established for CONAF. Future iterations of CONAF will be much simpler to cost.

The unit cost program receives as input unit strength, major equipment, equipment tonnage, aircraft inventory, annual aircraft flying hours, and several categories of SRC dependent cost factors and several categories of theater dependent cost factors. The program then computes the unit's initial costs and 13 annual recurring costs. These costs are then summed to provide initial and annual totals for OMA, MPA and PEMA appropriation categories under peacetime conditions for five theaters.

The force cost program uses this output as a data base and computes the cost of a force based on unit strength and quantity of each type unit in the force.

It might be well to review how the unit cost program operates before trying to explain how the baseline force has been costed and how the conceptual force designs are being costed. The cost categories are shown in Figure 6.

The model uses seven personnel categories to calculate MPA costs. Unit strength figures and per capita cost factors are used to calculate initial PCS, annual PCS, accession and training, medical activities (budget program 2400), army wide activities (budget program 2500), military pay army and central supply activities (budget program 2200). The central supply activities estimate also considers the tonnage of the unit equipment and computes a separate cost for the transportation of this equipment. The per capita based cost and the tonnage based costs are summed to provide the estimate of the total BP 2200 costs. The program also computes operating costs (BP 2000) on a per capita basis for certain units and provides this estimate on a unit basis for others. Aircraft costs are computed separately based on the number and type of authorized aircraft, program flying hours, and the estimated cost per flying hour. These costs are automatically added to unit operating costs of units which have assigned aircraft. The O&MA minor category includes the initial cost for OMA repair parts, station equipment and organizational clothing. These estimates may be provided as an SRC total or they may be computed using a per capita factor by type unit. Ammunition consumption is handled the same way. Certain units have a per capita ammunition consumption factor, while others have the ammunition consumption costs provided as a unit total estimate.

The last five cost estimates shown in Figure 6 are based primarily on the PEMA equipment assigned to the unit. The PEMA major includes

UNIT PERSONNEL STRENGTH BASED ESTIMATES

- MPA
- INITIAL PCS
- ANNUAL PCS
- A&T (3 CATEGORIES ANNUAL & RECURRING)
- MEDICAL ACTIVITIES (BP 2400)
- ARMY WIDE ACTIVITIES (BP 2500)
- CENTRAL SUPPLY ACTIVITIES (BP 2200)
- OPERATING COSTS (BP 2000)
- OMA MINOR
- AMMUNITION CONSUMPTION

UNIT EQUIPMENT BASED ESTIMATES

- PEMA MAJOR
- PEMA CONSUMPTION
- PEMA MAINTENANCE FLOAT
- DEPOT MAINTENANCE (BP 2300)
- PEMA REAPIR PARTS (INITIAL & RECURRING)

Figure 6 - COSTALS unit cost program operation

the initial purchase costs of all major TOE equipment. The other PEMA categories can be computed using the actual peacetime replacement factors, float factors and BP 2300 factors by line item of equipment found in a given SRC, or they may be estimated quite closely by using a percentage factor of the total dollar value of the PEMA major equipment. PEMA repair parts are estimated this way, by taking a percentage of the PEMA major equipment for the initial cost of PEMA repair parts, and a percentage of the PEMA consumption for the annual recurring costs of PEMA repair parts.

Applying the Cost Procedures. When the baseline force was received from ACSFOR, it was analyzed and units were grouped by SRC. These data (the number of units by SRC) were entered into the COSTALS force costing program. We were provided a print out showing which SRC's matched units available in the COSTALS data bank and which of the units in the baseline force had no match. There were 28 SRC's (which account for over 100 of the units in the baseline force) for which there was no H series SRC in the COSTALS data bank, but for which comparable data were available for the older G series TOE. There were 6 major units and 56 TD and TDA units in the European baseline force for which there was no data bank match. A search was made for similar units and substitutions were selected which matched the missing units very closely in personnel and equipment. These SRC's were entered into the baseline force to provide costing data for these units. For the G and H series discrepancies a similar search was made, and it was determined that the equipment within these two series TOE's was very similar; however, personnel strengths varied. The COSTALS program was modified to adjust the per capita based MPA and OMA costs according to the ratio of unit strengths. With these adjustments the COSTALS program was run on the baseline force. The costs were computed and the totals for each of the cost categories was provided.

An analysis of this COSTALS run indicated that there are five type units in the force for which no PEMA costs were included. It was decided to make these corrections and "modernize" the baseline force on an overall force basis. The PEMA costs for the units in which this figure was missing were computed and added to the appropriate PEMA categories in the totals. This gave a cost based on the COSTALS Model of the European baseline force as it is equipped today. Now all that was left to do was to modernize this force with the list of modernization items mentioned earlier.

Prices, float factors, peacetime replacement factors and BP 2300 cost factors for each of the modernization items have been requested from AMC; however, these costs are not yet available, so,the cost of this modernization is based on our own estimates, using the best data that was available. Most of the prices were derived from Selected

Acquisition Reports (SARS) and from the weapons systems cost data handbook which has been recently published by the Comptroller of the Army. For those items that were not included in these two documents, we used the prices from Annex B of the 1973-83 AFDP. Float factors were estimated based on float factors for comparable items that are included in the current Army Materiel Plan. These float factors were applied to force package requirements. Utilizing the new totals and the unit prices for each item of equipment, the cost of adding these modernization items to the force was computed. The net increase was applied to the COSTALS figure to provide a new grand total for PEMA major and float for the European baseline force. The other PEMA based costs were adjusted accordingly.

The units in the baseline force affected by this modernization were aviation units, artillery units, infantry units, armor units, cav units and air cav units. The strengths in each of these type units were calculated and the per capita factors for BP 2000, OMA minor and ammunition consumption, were increased proportionally. The amount of this increase was applied to the strength figure for each type unit and new totals for these cost categories were calculated and added to the totals from the COSTALS run.

The BP 2000 cost for the modernized aircraft were computed separately in the same manner that they are computed in the COSTALS program. It was assumed that the flying hour program for new aircraft would be the same as that presently used for current comparable craft.

We made a linear regression analysis of known factors contained in FM 101-20 plotting maintenance man hours per flying hour and fuel consumption against gross weight and got excellent correlation for both curves. Based on these curves the fuel consumption and maintenance man hours per flying hour for the new aircraft were estimated.

The flying hour cost was broken down into a fuel consumption cost component and a maintenance man hour cost component. Then these partial costs were increased based on the new estimates and summed. Applying this estimated cost to the number of aircraft added to the force and multiplying the result by the flying hour program provided a total BP 2000 flying hour cost for the new aircraft. This amount was then reduced by the cost of the old aircraft that were removed from the force and the incremental cost added to the BP 2000 figures from the COSTALS run.

A&T OMA costs were increased slightly to account for the increased operating costs associated with training pilots for new aircraft. In addition, a simple adjustment was made to the A&T OMA cost associated with training the personnel in each of the modernized units.

A&T MPA costs were increased to account for the increased cost of certain pilots. This increase was based on an older, higher pay grade trainee in training for a longer period of time. The increased costs associated with training CH-47 pilots was used as a basis for this estimate. No other MPA changes were incorporated.

A&T PEMA costs were increased slightly to account for the increased ammunition costs associated with qualifying crew members with missiles and the newer high rate weapons. With these changes the new totals for the modernized baseline force were obtained.

In this discussion only cursory mention has been given to the total evaluation process. This is not intended to rob evaluation of its true importance. Combat effectiveness criteria are difficult to ennumerate and their measurement is almost beyond the state of the art. Therefore, any discussion of effectiveness evaluation merits undivided attention. However difficult, it is almost a certainty that criteria will be established and measured. Early stages may not be sensitive to minor changes, yet it is likely that measurement will continually improve. This backdrop imposes an additional responsibility on cost analysts. This may be illustrated as indicated in Figure 7.

Let us suppose that combat effectiveness evaluation for two alternate force packages at an initial time is performed and that relative effectiveness for the two designs is as indicated in Figure 7. Now, let us examine maintenance requirements, supply requirements, transportation requirements and other support requirements. These requirements can probably be compared with the capabilities provided in each design plus applicable indigenous hire and civilian strength. In the illustration it is indicated that at some point the force deteriorates to the point that equilibrium is established. Such an equilibrium may not, in fact, be reached. However, at time t + something, combat effectiveness of design 2 approaches and exceeds that of design 1 simply because of higher materiel availability.

Which design is superior? The cost analyst cannot answer, for the answer ultimately depends upon the degree of risk to be accepted and the possibility of alternate concepts such as expanded contact teams. The cost analyst can but point up the problem in terms of resource implication.

Other aspects of this problem include:

Adequacy of the rotational and training base.

Possible costs and resource requirements for improving readiness conditions of selected units or forces

Incremental costs and risks incident to "imbalancing" forces.

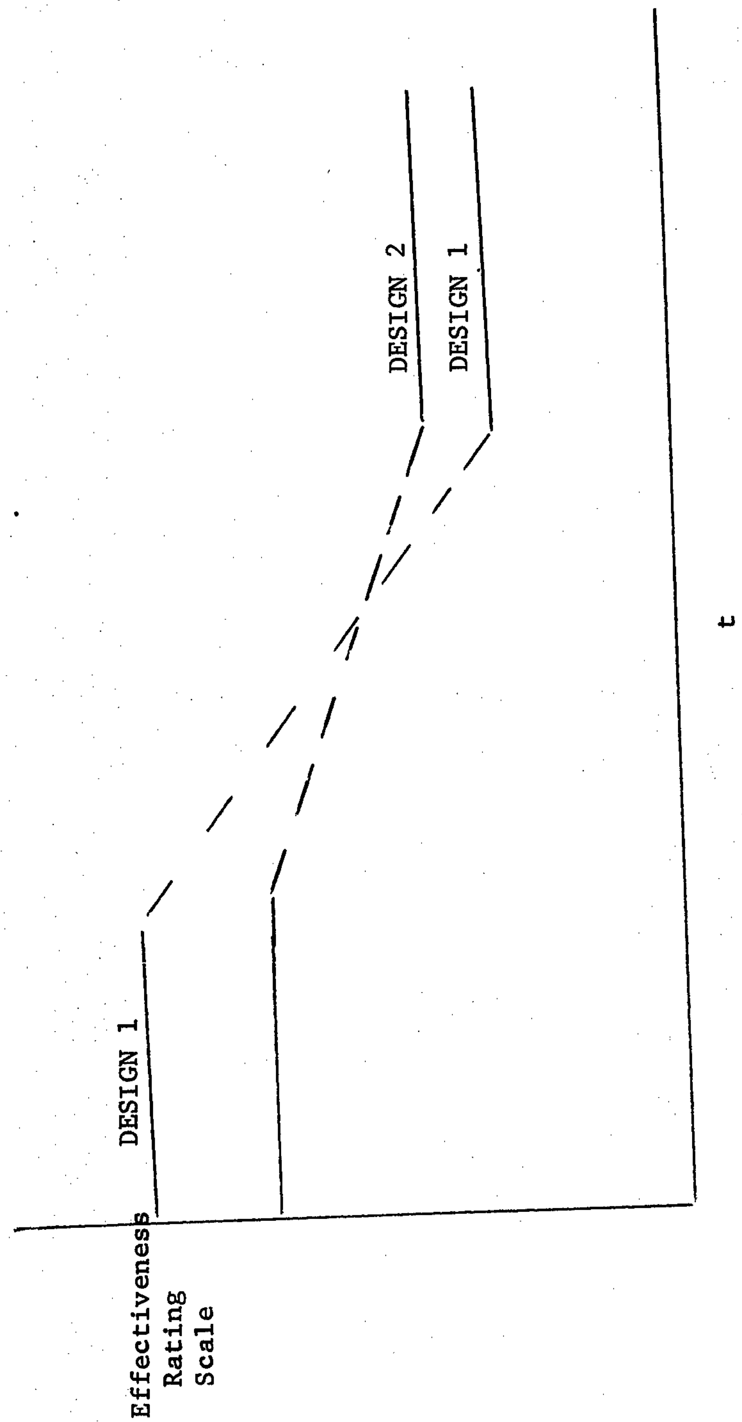

Figure 7 - Resource implication of design

As preferred designs emerge and the combat developer prepares appropriate recommendations, it hardly seems feasible to take a series of volumes containing descriptions, evaluations, cost analyses, organization and materiel quantities to the DA staff with a "buck slip" saying, "We will be back next year with another set."

Instead, the necessary resources must be planned and entered into the Planning Programming Budgeting System (PPBS) at appropriate spots considering lead times. These are specific responsibilities of DA staff activities. However, the staff would appreciate and probably will insist that the recommendations be accompanied by appropriate plans for items such as materiel procurement, distribution, unit priorities and personnel and organization.

The plan is for the economic and cost analysis community to identify affected elements of the Five Year Defense Plan and the PPBS and to prepare support for required decisions. This would include cost/benefit studies and cost analysis to support the trade offs required.

Transition Planning. This is another new area for economic and cost analysis. It may not properly belong to these individuals, but they have the necessary data and can, therefore, conduct this planning conveniently.

The purpose of these plans is to show the effect on the Army in the field of resource constraints during a change in concept. It seems apparent that resource planning cannot ignore for a period of years the combat effectiveness of the troop basis - the troops on the ground. Let us illustrate by assuming we have in a theater an artillery-heavy force with appropriate ground transportation. It is decided to change to an airborne force with aerial resupply. The necessary procurement, training and reorganization could not be accomplished instantaneously. Consequently, the changeover could, if not properly planned and time phased, result in a completely incompetent force for some time. Thus the need for transition planning. The objective is to maintain combat effectiveness during change in force concept and design.

There are probably hidden or omitted costs in the alternate design. These costs may be difficult to define and even harder to put a dollar value on. One obvious candidate is the cost of prepositioned materiel. The requirement for prepositioned materiel will probably vary with the number and type forces that are assigned to the various force packages. We will estimate the initial investment costs for this prepositioned materiel and the annual recurring cost for maintaining these stocks. The force package costs for each design developed by the costing sequence described will have to be adjusted by the cost of establishing and maintaining this prepositioned materiel.

Other hidden costs may become apparent after a thorough logistical analysis of each of the force packages of each force design. Each force will vary in its ability to sustain itself logistically and will have to be analyzed to determine its capability for supply and maintenance, transportation, construction and medical support.

A preliminary methodology has been prepared for the purpose of comparing logistics capabilities. It is based only on the assumption that we know something about the baseline force and can use this force as a basis for comparing the conceptual designs.

The logistical effectiveness of a force is a function of its logistical capabilities and its logistical requirements. We can define this effectiveness as the ratio of its capabilities to its requirements. We have elected to call this ratio a force support ratio.

Since the capabilities and requirements of the baseline force are known values, and we are going to use it as the basis for comparison for evaluating the force packages, we may define its force support ratio as 1. (Which may be interpreted as "the baseline force is fully as effective as the baseline force!")

By using the baseline force package as the basis for comparing the logistics adequacy of the conceptual force packages and by normalizing their requirements and their capabilities to the capabilities and requirements of the baseline force, we should be able to determine support ratios which are directly comparable to each other and to the baseline.

One support ratio will not be adequate to describe the logistical effectiveness of any design. Separate ratios must be computed for each of the major logistical functions and for any other function that is to be analyzed. Currently planned are force support ratios for: the supply and maintenance functions, the transportation function, the construction function and the medical function. They all may be determined in the same manner if we can quantify capabilities and requirements by using the Battalion Slice Model as a basis.

Whether or not these direct relationships can be applied remains to be seen. However, even if these ratios are not directly applicable to designs, they will at least indicate to the designer those areas where further analysis may be required or where adjustments may be needed in the design. In addition, they will be useful in determining the need for additional logistics support that must be considered in equal cost comparison.

Economic Analysis. The force designs recommended will constitute alternate investment options when compared to the baseline. When trade off analyses are completed to maximize the combat effectiveness of preferred designs, there may be suggestions for (1) altering the distribution of forces within the force structure; (2) altering the distribution of funds among appropriations within the budget;or (3) altering materiel procurement plans.

The increase in effectiveness of the force is an expected benefit. There will obviously be a range of these benefits and several ways of achieving these benefits. The discounted costs of achieving these benefits will have to be arrayed for comparisons. Thus alternate costs and alternate benefits will have to be analyzed.

These overall cost benefit analyses will in turn have to be supported by cost benefit studies of proposed major changes to the program elements of the FYDP - particularly, those elements concerning divisional force organizational elements and major materiel items. The procedure, scopes and level of detail in economic analysis have not yet been completed.

The Overall Role of Cost Analysis in Force Design. The foregoing illustrates several new and different responsibilities for the cost analysis program in the Army.

a. The cost analyst develops an array of available resources for planning and design.

b. The cost analyst calculates the effects of selecting materiel options and man-materiel combinations.

c. The cost analyst assist in identifying potential trade offs to support effectiveness objectives and assist in the cost analysis support of recommendations.

d. The cost analyst develops arrays of forces in terms of organization and materiel available by year in shifting from one design to another.

These applications of cost analysis depend upon the weapons systems cost analysis activities of AMC to obtain the appropriate incremental cost of changing materiel characteristics of a force. There is a need for OMA analysis expanded to application to new organizational designs. There is a need to develop an improved cost analysis effort on changing logistics concepts within force packages such as Europe or the Pacific theater.

There is also a need to develop methodologies for materiel priorities for procurement based on cost/benefit analyses.

Finally, these needs can perhaps be expressed in a single summary requirement. Cost analysis in itself needs to be extended to assist in bridging the existing gap between combat developments and force planning activities. This is particularly true if combat developments will be construed to mean all activities relating to development, modernizing and manning forces as they change from concept to reality.

WEAPON SYSTEMS ANALYSIS

Mr. Edward R. McCauley
Directorate of Cost Analysis
Comptroller of the Army

Weapon Systems Analysis encompasses aspects of cost, schedule, and operational characteristics related to a system. Consequently, the weapon systems analyst is continually analyzing the cost estimates for the Weapon System and in effect acts as a "Weapon Systems Analyst/Cost Analyst." To narrow the field of choices, I will mainly discuss cost with reference to the other fields only when necessary to further explain cost analysis. Over a period of years the final cost of a number of important weapon systems has been as much as 90% higher than the original estimate such as the M60A1E2 tank original estimate made in 1966 compared with the estimate made in June 1970. Errors of this magnitude have caused people to ask whether it is really possible to estimate development, procurement and operating costs of future systems (which cannot be completely defined in advance) with sufficient accuracy to use these estimates as a basis for major program decisions. Today's constrained budgetary conditions necessitate estimates that have sufficient accuracy but which radiate complete confidence in the estimate to the decision maker. To accomplish this, the weapon systems analyst/cost analyst must reevaluate his methods and tools to achieve more accurate cost estimates for studies such as cost-effectiveness studies.

Cost-effectiveness analysis is based on the economic concept that all military decisions involve the optimum allocation (best use) of limited resources among competing requirements. Military cost-effectiveness analysis is not a decision process but is an aid in facilitating decisions that must be made now in order to be prepared in the future. When reviewing studies that contain cost-effectiveness analyses the weapon system analyst/cost analyst must remember that a cost-effectiveness analysis is designed to examine the problem systematically and relate costs, effectiveness, and risks of alternative ways of accomplishing an objective.

The essential elements of a cost-effectiveness analysis are:

(1) Objectives (functions to be accomplished).

(2) Alternatives (feasible ways of achieving the desired military capability or accomplishing the function).

(3) Cost of resources required by each alternative.

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(4) A set of mathematical or logical relationships among the objectives, alternatives, environment, and resources (models).

(5) A criterion for choosing the preferred alternative.

Each of these items has several important facets which must be examined:

THE OBJECTIVE

The problem must be analyzed to determine the real functional need underlying the requirements for certain organizations and hardware systems. This element is very important to the analyst, in that he is required to remain within the limits set by current budgetary conditions, and possibly the objective as stated could be met by a system already in the current Army inventory, thereby negating the need and the cost for the proposed system. Cost, schedule, and operational characteristics all contain objectives, thereby indicating that the analyst should be familiar with all aspects of this system and analogous systems. A good definition of the objectives leads to other alternatives which could save money and be just as effective.

ALTERNATIVES

As was pointed out previously, the alternatives are limited only by creative imagination and good military judgment. By exploring alternative ways of using resources, it is often possible to discover ways of achieving an objective with fewer resources, or accomplishing more with the same resources. Again to the cost analyst, this is an important point. The use of existing systems which accomplish the same purpose as the proposed system may save money.

COST

This element, obviously, is the most important concern of the cost analyst. For a more adequate cost-effectiveness analysis, I feel that the cost analyst should be aware of the tools used by the cost estimator. This topic will be discussed more extensively later.

MODELS

Models are used in cost-effectiveness analysis to cope with the host of variables that are inherent in problems of the future. A model is simply certain relationships expressed in some way to simulate real or expected conditions in order to foresee, even to a limited extent, the expected outcome of a course of action. Models assist in simplifying the problem, in identifying the significant components and, interrelations, in determining which variables are especially important for the decision at issue, and which variables can be suppressed. In this manner, the decision process can be more precisely focused on those areas which require a judgment decision.

Models can be classified as three basic types: iconic, analog, and symbolic.

Iconic Models. Iconic models look like the "somethings" they represent. The model results from a metric transformation or scaling, and describes, in physical form, a static object or a dynamic object at one instant in time. Some familiar examples of iconic models are model airplanes, so-called working models frequently associated with inventions, and a globe representing the earth.

Analog Models. Analog models are produced by a convenient substitution or transformation of certain properties of the "something" being represented. Analog models do not look like the things they represent. Highway, terrain, and weather maps are examples of analog models, as are the representations of continents, rivers, and oceans on the surface of a globe. The electrical circuits of an analog computer function as analog models.

Symbolic Models. Symbolic models represent the characteristics and relationships of the original "something" by symbols. The symbolic model does not bear any physical resemblance to the original. Hence, in appearance it is far removed from the real world, difficult to understand, and difficult to relate back to the original. Mathematical models are examples of symbolic models and mathematical formulae such as Ohm's law are simple examples of mathematical models.

Many models of any appreciable size are of a compound nature, for instance some of the model components or submodels might be analog and others symbolic. A war game is a good example of such a compound model. The maps employed are analogs; the mathematical representations of certain subsystems are symbolic.

The mathematical form of the symbolic model is the most prevalent type of model used in cost estimating. Mathematical models are of two basic types: exact (deterministic) and probabilistic (stochastic). An exact model of warfare, of course, is impossible in peacetime. However, it is possible to create an almost exact model of some specific piece of hardware or activity and subject it to test. The final product of the model will then closely approximate the results from the actual hardware or activity. Most military problems are, by nature, made up of uncertainties. Models of these problems are considered to be probabilistic when the uncertainty is identified by a probability factor. For example, a war game using kill probability for an air defense system is a probabilistic model.

Models used in cost-effectiveness analysis sometimes tend to become mathematical and abstract. Consequently, they may be difficult to understand. A good cost-effectiveness analysis strikes a balance between simplicity and retention of enough detail to ensure that the expected outcome of an expected action will be adequately portrayed. In any case, all models have certain common elements. These are broadly stated as a definition of the problem, principal factors or constraints, verification and the decision process--or application of criteria. The validity of conceptual or mathematical models cannot be verified in a cost-effectiveness analysis by controlled experiments. At the best, they can be tested by their workability.

Criteria

Some types of criteria must be decided upon, in order to select the preferred alternative.

Three of the forms of criteria are: equal cost, assuming an arbitrary fixed budget, this analysis determines which alternative gives greatest effectiveness for the same expenditures; equal effectiveness determines the least cost for a fixed military capability; or incremental effectiveness at incremental cost which relates the increase in effectiveness achieved to the associated increase in resources required. Criteria must be chosen with care so as not to weigh a decision in any particular way towards one alternative. To the analyst, the incremental effectiveness form seems the most dependable due to the great variability of cost with any variation of the assumptions.

The preceding areas, then, are some of the essential elements of cost-effectiveness analysis. An analysis should begin with these elements being analyzed first, and only after thorough review should any other aspects be examined. To perhaps understand what is behind the review of any one of these elements, I will attempt to examine the element labeled cost. As was mentioned previously, it is essential that the analyst is aware of the tools used by the cost estimator.

There are three basic methods used for cost estimation--statistical approaches, analogy, industrial engineering, and a fourth method may be a combination of the three. In the statistical approach, estimating relationships with parametric explanatory variables, such as weight, speed, power, frequency, and thrust, are used to predict cost. This approach is best used in the early development stages (conceptual, validation, and full-scale development) of the system. The method of analogy is based on direct comparisons with historical information on like components of existing stages. This approach is desirable when the system has been definitized enough to recognize like components; these would probably be the validation, full-scale development, and production stages of the life cycle. Finally, the industrial engineering approach represents an examination of separate segments of work at a low level of detail and synthesis of the many detailed estimates into a total. The industrial engineering approach is best used in the full-scale development and production stages of the life cycle.

At all levels of aggregation, much estimating is performed by analogy: System A required 100,000 hours; given the likenessess and differences in design and in performance of proposed System B, the requirement for B is estimated at, say, 120,000 hours, Or, at a different level, engineers and shop foremen may rely on analogies when making a grass-roots estimate; in this event, analogy becomes part of the industrial engineering approach. The major drawback to estimating by analogy is that it is essentially a judgment process and, as a consequence, requires considerable experience and expertise to be done successfully. For the government analyst, analogy can be useful for a rough check of an estimate; however, when making estimates, analogy based on a sample of one, adjusted by some complexity factor, should be avoided. This caveat rests on the contention that, first, it is poor statistics; second, it is non-reproductible; and third, it cannot be evaluated by the user of the estimate.

There will always be situations in which analogy or industrial engineering techniques are required, but in general the statistical approach is useful in a wide range of contexts, whether the purpose is long-range planning or contract negotiations. In the former, a more highly aggregated procedure may be used because it ensures comparability when little detailed knowledge about the equipment is available. Total hardware cost may be estimated as a function of one or more explanatory variables; e.g., engine cost as a function of thrust, or transmitter cost as a function of power output and frequency. However, this approach is often a matter of necessity, not choice. Even for long-range planning, it is sometimes desirable to estimate in some detail.

In any situation the estimating procedure to be used should be determined by the data available, the purpose of the estimate, and, to an extent, by other factors such as the time available to make an estimate. The essential idea to be conveyed here is that, when properly applied, statistical procedures are varied and flexible enough to be useful in most situations that equipment cost analysts are likely to encounter. Although no specified set of procedures can guarantee accuracy, decisions must be made; it is essential that they be based on the best possible information. The analyst must seek the approaches that will provide the best possible answers, given the basic information that is available.

Other important aspects of cost estimating are data collection and adjustment. For any estimate to be worthwhile, a good data base must be established with competent material used. Any estimate of new or relatively new equipment or systems needs to be based primarily on historical data of like systems. This is based on the premise that new system costs will follow basically the same pattern as those systems which have been experienced. There are three types of historical data that the estimator could use; resource data, performance and physical characteristics data, and program data.

Resource data is usually in the form of applied costs and labor hours. This is generally classified under end item categories or functional categories, i.e., labor, material, overhead, and other direct charges. The source of this data is usually the contractor's reports.

Physical and performance characteristics data is as important as resource data. Data collection in this area can be time-consuming, particularly since it is not often clear in advance what data will be required. The goal, of course, is to obtain a list of those characteristics that best explain differences in cost. Weight is a commonly used explanatory variable, but weight alone is seldom enough; speed is almost always included as a second explanatory variable for aircraft airframes.

A third type of historical data is program data which is drawn from the development and production history of hardware items. The acceptance date of the item, the production rates, and the occurrence of major and minor modifications in production--all such information can contribute to the development of cost-estimating relationships.

These three types of historical data are used in the formulation of estimating relationships. The use of good historical data is an important aspect in the formulation, but even more important is the use of reliable statistical methods. These methods are used in the actual refinement of the historical data to obtain an estimating relationship. Care should be taken so as not to include in this new analysis any bias and inefficiencies that may be inherent in the historical data.

After the cost estimating relationship is established and documented, its actual use should be discussed. The advice is frequently given that an estimating relationship should not be used mechanically. This implies (1) that the function must be thoroughly understood and (2) that the hardware involved must be understood as well. Care should be taken to determine that the cost estimating relationship as developed is reasonable and sound.

Reasonableness can be tested in various ways--by inspection, by sample plots, and by complicated techniques that involve an examination of each variable over a range of possible values. Inspection will often suffice to indicate that an estimating relationship is not structurally sound. An estimating relationship can be used properly only by a person familiar with the type of equipment whose cost is to be estimated.

Another aspect of the use of cost estimating relationships is the need for judgment. Although this need may be self-evident, one of the problems in the past has been too much reliance on judgment and too little on estimating relationships. The problem of introducing personal bias with judgment has been studied in other contexts, but the conclusions are relevant to this discussion. In brief, a person's occupation or position seems to influence his forecasts. Thus, a consistent tendency toward low estimates appears among those persons whose interests are served by low estimates, e.g., proponents of a new weapon or support system whether in industry or in government. Similarly, there are people in industry and in government whose interests are served by caution. As a consequence, their estimates are likely to run higher than would be the case were they free from all external pressures. (In fairness to this latter group, however, overestimates are rare enough to suggest that caution is not a quality to be despised.) In today's atmosphere these types of deviations cannot be tolerated. Cost assumptions that are optimistic produce optimistic estimates, e.g., if the analyst assumes an optimum production rate, no funding constraints, optimum schedules, etc., the resulting estimate will be optimistic. For this reason the weapons system analyst/cost analyst should identify the funds available for the system and insert this fiscal constraint as a ground rule for the estimate so as to provide the decision maker with a cost estimate that, from a practical standpoint, is reasonable and has some relation to the "real world." As little personal bias as possible should be interjected into the estimate of a new system by the cost estimator.

The primary use of judgment should be to decide first, whether an estimating relationship can be used for an advanced system, and second, if so, what adjustments will be necessary to take into account the effects of a technology that is not present in the sample. Judgment is also required to decide whether the results obtained from an estimating relationship are reasonable. This does not mean reasonable according to a preconception of what the cost ought to be, but reasonable in a comparison with the past cost of similar hardware. Judgment must be based on well-defined evidence. The only injunction to be observed is that any change in an estimate be fully documented to ensure that the estimate can be thoroughly understood, and to provide any information that may be needed to reexamine the equations in the light of the new data.

The final, and I feel one of the most important, tools to be discussed is the learning curve (also known as the progress curve, improvement curve, or experience curve). Although there are several hypotheses on the exact manner in which the learning or cost reduction can occur, the basis of learning curve theory is that each time the total quantity of items produced doubles, the cost per item is reduced to a constant percentage of its previous cost, thus making it possible for the cost estimator to relate the unit cost of an item to quantity of that item produced.

The factors that account for the decline in unit cost as cumulative output increases are numerous and not completely understood. Those most commonly mentioned are:

(1) Job familiarization by workmen, which results from the repitition of manufacturing operations.

(2) General improvement in tool coordination, shop organization, and engineering liaison.

(3) Development of more efficiently produced subassemblies.

(4) Development of more efficient parts supply system.

(5) Development of more efficient tools.

(6) Substitution of cast or forged components for machined components.

(7) Improvement in overall management.

The above list of relevant factors is not complete, and it tends to understate the importance of the items sometimes considered the most important--labor learning.

For estimating to be effective, learning curves must be established on the basis of historical data relevant to the specific problem. Such curves are equally applicable to missiles, electronic equipment, aircraft, ships, and other types of equipment, but the slopes may be different for each of these. A recent study of avionics, for example, showed slopes ranging from 84 to 91 percent with a median value of 88 percent. If a comparison is being made between two weapon systems, one involving aircraft and the other missiles, the learning curve slope chosen for each could play a significant part in the total system cost comparison. The current feeling in learning curve theory is that learning is not an infinite function, but that the learning curve should flatten or level off after a significant quantity has been produced. Additionally, a misused learning curve will produce unreliable estimates.

Another important aspect of the learning curve is the effect of computerized production or automation. This type activity will have a negative effect on the learning curve since the human aspect of "learning" is greatly decreased. There could still be a small portion of learning what with the programer or analyst learning to use the production system more effectively, but this would be slight. Therefore, with current trends towards this type of automation becoming more popular, we foresee a decreasing use of the learning curve as the primary analysis/estimating technique.

These then are some of the tools available to the cost estimator. As was pointed out earlier, any estimate formulated within today's constrained budget needs to be as accurate as is humanly possible to negate any possible cost growth or problems of this respect. A majority of the responsibility for good cost estimates is in the hands of the weapon systems analyst/cost analyst since he is the reviewer of cost studies. These studies are used by the decision-maker in the decision-making process, thereby necessitating good cost estimates.

With this knowledge in mind, the analyst who is asked to review a study containing cost-effectiveness can ask himself several basic questions.

Is the Cost Model Identified?

A model could be simple equations computed by hand or a complex computer model. What type model has been used and is it sound?

Are the Cost Estimates Relevant?

Cost estimates depend on the problem under study and can rarely be obtained from books containing cost data although cost factors and cost estimating relationships (CER's) can sometimes be found in such books. For example, a hypothetical study considers as an alternative a new kind of missile system which has passed through the conceptional design stage. The answer to the seemingly simple question "What is the cost of this new 'missile system'?" depends on many factors including:

(1) Will it replace an existing missile system? If so, what kind?

(2) Where will it be stationed? e.g., in the CONUS, Pacific, Europe, etc.

(3) Will it have new Standard A equipment, or will existing assets of Standard B type equipment be used?

(4) Are there any existing Army units whose personnel, equipment, and facilities can be used by the new missile system?

The determination of which costs are relevant requires considerable analysis and judgment. It is not possible to prepare a universal list of costs that are always relevant. Ideally, a study should indicate why certain costs were considered relevant and others not. The questions that follow are designed to help the analyst determine whether the cost estimates used in a study are relevant. For instance:

Are All Training Costs Included?

Initial training and replacement training costs could be significant and should be accounted for.

Is the Cost Data Accurate?

As has been stressed throughout this discussion, cost estimates in today's climate need to be as accurate as is possible. This question then should be one of the most important questions pondered. Cost data furnished by manufacturers should be viewed critically. Experience has shown that such data are usually understated, particularly for advanced systems. Advanced system costs stated as an exact figure rather than as estimated lower and upper values are particularly suspect.

Are Cost Aspects of all Alternatives Treated in a Comparable Manner?

Inconsistency in handling the cost aspects of competing alternatives prevents an objective evaluation of their comparative or relative costs and usually leads to erroneous conclusions. It is not always possible to use the same cost estimating technique for calculating a cost element such as attrition replacements. This is often the case in studies involving alternative systems of other military services. For example, one service may calculate aircraft attrition replacement as a function of an activity rate (e.g., per 100,000 flying hours) while another service may calculate it as a function of the activity inventory (3 percent of the active inventory per year). The analyst should determine that the final dollar estimate is related to the actual resource requirements for the alternative and that computational peculiarities do not distort the cost results.

Treating alternatives in a comparable manner must not be carried to the point that costs which may be insignificant in one alternative are therefore, not considered at all in other alternatives. For example, civilian personnel might not be used in one alternative but may be required by another alternative in significant numbers. To exclude this cost could distort the results.

Are the Cost Estimating Relationships Valid?

This has been covered previously but it is still a very important question and must not be understressed.

Are Indirect Costs Included in the Estimate Along with Direct Costs?

This is important because a sizeable chunk of money could be included in this element, since it is often difficult to define what should be included in "indirect" costs.

Now that we have covered the tools used by the cost estimator and we are aware of the techniques used by the analyst in his review of cost-effectiveness studies, I think we should now look at the life cycle of a system. Just where are costs estimated and what importance do they play? What type estimate is used at what points in the life cycle? These and other questions have probably come to mind at this point.

To begin with, the Life Cycle of a weapon system is divided into four major phases: Conceptual, Validation, Full-Scale Development and Production. DA Pamphlet 11-25, "Life Cycle Management Model for Army Systems" is being revised to reduce the number of documents required (e.g., QMA, QMR, ADP, etc.) during the life cycle of a system into a single materiel need document.

This discussion will dissect each one of these phases, with all important cost impoications pointed out. We will tie this in as much as possible with what has been discussed and keep in mind that the period of time we will be discussing is several years.

CONCEPTUAL PHASE.

The first stage of the life cycle is the Conceptual Phase. In this phase the basis (technical, military, and economic) for the acquisition are established. This is accomplished by experimental development and comprehensive system studies. The development of future systems is based upon estimates of future threats, or problems, and approved plans to counter such threats or problems. This phase contains the most risks since very little except an idea exists at this time in the life cycle. In fact, this phase is devoted to a definitization of the system, i.e., what it is actually going to be. The cost estimates which are formulated at this time should invariably be based on parametric methodology with a range of costs given rather than a point estimate. Additionally, Life Cycle Cost Estimates should be made on the systems with the understanding that the Life Cycle Cost Estimate is in reality providing only an "order of magnitude", since the system is ill-defined at this point in time. This is true because of the great variation of assumptions that can take place during this period. The tool most frequently used by the cost estimator during this phase is the cost estimating relationship, for variables such as weight, speed, etc., are all he has to work with. Any estimate made during the conceptual phase should be examined very closely with a high probability of error taken for granted.

The use of the cost effectiveness analysis at this stage in the game is to be prepared for a demonstration that shows that the proposed new item of materiel represents such a significant increase in operational capability that the expenditure of resources is warranted. The cost estimates to be used in the cost effectiveness analysis should be a reasonable "point" estimate found between the upper and lower thresholds of the range of costs for the system. Continuation of the system relies heavily upon a clearly stated and favorable cost effectiveness analysis.

The conceptual phase ends with a final System Status Evaluation in which a special committee reviews all aspects of the system (operational and cost). If this SSE finds the system eligible, it is then requested that OSD approve the transition into the next stage.

Approval to proceed into the validation phase depends on verification that the conceptual phase has in fact accomplished the following prerequisites:

a. The technology needed is sufficiently in hand and primarily engineering rather exploratory effort is needed.

b. The mission and performance envelopes and the broad logistics support approach are defined.

c. The best technical approaches have been selected.

d. Thorough trade-off analyses have been made, including the stated operational requirement against engineering design and between the design parameters themselves.

e. The cost-effectiveness of the proposed item throughout the life cycle has been determined to be favorable in relationship to the cost-effectiveness of competing items on a DOD-wide basis.

f. Cost and schedule estimates are credible and acceptable.

g. The high risks have been identified and plans made to resolve them.

VALIDATION PHASE

The next phase in the life cycle is the validation phase. This phase consists of the steps necessary to verify design and engineering, accomplish planning, and examine proposals for development. The main objective of the validation phase is to determine if the system is ready to move into Full-Scale Development. The main goal of this phase is to verify achievable performance specifications backed by a cost-plus-incentive fee proposal for development or, when minimum technical risk exists, a fixed price type proposal (FPI or FFP) may be considered. Other objectives which will be sought are:

a. To provide a basis for a signed contract.

b. To establish firm and realistic performance specifications.

c. To define organization and responsibilities.

d. To demonstrate that all high risk areas have been eliminated or reduced to a reasonable level.

e. To verify technical approaches.

f. To establish firm and realistic schedules and cost estimates for Full-Scale Development.

These last two points mean that the estimate which is formulated during this Phase needs to be more than a range, it should be a point estimate possibly done parametrically or by the engineering approach with the emphasis on RDT&E. Confidence in the estimates increase in this phase, naturally, over those estimates made in the Conceptual Phase since we know more about the system. With the design and specifications becoming firmer, the estimate should become sounder. This is a very important stage for costs because, as was previously pointed out, negotiations will be based on these costs and if these estimates are bad, the probability of a cost growth increases. Of course, no one can foresee all the problems that could be encountered during development but a concerted effort should be made to get a good baseline estimate upon which future cost estimates can be compared to ascertain "cost changes."

All these factors are analyzed for approval to go from the Validation Phase to Full-Scale Development, this in conjunction with a Development Concept Paper (and in some cases, the Selected Acquisition Report). The Development Concept Paper has become an important tool to the management cycle of a weapon system. After confirmation that all the technical, financial, and schedule factors have progressed sufficiently, the system can move into the next stage, that of Full-Scale Development.

Before proceeding further, some time should be spent on the Development Concept Paper. The DCP is needed not only to proceed from the Conceptual Phase to the Validation Phase but together with a Defense Systems Acquisition Review Council (DSARC) to go from the Validation Phase to Full-Scale Development. It is a summary top management document prepared for the Secretary of Defense for his use in decisions on important development programs. The DCP provides information on the issues and subissues, the driving force, discussion of the problem, management plans and thresholds. These thresholds prescribe the degree of variance a program may have in the most critical areas, those of cost, schedule, and performance. Therefore, if any of these thresholds are estimated to be exceeded, then a review is warranted. This is an example of management by exception, e.g., if the system remains within its threshold, a review is not required. The cost estimates in the DCP's to support the decisions to enter Full Scale Development and Production are especially important to the analyst since these cost estimates become program cost estimates. By this is meant that the cost estimates need to be converted to a stream of costs by fiscal year by appropriations and placed as a Resource Annex to the DCP. Once generated, this Resource Annex represents the decision document to approve funds for the weapon systems and these costs are inserted in the Five-Year Defense Plan and therefore represent the program manager's Total Obligational Authority.

FULL SCALE DEVELOPMENT

To continue with the life cycle, the next stage is Full-Scale Development. This stage is mainly concerned with a further uncovering of technical and engineering problems that need to be solved. This is true even though risk has been addressed in the Conceptual and Validation phases. Procedures will be developed during this phase by which these problems will be continually addressed, including possible tradeoffs with stated operating requirements, cost, and operational readiness dates. It is also necessary to have assurance that those problems encountered during earlier development have, in fact, been solved. This requires that milestones be established to demonstrate achievement of objectives at appropriate points in the development program. These milestones will include such things as completion of appropriate stages in the overall system design and testing of critical items of hardware. Consideration must be given in development to all matters necessary in a full operating system, e.g., maintenance, logistic support, and training, However, where these matters are dependent on the final production design, as much of this work as possible should be delayed until the production phase. In general, Request for Proposals (RFP's) for development should be carefully reviewed to eliminate demands for reports, documentation, and work tasks which are not absolutely necessary for the efficient accomplishment of the actual development work. These considerations and demands must be limited to those which directly contribute to the design of the system itself.

A life cycle cost estimate will again be required at this time which emphasizes RDT&E, PEMA, and Operating Costs. The three types of estimating methods, parametric, engineering, and analogous will be used with the parametric and analogous methods the most efficient at this time. The system should be developed enough by this time that comparisons could be made with other like systems. Also the physical and operational characteristics of the system should be well definitized thus leading to better use of the parametric approach to estimating. The estimate should be a point estimate with the PEMA estimate demanding greater emphasis than the RDT&E. On those components that are off-the-shelf items or have an approved technical data package, engineering estimates should be used. Again this estimate will probably be used as a basis of comparison with future estimates, therefore, the more accurate the estimate is, the smaller the chance of a cost growth.

Technical advancement is stressed during the full scale development phase. The key criterion in the degree of technological advancement permitted in Full-Scale Development is the level of confidence in the probability of successful development. It is not intended that the system will be limited to an assembly of off-the-shelf items. It is intended that the technology that is required to meet a system specification not exceed in quantitative performance that which can be demonstrated in developmental engineering form or in laboratory form. Projection into Full-Scale Development of anticipated developmental achievement will be permitted only when sufficient quantitative results have been obtained, in laboratory or experimental devices, to allow such projection with a high confidence. In general, these projections will assume the probability of Full-Scale Developments matching but not exceeding laboratory results.

The most important consideration for moving out of full-scale development into production is to have assurance that the engineering design is completed, that all major problems have been resolved, and this has been demonstrated to the extent practical by actual performance, e.g., prototype demonstration to "fly before buy." At the end of development, in a special review it will be determined that all the milestones which demonstrate the achievement of a practical engineering design have been met and all important engineering problems encountered during the development programs have been resolved with appropriate trade-offs with stated operating requirements so that the production, maintenance and operating costs are optimized.

PRODUCTION

The start up of production must be scheduled to minimize financial commitments until it has been demonstrated that all major development problems have been resolved. In most cases production engineering and production tooling are necessary to demonstrate that the engineering has been satisfactorily accomplished. It may be necessary to develop and demonstrate new production processes, methods, and procedures. Thus, some limited expenditure may have to overlap development.

The cost estimate at this time should be a life cycle point estimate which concentrates on PEMA and operating costs. The research and development costs should be firm by this time and indeed the major section of RDT&E has been expended. The estimating method most frequently used at this time would be the engineering approach. Again, as we have stressed many times, the estimate at this time must be the most accurate possible, for this estimate will be used in the decision-making process throughout production.

After production there is one more area that needs to be covered. This is the operating phase. This phase will probably overlap with production. During this phase the system is actually utilized in the field until obsolete or replaced. Budget constraints occurring throughout the life cycle may dictate that the weapon system be made as an austere version of the initially envisioned weapon, therefore necessitating a new cost effectiveness study under these new budget constraint ground rules.

We have now examined the analysis of a weapon system through its life cycle. We are aware of how the analyst predicts costs and we know what tools he uses to analyze these costs. Now we should look at what is being done within the Department of Defense to create an atmosphere of improvement in weapon system acquisition. This question covers every aspect of the acquisition process, from cost estimate to contract award.

Current OSD guidance is aimed at enabling the Services to improve management of programs. This in turn demands that the programs be better executed to accomplish this task. Several areas of improvement have been addressed - these are as follows:

MANAGEMENT

OSD guidance in this area is aimed at the program manager level. It seems to be felt that as the expertise of these people is increased so will be the management of the program. This is to be accomplished through longer assignments, more authority, and more capable people. In this regard, it behooves all concerned if the weapon systems analyst can be assigned a weapon system from inception to retirement.

DEVELOPMENT

The main points attacked by OSD in this area are the use of trade-offs between stated operating requirements and engineering design and a sensible program schedule, one that allows time for accomplishing important objectives without overlapping.

Conceptual development has been placed high on the scale of crucial stages. This is the stage when risks are abundant. Suggested minimization of risk techniques are:

1. Risk Assessment. The first is to make a careful assessment of the technical problems involved and a judgment as to how much effort is likely to be necessary in finding a solution that is practical. A careful look at the consequence of failure, even of "low risk" program elements, is also critical. The analyst should always ascertain that he has realistic estimates on the high cost items in the weapon system work breakdown structure.

2. System and Hardware Proofing: The second and only sure way to minimize the technical risk is to do enough actual engineering design and component testing in the conceptual development stage to demonstrate that the technical risks have been eliminated or reduced to a reasonable level. Component or complete system prototyping, or backup development, are examples of this. In this regard, the analyst should insure that the weapon system estimates contain the necessary resources to satisfy the additional test requirements.

3. Trade-offs (risk avoidance): Since program risk and cost are dependent on practical trade-offs between stated operating requirements and engineering design, trade-offs must be considered not only at the beginning of the program but continually throughout the development stage.

Full scale development is a sounding board for technical and engineering problems that need to be solved. The point is stressed to insure that any problem which is encountered during this stage has in fact been solved. Special milestones, will be established to demonstrate achievement of objectives. OSD also points out that all RFP's for the Development phase should be examined carefully to insure that no unnecessary work or work that could be performed during production is included.

PRODUCTION

Before production can begin the most important consideration is to have assurance that all engineering design is completed, that all major problems have been resolved, and that this has actually been proven by performance testing. There must be a period of time before full-scale production is entered into when there is an overlap of production into development. This is to insure that all problems have been resolved and to absorb any changes which necessitated the development and demonstration of new production processes.

CONTRACTS

The weapon systems analyst should be intimately familiar with the contract. Guidance in this area has shown that in both advanced and full-scale development the type of contract that is preferred is the cost plus incentive type. Fixed-price type contracts should be used when the risks have been reduced to a suficient level that realistic pricing can take place. Of course, the contracting officer should have the flexibility to consider the situation and decide upon a contract type best suited to that situation.

The competitive type environment is greatly stressed, especially in the award of a fixed price contract. This is true because it is desirable for costs to be established in a competitive environment, hopefully accomplishing substantial savings.

This then is not everything involved in weapon system analysis, but it is an introduction to the analyst's role in this time of constrained budgets. As can be seen, it is quite a complicated process, which is not easy to isolate since weapon systems analysis evolves as new techniques and procedures are introduced. Today's conditions necessitate that this aspect of the Army's total picture be examined very thoroughly to make this as an exact an art as possible for every estimate needs to be as defensible as is possible for today's decision-making process.

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FORCE ANALYSIS

Major Brian R. McEnany
Directorate of Cost Analysis
Office of the Comptroller of the Army

Force Analysis in a constrained environment is presenting a major challenge to analysts at Department of the Army level. I would like to briefly cover how my office is meeting this challenge and discuss several new systems and models which have substantially aided our efforts.

First of all, let's look at a few definitions and a few problems which may be encountered in constrained costing exercises. (Fig. 1)

Total Force Costs
Incremental vs Zero Base
Unconstrained vs Constrained
Gross vs Detailed
Direct vs Indirect
Reporting Systems

FIGURE 1.

Total force costs represent the simultaneous allocation of resources among many competing systems and activities. It is an estimate or a planning cost as contrasted with a budget cost. It thus represents the entire spectrum of economic activity; research and development, investment and operating costs. These costs are simultaneously projected for the multitudes of units, systems and activities making up the entire Army.

The second definition, incremental costing, is a method of estimating the costs of such forces. It has been said that total force cost analysis aims at incremental costing in its fullest sense.[1] It simply means the addition or deletion of the costs associated with incremental changes to a particular force structure or base. This base can be any available structure and normally is the current planned force. We generally use the Army Five Year Defense Plan as a base and develop factors from it to use in making these incremental changes.

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[1]Quade, E. S., "Analysis for Military Decision," Rand Report R-387-PR, The Rand Corporation, Santa Monica, California, p. 286.

Zero base costing is yet another method of calculating costs. It is an approach taken which is analogous to adding building blocks, one atop the other, except that these blocks are the costs of force units. I mention this approach because one of the primary models used by my office is a composite of both of the above methods.

Unconstrained costing attempts to answer the question, "How much is necessary for a particular need or requirement?" These costs can be found in the various Strategic Objectives plans submitted at the beginning of the fiscal cycle. It represents an upper limit against which you can objectively measure risk. Constrained costing means that the emphasis lies in the availability of resources which must be allocated among many competing systems and activities. The application of fiscal constraints often as not introduces the probability of military risk into an exercise. Thus, a series of equal cost alternatives may vary in effectiveness and it must be determined elsewhere which alternatives will be chosen for further analysis.

Gross costing is normally found in the initial phases of a costing exercise. A rough price tag is affixed to each alternative. The Army's FOREWON system develops gross costs for the Division Forces area of each alternative force structure. These estimates are then compared with some known constraint in order to eliminate clearly infeasible alternatives from further discussion or analysis. A second phase effort in costing is then begun. Detailed costs are developed in this phase for those chosen alternatives which apparently meet the requirements of the plan. For example, all alternatives within a certain price range may be considered for further analysis. Detailed costing involves the entire staff and thousands of bits of information are generated.

Direct costs are those costs which are directly attributable to a specific activity. These are generally, military pay, operating and maintenance, research and development and procurement monies. In most instances, direct costs can be estimated fairly easily. Indirect costs, often as not, turn a relatively simple exercise into a very time consuming one. Indirect costs are those costs which are related to the force being analyzed, but not necessarily associated directly with a particular force unit. A simple example is that of the costs of the training base. It is clearly related to the force structure because its output is designed to provide the necessary manpower, but it is not associated with any particular unit as it supports the force as a whole.

Allocation of these indirect costs can be done in a reasonable manner. However, everyone has their own method of doing it. This often causes problems such as described in a recent article which appeared in the Washington Post. The article stated that the deactivation of a single division was equivalent to a savings of 800 million dollars. It is

LFCS	PROGRAM	FGC	APPROPRIATION
Division Forces	1. STRATEGIC FORCES	MAJOR MISSION FORCES	MPA
Special Mission Forces	2. GENERAL PURPOSES FORCES	Strategic Control & Surveillance, Land Forces, Mobility Forces	OMA
	3. INTELLIGENCE & COMMUNICATIONS		PEMA
General Support Forces	4. AIRLIFT/SEALIFT		RDT&E
	5. GUARD & RESERVE	OTHER MISSIONS	MCA
Individuals	6. R&D	Intelligence & Security, Communications, R&D, Support to Other Nations	MCAR
	7. CENTRAL SUPPLY & MAINT		MCARNG
	8. TRAINING, MEDICAL & OTHER		OMARNG
	9. ADMINISTRATION	GENERAL SUPPORT	RPA
	10. SUPPORT TO OTHER NATIONS	Base & Individual Support, Training, Command, Logistics	NGPA
		MISCELLANEOUS COSTS	
	TOTAL BUDGET $	TOTAL BUDGET $	TOTAL BUDGET $

FIGURE 2.

questionable how this figure was arrived at. Our own calculations put the figure at a somewhat lesser amount, but it all depends upon what you consider to be truly related to the division. There is a wide credibility gap in this area and it requires more detailed analysis. We are pursuing several courses of action in attempting to determine better estimating relationships for indirect costs. Allocated costs are also being used to compare force units between services. As long as similar methods are used to develop the indirect costs, it will provide a set of relative costs which may be meaningful for analysis. However, each service determines its indirect costs in an entirely different manner and in varying degrees of accuracy. Cost comparisons between services are thus clouded by the inability to accurately determine or isolate the indirect costs and must be viewed critically.

I have saved the next definition until last because it represents both a challenge and an enigma to the force analyst. (Fig. 2) These are the three major systems which the force analyst must be conversant in. The first is the Land Force Classification system. It is in this system that all Army plans are developed. Each unit in the Army is identified and assigned against one of its major categories. These categories are Division Forces, Special Mission Forces, and General Support Forces. The fourth category contains manpower which are those individuals who are over and above the authorized strengths of the units in the force structure, such as students, prisoners and trainees, etc.

The next system is a financial reporting system. It is composed of the ten major programs which make up the Five Year Defense Plan. Each program is comprised of a number of program elements.

PE 22213A
8 inch Howitzer Battalions
FY 62 . . . . FY 76
$ People Units

FIGURE 3.

A program element is the lowest aggregation of financial information available to us. It contains both planned and historical obligations for specific activities or units. A typical PE would be 22213A 8 inch Howitzer Battalions. This PE would contain all separate artillery battalions of this type. It would show, the total number of units, manpower, and the various obligations which are allocated to them. There are approximately 400 program elements in use.

The last financial system is called Fiscal Guidance Categories. Each of these categories contain groupings of the same program elements found in the ten major programs but they are aggregated differently.

For example, the Fiscal Guidance Category, Land Forces, will contain most of major program 2, as well as some elements from programs 3, 5, and 6. It is basically an attempt to logically structure the financial system so that like program elements can be analyzed together. Fiscal Guidance Categories are a recent (1969) innovation of OSD (Systems Analysis).

The challenge, to the analyst, therefore, is to be conversant in all three systems and to be able to translate or "cross walk" between them. The enigma is as follows. Appropriations, the way money is authorized by Congress, are spread across both financial systems. The major programs are supposed to make up the major planning, programming, and budgeting document for use by DOD. However, fiscal guidance categories are the method by which fiscal constraints are imposed upon the services. The Land Force Classification System does not track with either financial system. Thus, the plans, programs and budgeting are each done almost in isolation from one another. The Blue Ribbon Defense Panel noted this same fact and recommended that the various categories used in conjunction with the Planning, Programming and Budgeting cycle be made to coincide as nearly as practical and be stablized.[2] It presently requires that a vast amount of energy be spent in translating from one system to the next which might be better spent on analysis.

The force analyst must be able to answer several questions before he begins any particular exercise. The questions listed below are not meant to be all inclusive; but merely representative.

1. Gross or Detailed Costing?
2. What Reporting System?
3. Is Sufficient Information Available?
4. Will New Methods Need to Be Developed?
5. Are Both Direct and Indirect Costs Required?
6. How Much Time is Allotted for our Efforts?

FIGURE 4.

The last two questions really refer to whether we can use current automated programs or must develop new ones. The development of a new program is, of course, lengthy and sufficient time must be allocated.

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[2]Report to the President and the Secretary of Defense as the Department of Defense by the Blue Ribbon Defense Panel, 1 July 1970, p. 117.

So far I haven't really approached the subject of constrained costing. The emphasis which is being placed on the Defense Department to thoroughly review existing programs and provide the same output within constrained budgets has created a different atmosphere for the force analyst. No longer is he merely the final step in a lengthy planning process, necessary only because a price tag must be affixed. He is involved from start to end in varying degrees of activity. Basically, his efforts are sought in the area of initial information to be provided to the decision maker on the effects of fiscal constraints. Secondly, this information must be rapidly disseminated to the staff. Third, he must be able to identify a set of feasible alternatives for the decision makers. Finally, he must still provide the detailed costing and analysis of the chosen alternatives. I should like to spend the rest of my time pointing out several new systems which are now being used at Department of the Army level. These systems are aiding us in providing information, analysis, and identification of fiscal constraints and feasible alternatives for the decision makers.

Total force costing lends itself easily to automation, or at least partial automation. The identification and aggregation of the costs associated with a particular force structure must be done in a framework which permits cross classification of all costs. This is done in order to gain insight into specific areas of interest. The methods used to aggregate these costs must be sufficiently refined in order to reflect the cost implications of significant changes in a particular force structure.[3] Automated procedures allow the analyst to estimate the costs of several alternatives in the same time previously allocated to manual efforts. In a constrained environment, the decision makers cannot afford to wait several weeks in order to get an answer. Thus, we are relying heavily upon automated methods for aggregating, "crosswalking" and analyzing total force costs.

In this respect, the Office of the Assistant Vice Chief of Staff has recently completed a project called the Integrated Fiscal Guidance System. It is composed of two sub-systems, each designed to meet certain criteria. One is called the MARK TWAIN Financial Information System and the other, the Executive Decision System. First, let's talk about MARK TWAIN. I'm particularly interested in this project because it has occupied my efforts for the past year.

At the Army's Cost Research Symposium, held in Gaithersburg, Maryland last year, the Office of the Secretary of Defense (Systems Analysis) offered the Services the product of a year long effort called

[3]Quade, E. S., Ibid, p. 284.

the Electric FYDP System. This system is built around a large scale Leontief Input-Output model. It is coupled with several computer programs which create a variety of reports, perform variance analysis, and convert obligations to expenditures in terms of either current or constant year dollars. The Army, in particular, Captain Marc Blum from Assistant Vice Chief of Staff, has been instrumental in having the existing OSD programs transferred to Army machines. In addition, a joint Comptroller of the Army/Assistant Vice Chief of Staff effort redesigned the then existing cost model so that it would better represent Army cost estimates at OSD level. This effort lasted about one year and has resulted in a new model which better fits our purposes for gaining visibility into specific areas, dissemination of information, and has become an analytical tool for discussion between us and OSD.

The use of Input-Output models has generally been limited to basic economic applications over the past two decades. The first major effort in this area is credited to Professor Wassily Leontief of Harvard in his book, "The Structure of the American Economy," published in 1951. Its use has generally been in the field of national economies and the interactions between industries. Two years ago, Joseph Augusta, of the Center for Naval Analyses, submitted a paper for publication which described the use of an Input-Output model for estimating the costs associated with a portion of the Marine Corps. George Patton, Cris Snyder, and Dick Szymkowski of OSD (SA) (Cost Analysis) were interested in how this model could be adapted to their use in developing fiscal guidance and began a year long effort which resulted in the Electric FYDP System. This system now contains working models of each service and is used in the development of the Fiscal Guidance Memorandum, the basic document in the constrained costing area.

The Army's cost model is very simple in concept. Here, in a few diagrams, I think I can get across to you what we have attempted to model.

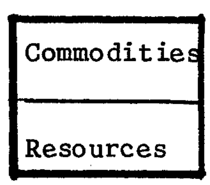

FIGURE 5.

As you can see this figure breaks the Input-Output matrix into two halves called Commodities and Resources. Commodities are the support outputs of the support program elements. They are goods and services such as training or maintenance. Resources are manpower, monies and assets. The next figure shows a second partitioning into Support and Forces sectors.

Support	Forces

FIGURE 6.

By summing across rows in the matrix you will have determined the entire need for a particular commodity such as training. For the first time, the analyst can see the needs of both support and forces together.[4] One innovation in the Army's model has been our attempt to interface with the force planners. Our force Posture Y is composed of the same elements that the planners use in designing a force structure, i.e., Divisions, Brigades, Maneuver Battalions and the supporting increments which are found in Division Forces. We use a building block approach to build the entire Division Force in terms of the above elements. We even attempt to take into account reduced manning levels by a weighting technique.

Inf Div	Mech Bn	Armor Bn	Abn Bde	Support Increment (ISI)	= Y

FIGURE 7.

Once a known force has been broken into its components of Support, Forces, Commodities and Resources, a mathematical inverse is calculated in the Support Sector. This creates a set of technical coefficients which are now used for estimating any other force. A new force posture Y' can now be passed over these coefficients and the necessary support is developed. The end result will be the creation of a total force cost for the new structure.

The Input-Output model creates as output a tape which is exactly like that of the OSD Comptroller master tapes. This tape is now passed to several computer programs which perform the previously tedious job of crosswalking between the different financial systems, performs a variance analysis by comparing two tapes, and converts the estimated obligations into expenditures which can then be compared with the fiscal constraints imposed by OSD. (Fig 8)

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4 "The Electric FYDP" Patton G., Synder C., Szymkowski, R., Proceedings of the Fifth Annual Cost Research Symposium, Vol II, pp 376-382.

The MARK TWAIN Financial Information System

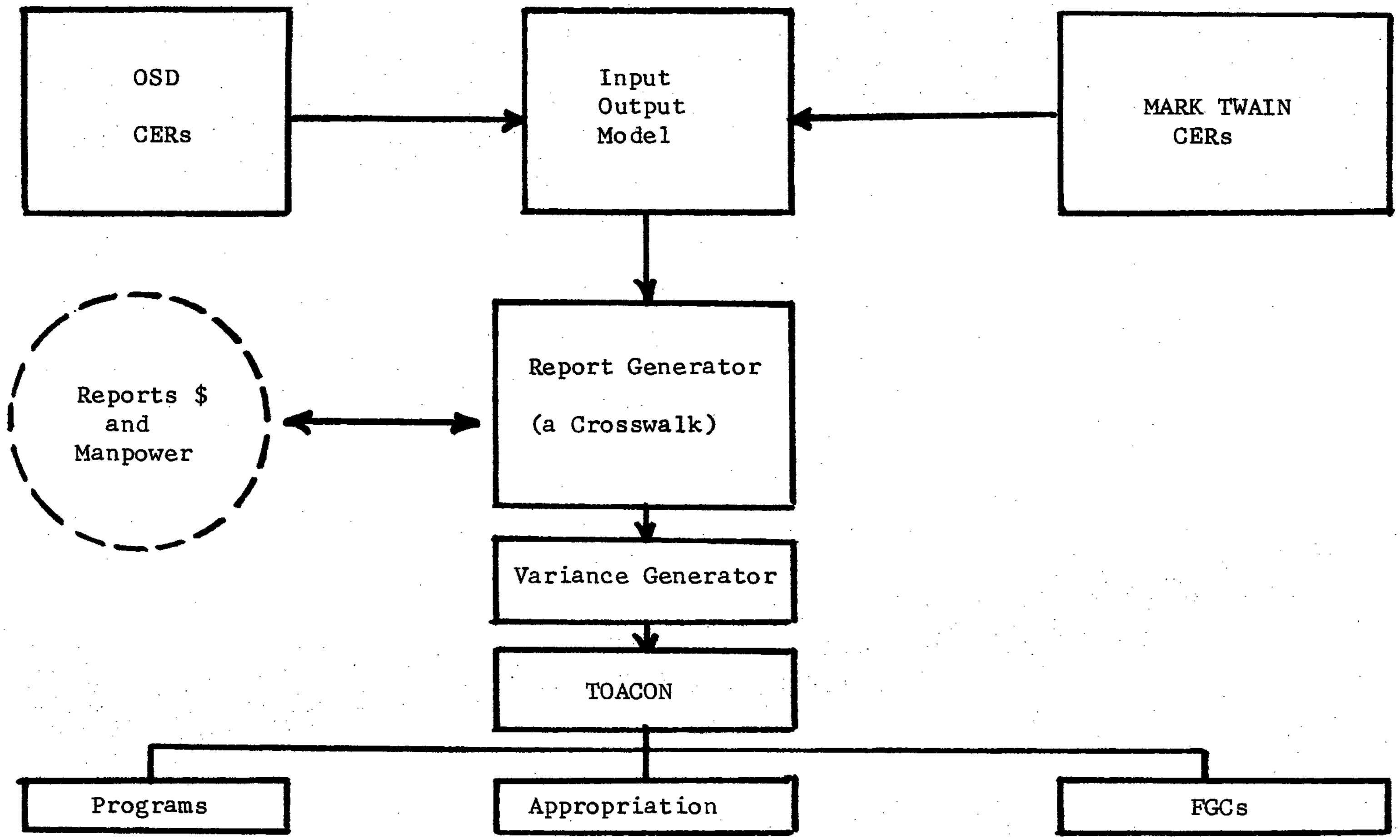

FIGURE 8.

We have put a few new wrinkles into our estimates. For the first time, we are including civilian personnel, and their effects on available resources, into our costs. We have also created a means of selecting special interest areas for analysis by stripping their effects apart from the total costs in special reports. The basic reports are provided in terms of major programs, fiscal guidance categories, appropriations, manpower, both civilian and military, and combinations of the above. We have chosen to differentiate those reports which can provide information at summary level to the decision makers from those which are of special interest to action officers in the various staff agencies. We are by no means alone in our efforts to use and maintain this model. The staff is supporting us and as changes are made in pay rates or manpower allocations, it is a simple task to change IBM cards which will reflect the new relationships. No computer reprogramming is necessary. Thus, we can maintain the model in a dynamic state which reflects the current set of cost factors in use by the staff.

The overall system aids the analyst by rapidly comparing a set of fiscal constraints against our current program. This, in effect, allows us to highlight the differences and provide this information to the decision makers. Rapid dissemination of this information, coupled with adequate guidance, enables the staff to react much more rapidly than in the past. It also provides us with a framework for aggregating the detailed cost information the staff will now begin to generate.

I spoke earlier of the identification of feasible alternatives, in a constrained exercise, as being a relatively new task for the force analyst. How many feasible alternatives can be determined by manipulating the total constrained dollars in accordance with some set of logical decision rules? It would appear that this is nothing more than the dual problem of linear programming; minimize a cost function subject to certain constraints. However, there are too many unknowns and too few equations for this approach to be feasible. Consequently, the development of the second system, the Executive Decision System was begun. It has rapidly become a viable method for preparing a set of feasible alternatives within specified constraints.

It is a realtime, visual model which aids in the evaluations of range of alternative methods of allocating resources. Given a set of decision rules, the analyst can change the current resource allocations in a target budget from his keyboard and show the impact upon the various appropriations to the decision makers. (Fig. 9)

As you can see, it is composed of several sub-models which are in various stages of development. The Procurement (PEMA) model is perhaps the most detailed. This model allows the analyst to develop a recommended procurement buy and distribution for any constrained procurement dollar budget by line item.

EXECUTIVE DECISION SYSTEM

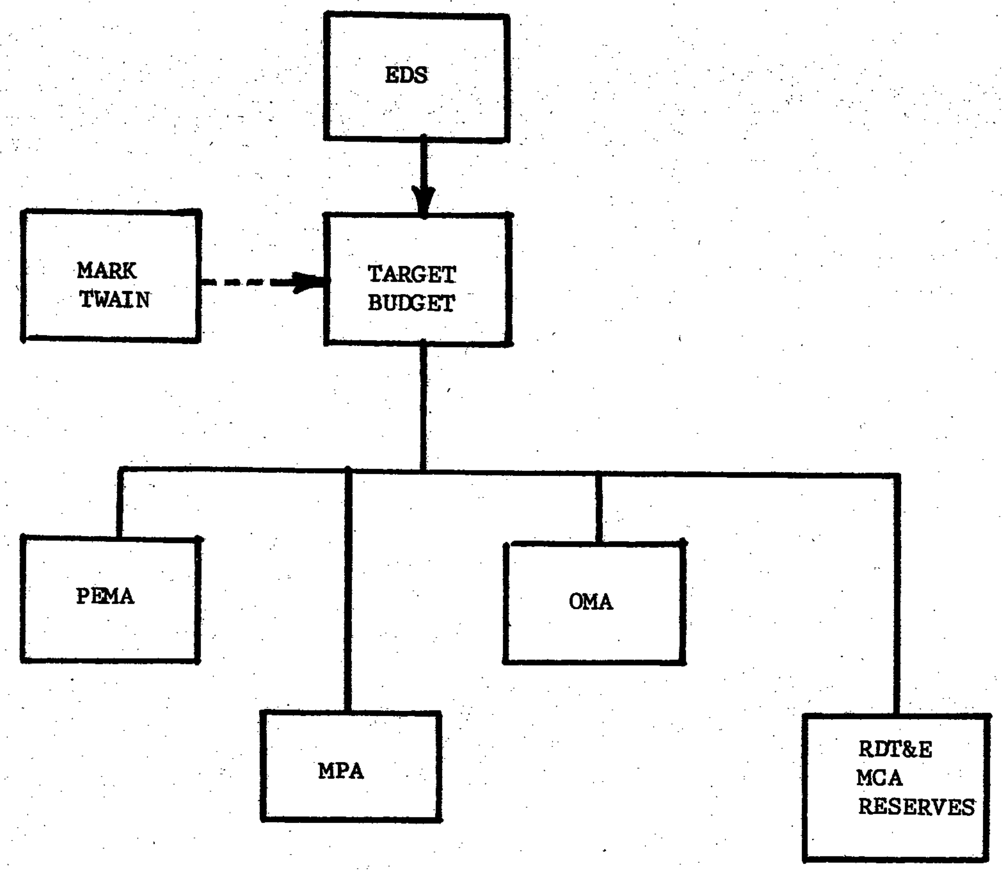

FIGURE 9.

The Military Pay (MPA) model develops manpower programs to meet a specified objective; develops corresponding military pay costs; and develops force structure alternatives from within the Active Army that meet manpower requirements.

The Operating and Maintenance (OMA) model develops estimates based upon specified guidance. The effects of changes in any of the above models will be reflected in the budget displays once all changes have been made.

The RDT&E, MCA and Reserve models vary from the conceptual stage to initial programming stage. At this time they are used as storage of input data which affect the four sub-models.[5]

A typical exercise using this model might be the following. Given a set of fiscal constraints, develop several alternative means of providing equal cost force structures. These may range from all decrements coming from the force structure itself, or all decrements being taken from the investment or research and development accounts. Although, these alternatives are unlikely candidates for serious consideration, they are illustrative of the type solutions which can be shown the decision maker. The range of alternatives which lie between the above extremes actually represent the real battleground for discussion and choice.

So much for initial guidance. The Army Staff, provided with sufficient information and a firm set of alternatives can now work up the necessary detailed inputs for each force structure. These inputs are coordinated by my office so that the detailed costing and analysis effort will fit into the overall timeframe of the study. The MARK TWAIN provides the framework for aggregating the thousands of bits of information before the final price tag is affixed. It would appear that analysis is being done only at the total force level and this is quite untrue. Therefore, let me say a few words about sub-optimization.

One such effort is being accomplished by my office. A strategic forces cost model has been designed which allows an analyst to examine not only the Army's strategic forces, but those of the Navy and Air Force as well. (See Fig. 10) It computes investment, personnel costs and other operating costs by using the quantities of weapons

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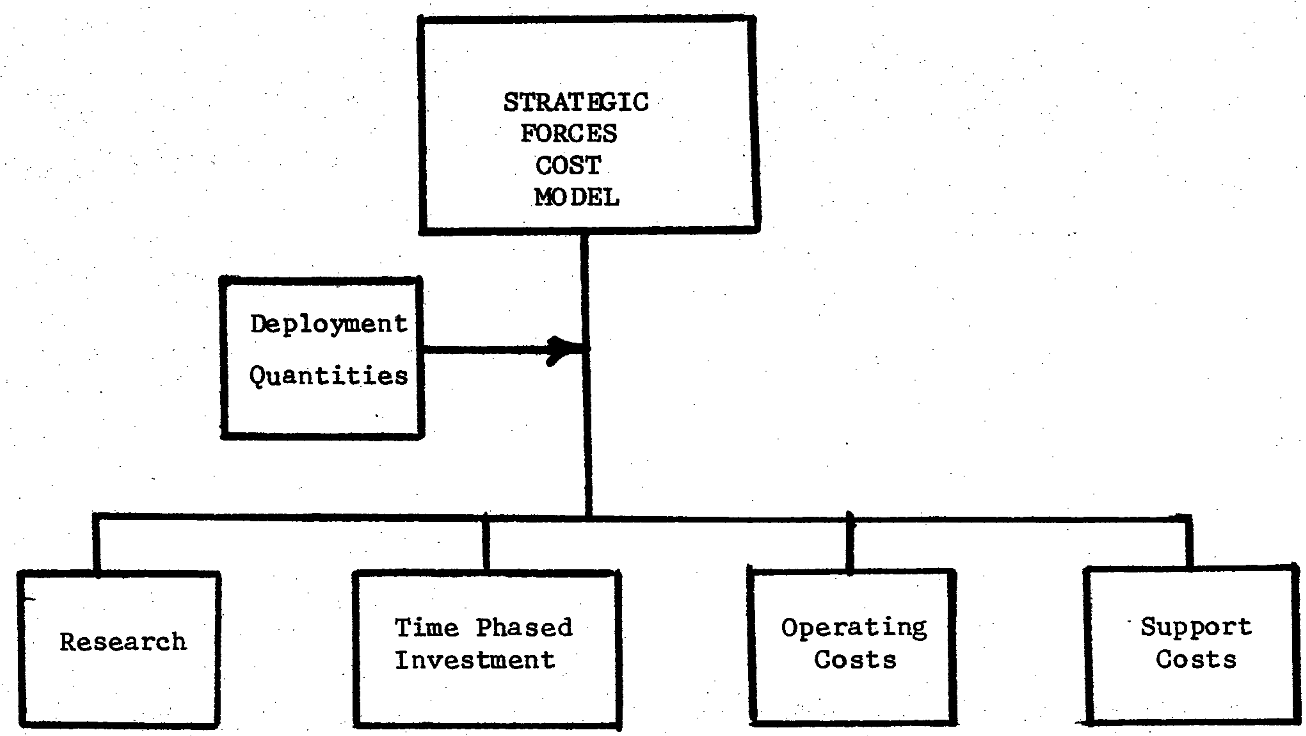
[5]Draft User Manual for Executive Decision System. Executive Programming Analysis Team, OAVCS, 1971.



SUB-OPTIMIZATION

FIGURE 10

systems to be deployed as the driving variable. Included within this model is the development of a time phased procurement program which incorporates learning curves, production rates and lead times for the basic system and all of its major components. It has the capability of costing an unlimited number of program elements and provides both indirect and direct costs for each weapons system being investigated. This model was used in conjunction with the Stanford Research Institute (SRI), extensively during a recent study on strategic options. It is currently being used by SRI, OSD (SA) and my office, as requirements dictate. The beauty of sub-optimization is that as results are obtained, they can be inserted into the Input-Output model relatively easily. Similar information is expected from other detailed studies in the future.

But the force analyst is not done yet. He cannot sit back and simply let the machine aggregate the final costs. A cost analysis of the total force provides a host of supplemental information. His primary interest lies in determining if there are major problems which are not readily apparent in viewing the total cost alone.

1. Marginal Costs.
2. Time Phased Deployment Costs.
3. Graphical Displays.
4. Sensitivity Analysis.
5. Accuracy of Estimates.
6. Inflation Effects.

FIGURE 11.

Marginal costs of the major force units are one of the by-products of machine processing. It represents both the direct and indirect allocation of resources which can be related to the force unit. As a marginal cost it must meet its economic definition of the extra cost incurred in the increase, or decrease, of one force unit above, or below, the total cost of the force. Such information should be made available to the sponsors of the study so that if further changes are made to the force structure the associated cost changes can be determined easily and without re-costing the entire force.

Another area of interest lies in the effect of the time phased procurement of weapons systems deployed during the timeframe of the study. The impact that these systems will have upon the procurement and research accounts will also aid in making further decisions if changes become necessary. Such cost information must track with current estimates provided through other channels. Its effects on plans, other than the current force, must be known so that appropriate comparisons can be made.

Another analysis approach, which we are attempting to develop, is a quick method of looking for problem areas. This is the development of graphical displays which will summarize the many estimated costs. One such method plots the new estimated appropriation totals against our current approved program and last year's estimates. Hopefully, any massive errors will be seen as either an appropriation shortfall or as a violation of some fiscal constraint. Once such a problem is located, the analyst can then turn to his more detailed reports and attempt to pinpoint the trouble. It may be that such errors cannot be corrected and then they become an issue point in the study. Further analysis is warranted in such cases.

Sensitivity analysis at the total force level is very limited. The inputs required for a detailed costing exercise are so voluminous that the staff can provide only a limited number of force structures in the timeframe of a major exercise. Thus, sensitivity analysis is normally found at lower levels. This in effect is the sub-optimization I spoke of earlier. The results of these studies would provide a series of optimum sectors which form the Army's position for a particular force structure or base case. An alternative case may also be provided which would show how the Army would like to allocate its money if certain fiscal constraints were eliminated while still keeping the same total cost.

I have said very little about the accuracy of our estimates. Although constrained costing requires that the best estimates available be made, the end result can only be as good as the input data. If this data is prepared in a haphazard manner, then the final product can also be considered in that category. It is hypothesized that when an incremental method of costing is used, we can vary slightly about that point on the total cost curve which represents the cost of our current force, and we can say that our estimates are good. However, if a large incremental change is made then we are unsure of the validity of the final cost. By inspecting figure 12, we can show that, so long as the total cost curve doesn't make any violent changes in direction, we will over estimate the true cost above the current force level and under estimate it below. Zero base costing does not allow us to make such generalizations. However, once several constrained exercises have been developed, then we feel that we can compare their estimates against the actual costs of such plans which have been implemented and at least make some estimate of the error in our overall total costs.

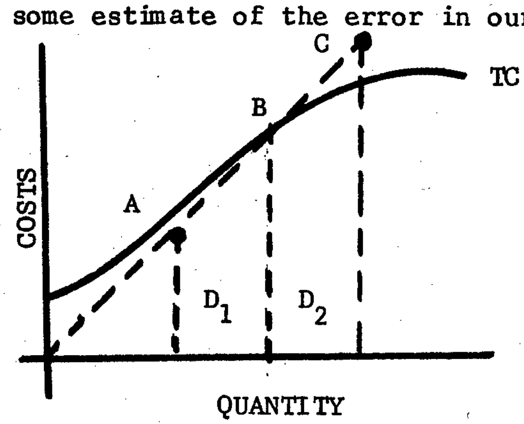


FIGURE 12

For the present, we can tell if we are generally in the ball park by using a simple one-tailed T-test. By testing whether or not a particular appropriation comes from a distribution composed of similar appropriations, estimated in other studies, we can make a subjective determination of the validity of our estimates. If our new estimate fell outside a pre-determined threshhold it would call for an examination of our methodology and cost factors.

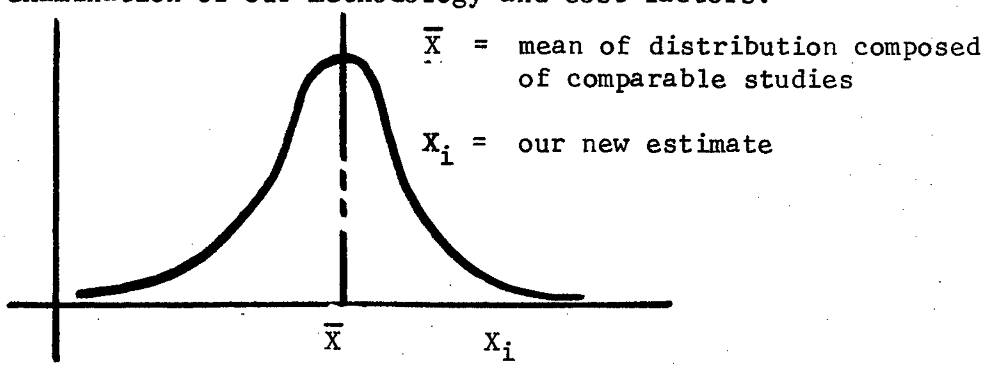


FIGURE 13.

One further area has recently become of concern to us. The inclusion of inflation in estimates provided for plans, both unconstrained and constrained, makes cost comparisons difficult to say the least. The current budget force does require inflation to be included and it is identified separately in the Five Year Defense Plan, and on the OSD master tapes. It is relatively simple to strip out the effects of inflation for analytical purposes. However, since the inclusion of inflation in total cost estimates is relatively new we must be extremely careful in comparing our estimates with older studies.

To sum up, I hope that I have provided you with a good overview of the field of force analysis and total force cost estimating and analysis. As you have seen, our problems are many and our mission in a constrained environment has become increasingly complex and demanding. It is both challenging and frustrating to try and provide information based upon limited or minimal data. The advent of automated procedures for handling large masses of data quickly and efficiently has vastly improved our capability. This improved capability will allow us more time for real analysis.

The rapid exchange and dissemination of machine processed reports, designed for both executives and action officers, aids in establishing both communication and cooperation among agencies. The overall result is expected to be better and more analytically supported estimates provided to the decision makers.

The constrained environment has drastically altered the force analyst's job. It has, of course, had detrimental effects in terms of force reductions and constrained budget levels. However, it has brought to light the great need for critical analysis and information to be provided in the shortest possible time. The force analyst provides only a portion of the ultimate solution, but we feel that our efforts in the force analysis field is substantially aiding the decision makers at a critical time in the Army's history.

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OVERVIEW OF THE ROLE OF COST ANALYSIS

(FOR AN ECONOMICALLY CONSTRAINED ARMY)

T. Arthur Smith
Director of Cost Analysis
Comptroller of the Army

PURPOSE

The purpose of cost analysis is to provide managers with information about the resource implications of current plans and their alternatives. In a period of economic retrenchment such as the one currently in progress within DOD, this information becomes vital to the manager who must struggle with the complex question of what can be cut and what must be retained to maintain a viable balance of forces. A manager wants concise, simple answers to questions such as:

How much does it cost?

Is it cheaper in absolute terms (disregarding effectiveness)?

Is it cheaper considering differences in effectiveness?

What parts are most expensive?

What would be the effect of making it less expensive?

How accurate is all this information?

What is still unknown?

In the Pentagon there are many managers, more innumerable resource implications, and occasionally some worthwhile, rationally presented, information. At least some of this last quantity is due to the work of cost analysts.

This paper will present an overview of cost analysis at DA HQ. It will show what cost analysis concerns and how it differs from budget analysis. It will illustrate the differences between the two major parts of cost analysis - force analysis and materiel analysis. Additionally, this presentation will show some studies that cost analysts are currently performing. Finally, it will try to tie-in the essential role of cost analysis in periods of economic constraint.

Sponsored by the Plans and Economic Analysis Division, Office, Comptroller of the Army.

HISTORY

The Army Cost Analysis Program was established in 1966 by the Secretary of Defense to extend to the Army the techniques that were then being used by the Systems Analysis Group at OSD. Therefore, from the Army point of view, the program was designed as a response to systems analysis; while in fact, it might be more accurate to say that cost analysis was a counter-attack on systems analysis. There had been numerous bitter words about systems analysis, but the basic difficulties were mainly due to what the services were not doing, instead of being the result of what OSD systems analysis did. It is a fact that systems analysis did not give enough emphasis to integrated analysis of total programs. Most of the talent was in OSD, but OSD was dealing with problems within the services. Sometimes an analysis was done without the benefit of full knowledge of a program; the analysis led to wrong conclusions and everyone knew there was something wrong but they couldn't really explain what this something was.

By and large those days are gone. Now there are relatively few disagreements between Army and OSD analysts about techniques. The Army may have differences about assumptions, but the communications gap has been closed. The rapport that has developed in the analytical community in the last few years is one of the things that makes the new doctrine of participatory management both possible and effective. Many of the questions that used to be directed to OSD analysts now go to Army analysts and many of the problems that used to be raised in OSD are now raised and solved within the Army.

COST ANALYSIS AND BUDGET COMPARED

At this point, the distinction between cost analysis and budgeting is beneficial.

COST ANALYSIS	BUDGETING
Plans and Programs	Budget
5, 10, 20 Years	Current Year-Budget Year
Examine Alternatives	Allocation of Shortages
Systems Approach	Appropriation, Commands, Accounting

(Figure 1: A Cost Analysis/Budget Comparison)

Budgeting centers on one document - the budget request that the Department of Defense makes to Congress. It deals with 3 fiscal years - prior year, current year, and budget year - with the emphasis being on the current year and the budget year - the year for which the budget is submitted. Developing a budget is a process of allocating shortages - the job is to take the approved program and fit it into the latest dollar constraints - and spread the shortfalls as best possible. Finally, the budget is prepared along the lines of appropriations, commands, and the accounting system - it has to be that way - it is the document by which the Army gets its money and the dollars have to be parcelled out the way they'll be spent even if the one who benefits from an expenditure isn't the one who makes it.

On the other hand, cost analysis is concerned with a multitude of planning and programming documents. Usually cost analysts work from a few to 20 years into the future - when there is still time to make major revisions in a course of action. Cost analysts are less concerned with finding out exactly how much it will cost to do something than about finding the difference in cost between two courses of action. The job is to look at the cost of alternatives in a time frame when the options are still open.

If Army is faced with two alternatives, the planner wants to choose the one that gives the most for the money. With a go/no-go decision to make, the decision maker wants to know all its implications; and if Army is trying to save money it may need to take action some years in advance in order to reap later savings.

The budget analyst is frequently faced with political restraints just as his budget is being developed - any action he takes will be undesirable for the Army; but, he must do something. The cost analyst's relation to the budget makers is to help provide a well-balanced base program as the basis for their work. The budget problems that do arise, come from untimely revelations of constraints or from an inability to provide a sound programming base within the constraints known to exist.

WEAPON SYSTEMS ANALYSTS

The most important distinguishing characteristic of cost analysis is the emphasis on the systems approach. In looking at a weapon, the analyst pulls together the costs that the budget has parcelled out in various nooks and cranies - the research and development, including that in closely associated technical efforts; the basic equipment cost in the procurement list; the spare parts and production base support; the ancillary equipment; the ammunition; the support equipment; the operating costs; e.g., pay for the crew; their PCS costs; the money CONARC spends to train them; and the maintenance costs from the organization to the depot. In looking at two tanks, the analyst is interested in the total resource implications of each. He follows the same approach for a force unit; in looking at a division he is interested in not just the money that goes through the division finance officer, but also the investment cost of all its equipment, the cost to MTMTS to send the division overseas, the cost of recruiting and training the men of the division, the overhaul costs of the equipment, and the cost of the items consumed by the division. The budget, following the appropriation, command, and accounting lines, doesn't assign resources to the end users the way cost analysis does. The budget is fine as a way to allocate funds and control expenditures, but even with recent changes it has seen, the budget doesn't fit the mold of an analytical document. Thus far I have spoken about cost analysis as it relates to weapons systems.

FORCE ANALYSIS

But there is another part of cost analysis - force analysis - and this paper will be divided equally between discussing the analysis of forces and the analysis of materiel.

FORCE ANALYSIS THE UNIT:	MATERIEL ANALYSIS THE WEAPON SYSTEM:
Personnel	Research & Development
Equipment	Investment
Support	Operating

(Figure 2: Force Analysis/Materiel Analysis Comparison)

It will be easier to see how the materiel analysis is used and to understand some of the things that come out of the Pentagon once familiar with what is done in Force Analysis. Of course, the difference between Force and Materiel Analysis is that Force Analysis looks at an organization of men equipped with various weapons to accomplish a mission while materiel analysis looks at a particular weapon with its support and sees how it accomplishes a mission. In force estimating, DCA is frequently both the initiating and reviewing agency at the same time. Most of the force analysis done in the Army is done at DA, but CDC is now getting more involved in this area. The heart of force analysis lies in the identification of the resource implications in a particular force structure. The development of a reasonable methodological approach, which fits the level of detail required, presents both a challenge and an obstacle to the force analyst. This is particularly true in the development of total force estimates in a constrained environment. Analysts act both as coordinators of staff inputs and devil's advocates to insure that all necessary cost information is being generated by the staff or developed by estimating relationships. It is as important for the force analysts to be conversant in the language of force planning as they are in the area of financial transactions.

The implementation of some of Project Prime's recommendations in the development of war plans has caused a proliferation of alternative force structures in each exercise. This has caused heavy reliance upon ADP processing to handle the massive amount of data required. New ways are continually searched for with which to provide faster and better estimates of the costs associated with a total force. Hopefully, analytic reviews insure the focusing upon issues which either must be resolved or brought to the attention of the planners and financial managers prior to the formulation of the budget.

Army involvement in the Planning, Programming and Budgeting system will serve to illustrate the variety of exercises in which force analysis plays a large role.

PLANNING, PROGRAMMING AND BUDGETING

The first area for discussion is force analysis and in particular the cost analysis involvement in the planning, programming, and budgeting system. Figure 3 lists the basic documents found in this system.

National Security Study Memorandum - NSSM
Joint Strategic Objectives Plan - JSOP
Army Strategic Objectives Plan - ASOP
Army Force Development Plan - AFDP
Fiscal Guidance Memorandum - FGM
Joint Forces Memorandum - JFM
Program Objectives Memorandum - POM/Budget/FYDP

(Figure 3: The Components of the Planning, Programming, and Budgeting System)

The first item listed here, the National Security Study Memorandum, is not generally recognized as a formal part of the PPBS. The series of NSSM's that the Directorate has received really are outside and above the formal PPBS, but they are the basis of all its plans and programs. These are the memos from Dr. Kissinger, President Nixon's foreign affairs advisor, which call for reviews to be submitted to the National Security Council. The day President Nixon was inaugrated, Dr. Kissinger signed NSSM-3 calling for a complete review of our strategic and general purpose forces. The Defense Department presented information, including five year costs, on several alternative defense strategies. The analysis of what Army presented and the information from the Council of Economic Advisors, the Bureau of the Budget, and the Treasury led to the basic decisions on the defense posture and budget constraints that DOD has been implementing lately. Since NSSM-3 cost analysis has moved on to other studies dealing with

NSSM-84 on forces in Europe. These studies represented a major effort, but they've raised long-range questions to the President, and the decisions made on the basis of these studies have given Army the basic guidance needed for effective planning instead of last minute fire-fighting.

The first step in the formalized PPBS cycle is the preparation of the Joint Strategic Objectives Plan. The JSOP is the advice prepared by the Joint Chiefs of Staff for the Secretary of Defense and the President on the military strategy and force structure requirements for attaining the national security objectives of the United States.

The Deputy Chief of Staff for Military Operations, who represents the Chief of Staff in joint actions, prepares the Army Strategic Objectives Plan as the Army input to the JSOP. The Directorate of Cost Analysis is tasked to assemble the costs that go into the ASOP and review both the ASOP and JSOP for their cost implications. The unique feature of the ASOP and JSOP is that they are not fiscally constrained. The JSOP represents what the JCS feels is the appropriate defense posture, based on the broad guidance from the National Security Council. There's no sacrifice of capability in order to meet a dollar ceiling. It is just this feature which has drawn heavy criticism to the JSOP lately. The differences between the cost of the defense posture that is needed for a 2½ war strategy and the actual budgets received became so large that the JSOP tended to become an academic exercise in force planning. The broad guidance from the National Security Council, which is now more closely in line with budget constraints than it has been before, does make the JSOP more realistic as a planning document. But a lack of realism in the PPBS is what led Secretary Laird to revise the PPBS by advancing the submission date of the JSOP and inserting a new series of force planning exercises based on fiscal constraints. In the present system, the JSOP becomes a recommendation that will influence the fiscal constraints established for later studies.

This job of providing information to OSD in order to influence the fiscal constraints becomes very important. The Army provides information to OSD by means of the Army Force Development Plan. With the changes that have taken place in the Army Planning System, the AFDP was, for a time, a document without a purpose, but now it has become an analysis, from the Army's point of view, of our current program and the programs proposed in the ASOP. This document is the overall responsibility of the Assistant Chief of Staff for Force Development, but again the Comptroller provides the costs. The fiscal constraints spoken of are established by the Secretary of Defense Fiscal Guidance Memorandum. This memorandum sets dollar ceilings for each service for the time period covered by the Five Year Defense

Program. The guidance is not very detailed; it is in terms of approximately one dozen fiscal guidance categories. Army obtains the backup data from OSD analysts and then has about three weeks to comment on the guidance while it is still tentative. This year, an additional step has been added. A Force Capability Guidance will be issued concurrent with the FGM. This document requires a force capability proposal to be made for several levels of funding. After submission of the Army's response, OSD reviews and analyzes the JSOP, the comments of the services, and submits its recommendations to the Defense Program Program Review Committee. This review hopefully leads to national level decisions on strategy, fiscal guidance and selected capabilities.

The end result is a revised fiscal guidance issued by OSD to the Services. This guidance is provided on Service TOE and outlays, and on selected specific capabilities to be programmed in terms of changes to a base program.

In an economically constrained Army, any leeway in this final guidance has usually been in the form of decrements from the base program. It required a thorough soul-searching by all military agencies and departments in order to prepare a balanced response in the POM and JFM.

The JCS response to the fiscal guidance is the Joint Force Memorandum - DCA puts together the Army's cost input. Since the JFM is a joint document it tends to stick closely to the fiscal guidance. However, each service also prepares its own response to the fiscal guidance, the Program Objectives Memorandum. The role of the POM has grown from what was originally envisioned. The Army POM was originally submitted last spring, but since then it has been revised repeatedly. The POM has actually become the basis of the Army budget and Five Year Program. OSD was to issue a series of program decision memoranda before the budget was submitted. These were to give the Secretary of Defense's position on issues raised in the whole series of documents from the JSOP through the JFM and the various revisions of the POM. Instead the Secretary approved the service POM's as the current program and asked for a budget based on these documents. The POM has become a 6 month preview of the budget and Five Year Defense Program.

The POM, the Budget, and the FYDP are used by cost analysts but the costs are prepared by the Director of Army Budget and the appropriate Directors in the various staff agencies. These are the principal documents of the PPBS cycle. Investment costs are included in the PPBS, of course, but they are balanced against the operating costs to form the total program - many of the key decisions about materiel items are made through special reviews outside the formalized PPBS.

Investment decisions, since they are relatively controllable compared to operations, and since they draw so much public interest, are subject to intensive management within DOD.

Figure 4 shows some of the topics dealt with in materiel analysis.

Development Concept Papers - DCP
Senior Officer Materiel Review Board - SOMRB
Materiel Procurement Priority Review
  Board - MPPRB
Selected Acquisition Reports - SAR
Cost Information Reports - CIR
Cost Effectiveness Studies
Life Cycle Cost Estimates - LCCE

(Figure 4: Aspects of Materiel Analysis)

First, the Development Concept Paper (or DCP) - it is, so to speak, a contract between the service secretary and the Secretary of Defense authorizing development of a new system. The DCP is written early in the life cycle of a new system and it establishes cost, performance, and schedule thresholds for the system. If these thresholds are not met, the Secretary of Defense makes a thorough review of the system and the DCP before the program can continue. The DCP is prepared by the Director of Defense Research and Engineering in OSD with the assistance of the services. DCA is responsible for advising the Secretary of the Army on whether the cost thresholds are reasonable - whether or not the DCP is a good contract to sign. When dealing with something that's just coming out of exploratory development and unknowns may still dominate the project -- deciding the merit of a cost figure in a DCP presents quite a problem. This is one of the areas where parametric estimating techniques are very important. It may be that all we have is a list of parameters.

SPECIAL REVIEWS

The next item gives you an example of some of the special reviews outside of the PPBS that were mentioned before. Last year there were a series of Senior Officer Materiel Review Boards (or SOMRB) - one for tanks, one for air defense, and one for communications. Each SOMRB conducted a detailed review of its area. Although all SOMRB's were formally separate - the boards in each case consisted of the same men - that is, most of the 3 star generals at HQ DA. These were among the most detailed reviews the Army has ever made at that level - in fact one of the problems was that there were too many top level people dealing with too many details. DCA prepared life cycle costs for each of the systems being looked at. In several cases it was quite clear the direction the Army was headed was pretty unrealistic from a funding viewpoint. The comparisons of life cycle costs raised questions as to whether systems being developed were desirable at all - some of these questions are still being resolved. And in at least the case of the SAM-D system, the statistical approach to cost estimating used, showed a large variance in cost estimates that were prepared utilizing engineering estimating methods.

Now the Materiel Procurement Priority Review Board or MPPRB is in a way, a special PPBS internal to the Army for weapons systems. It is a group of General Officers who periodically examine our Weapons Acquisition Program to insure that it is balanced both in itself and in relation to our other programs. They determine the priority the Army will place on buying various weapon systems and keep our program within a reasonable fiscal constraint. DCA is responsible for reviewing the cost data the MPPRB receives and for supporting the Deputy Comptroller in his role as a member of this board.

SELECTED ACQUISITION REPORTS

The Selected Acquisition Reports (SAR's) are the one set of reports outside the PPBS that draws mass attention. Reviewing these quarterly reports to Congress on the status of Army's largest acquisition projects represented a backbreaking load on cost analysis when this directorate first took them on. It's only within the last year that cost nanalysts have begun to see light and the SAR's have become worthwhile. The SAR is not part of the PPBS, but the importance of accurate reporting and tracking of changes involves DCA repeatedly in the complexities and politics of the Budget. Conceptually the SAR is a very simple document that provides just what the Secretary of Defense and Congress are looking for - a snapshot of the system progress. But changes in the ground rules and special problems in each system, always complicate the situation - and create almost insurmountable problems for analysts trying to make the SAR a rational report. Army analysts are in a never ending struggle to avoid footnotes to the footnotes.

Hopefully, the efforts are worthwhile - the SAR's get a full review within the staff, detailed personal scrutiny from the Assistant Secretaries of the Army, and the personal attention of the Secretary of the Army and the Secretary of Defense. There are some who wish Senator Proxmire would devote less attention to the SAR.

COST INFORMATION REPORTS

The next report on the list, in contrast to the SAR, is a quiet little report that hardly anyone ever looks at. One of the real tradgedies in the cost analysis business is that analysts don't have resources to collect and analyze more cost information reports (or CIR's).

These reports of historical contractor costs on our largest weapon systems can be invaluable to the analysts. They are prepared by the contractor, they come through channels to DCA, who sends copies to OSD Systems Analysis. The CIR has two functions: First, a data base for future cost estimating, and second, a report that can't be fudged on the success the contractor is meeting. There have been cases where the detailed information in the CIR was the first sign of a serious cost overrun.

COST EFFECTIVENESS STUDIES

True analytical studies of cost effectiveness and life cycle costs are the basis for much of Army's information. A good study will give answers or give the data to generate answers to many of the questions being asked so DCA is very interested in improving the quality of studies they receive. DCA spends a lot of time going over studies received by HQ DA. The Secretary of the Army and the Chief of Staff do not read ten volume studies, but they do ask for briefings or papers summarizing them and they want their staff to assure them that the study was sound. So the Directorate is sometimes in the position of summarizing two hundred pages into two pages - and cost analysts carry around all the caveats and problems in their heads to make sure that a decision maker who hasn't read all two hundred pages doesn't go astray.

The analysis in these two kinds of studies is aimed at improving the quality of decisions. That's why the utility of these analyses - whether they're understandable and pertinent - is just as important as the accuracy of these studies.

ECONOMIC ANALYSIS

Analysis for making resource related decisions is being referred to as economic analysis these days. Economic analysis shows up in a lot of disciplines - cost analysis, cost effectiveness, system analysis, cost benefit analysis, operations research, and audit. Depending on your preference, it includes, overlaps, or is a subset of these. In spite of the name, the essential characteristic and the only essential characteristic is a rational approach to the problem of choice. There has been more emphasis from OSD lately on using analytical techniques everywhere and in fact a formal requirement to include an economic analysis with proposals - unless it can be shown to be clearly unnecessary because of overriding circumstances. DCA is going to have to make sure it doesn't turn to a cookbook approach or overburden itself with detail in meeting requirements while ignoring the real econonomic issues.

Economic analysis is best applied to a situation away from the battlefield - because of the problems of quantifying effectiveness and benefits on a battlefield.

Facilities

- Industrial

- Posts, Camps, Stations

Equipment

(Figure 5: Economic Analysis of Alternative Investments)

Cost analysis can do a pretty good job on simpler questions like the replacement of facilities in a depot and consolidating installations. It is also pretty good at lease vs buy decisions or even choosing between similar types of equipment. However, the analyst does begin to get grey hairs over the relative value of helicopters and tanks or ABM's and missile submarines.

CONCLUSION

Hopefully, this presentation has shown that cost analysis is an attempt to quantify projected costs of alternative desirable force and materiel configurations using valid logic to give the decision maker a factual handle on the monetary implications of projected policy decisions. The tighter the monetary belt is worn, the more important to proper fit the measurement of the Army's midsection becomes.

SESSION V A. - DISCUSSION

You may recall that when we started I gave a rather flip comparative title for this: "What to do when they cut the hell out of our budget". I said that on purpose, because I think the major theme now and the one that comes from all of this is, we are part of they, and the extent to which we participate in the proper identification and utilization of information in the decision process. We are indeed part of the budget decision process. We are part of the "they". And it's that balancing of the budget that I think came out very strongly. I thank you very much Mr. Smith for a very, very fine session.

NOTE: The comment included in this section is not necessarily complete. It was necessary to delete some remarks as they were unitelligible on the recording.

Computer Simulation as a Tool to Predict the Performance of a Future Army Electronic Surveying System

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I. Introduction. In 1969 a requirement was generated to perform an error analysis on the proposed Long-Range Position-Determining System (LRPDS) which is based on the recently invented range change method and which is being developed by the U. S. Army Engineer Topographic Laboratories. Since this was a new way of solving the problem, it was decided that before awarding a contract for development of the equipment an error analysis was needed to determine if the proposed system could meet the military requirements and if there were any problem areas.

II. Background. The Long-Range Position-Determining System (LRPDS) consists of a ground control unit, an air-borne transponder and ground transponders. The ground control unit includes a computer which controls the system's operation as well as doing the data reduction. The ground transponders are placed on points whose coordinates are accurately known (Base Stations), and other transponders are placed on points whose coordinates are desired to be known (Unknown Stations), similar to Figure 1. An aircraft containing the air-borne transponder flies over the Base Station area transmitting a signal which is received by the ground transponders. At a given signal all the ground transponders take a reference measurement with respect to which the range changes are measured. (That is, this is set as the point of zero phase shift.) Figure 2 shows the basic idea of range change measurements. At time t_0 each station takes the reference measurement to obtain the zero phase shift point for that station. At time t_1 each station takes a phase shift measurement to obtain range change one ($\Delta R1$) for that station. This is repeated until sufficient measurements have been obtained to solve for the Unknown Stations with the desired redundancy. The range change data are then sent to the ground control unit for data reduction.

III. Objectives. The main objective of this analysis was to determine what parameter accuracies were necessary in order to meet the minimum specifications for the Unknown Station position accuracy. Some parameters considered were the survey accuracy of the Base Stations, the aircraft flight pattern, the Base Station pattern, the number of range measurements, etc. Also, these parameters could realistically be varied only within certain limits due to equipment constraints, specification constraints and other physical limitations.

The results of the analysis were also used to show some of the possible trade-offs between parameter accuracies that essentially give the same

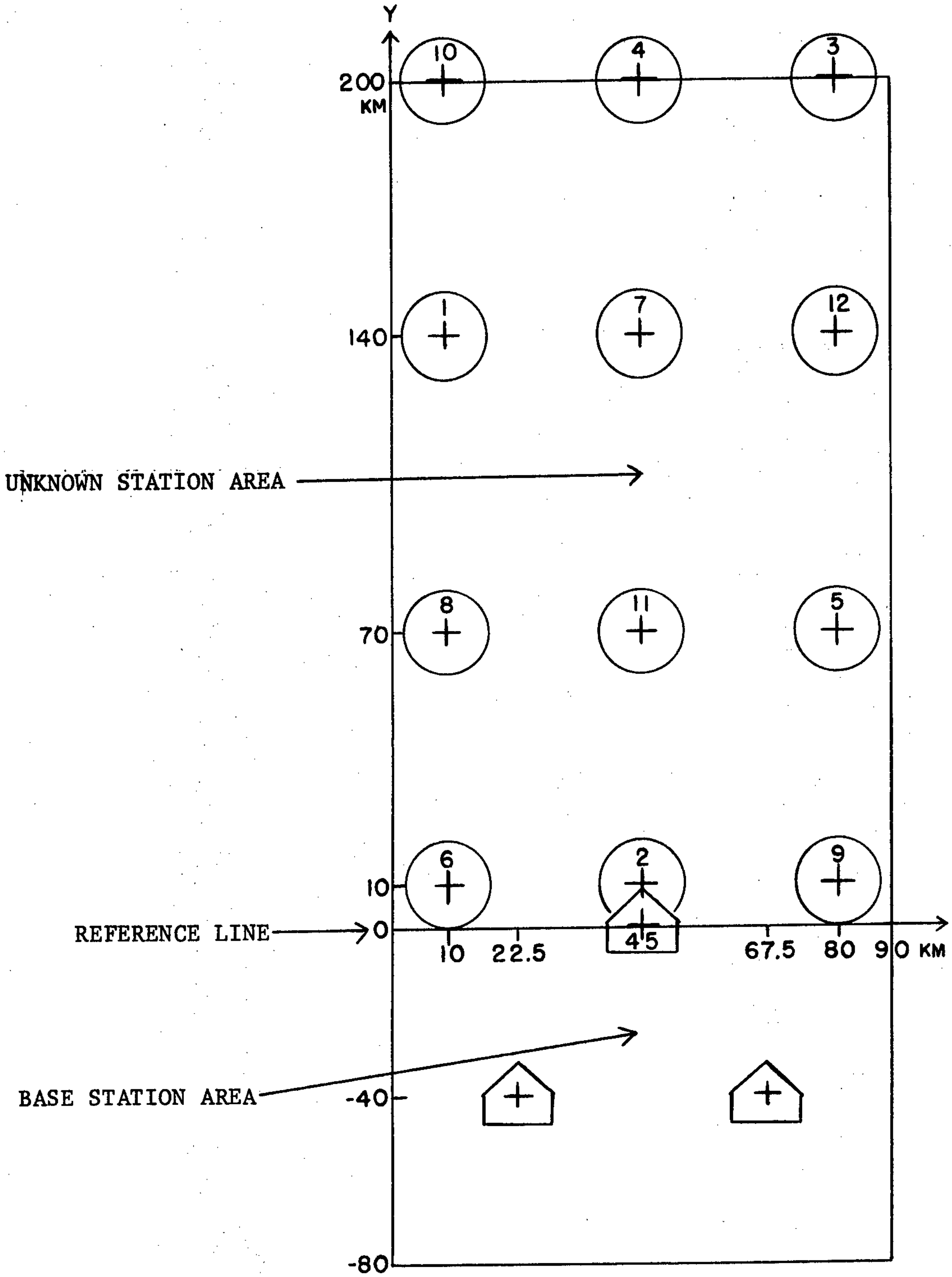
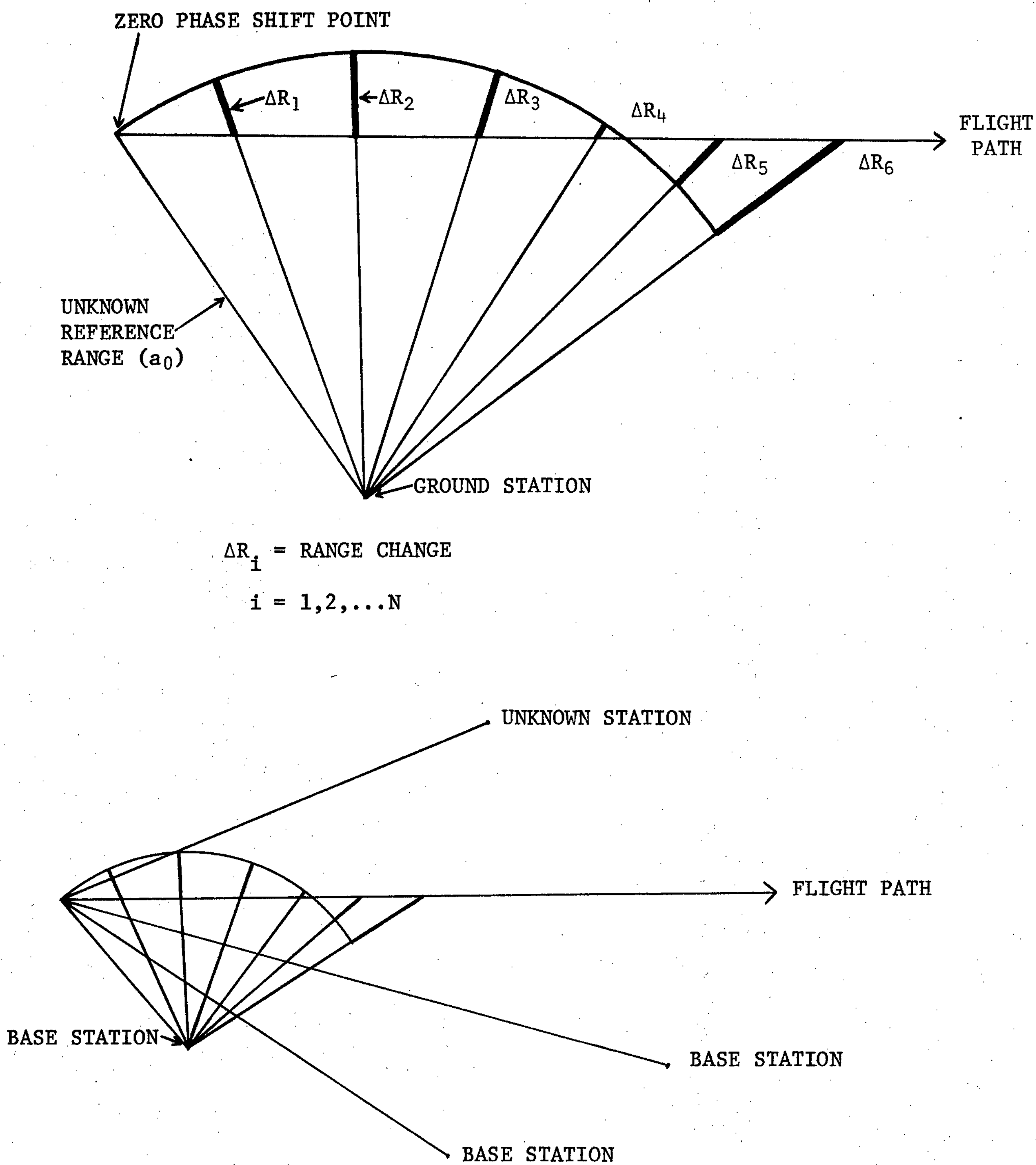

Y
200
KM
140
UNKNOWN STATION AREA
70
10
REFERENCE LINE
0
X
10
22.5
45
67.5
80
90 KM
BASE STATION AREA
-40
-80
10
4
3
1
7
12
8
11
5
6
2
9

FIGURE 1

RANGE CHANGE METHOD



Range change measurements made simultaneously from all ground stations (only shown for one ground station).

FIGURE 2

result. It can be shown from the analysis which parameters are highly sensitive to change and which are relatively insensitive to change. Also, the weak links in the system's accuracy are pointed out.

Other objectives were to provide information to help in evaluating the proposals for developing the hardware and afterwards to help make decisions during the monitoring of the contract.

IV. Mathematical Model.

The basic observation equation on which the mathematical model was based is:

$$R_{ij} = -a_o + [(\bar{X}_j - X_i)^2 + (\bar{Y}_j - Y_i)^2 + (Z_j - Z_i)^2]^{1/2}$$

where R_{ij} = range change measured for ith ground station and jth air position.

a_o = ambiguous range ($R_{ij} + a_o$ = total range between i and j)

$\bar{X}_j$, $\bar{Y}_j$, $\bar{Z}_j$ = aircraft coordinates of jth aircraft position

$j = 0,1...n$

X_i, Y_i, Z_i = ground coordinates of ith ground station (Base Station or Unknown Station)

$i = 0,1...m$

n = number of aircraft positions

m = number of ground stations

A batch least squares error model was constructed such that given a set of preassigned standard deviations for the observed quantities, it will compute the expected standard deviations for the unknown parameters.

The model was then used to determine the effect that varying the input parameters one at a time has on the accuracy of the unknown stations.

V. Assumptions Made and Parameters Varied. The following are the basic assumptions made and input parameters varied in conducting the error analysis:

1. The model uses a local coordinate system based on a flat earth.

2. The pattern and ordering of the Unknown Stations (shown in Figure 1) were chosen to uniformly cover the area in a somewhat random manner.

The ordering enters the problem mainly in that if only three Unknown Stations are used, numbers 1, 2 and 3 will be used and if six Unknown Stations are used, then numbers 1, 2, 3, 4, 5 and 6 will be used, etc.

3. A sigma value of 2 meters was assigned to the range change measurements except for the case when the range change was varied to determine its effect on the accuracy of the Unknown Stations.

The 2 meters was arbitrarily picked to be a reasonable first guess since this quantity encompasses phase shift, frequency drift, refraction error, etc. When this error analysis was prepared, it was planned in a future analysis to break up this term into its individual components to get a better idea of the effect and allowable limits on each term. However, to simplify it and to get the program running and debugged, it was decided to use the single range change measurement error term for the first go round.

4. The Base Station survey accuracy was one part in 10,000 except for the runs checking the effect of varying survey accuracy. One Base Station is the reference point (sigma (x,y,z) = 0.0001) upon which the survey accuracy is based.

5. Most runs use a two level flight path to better obtain height information for the Unknown Station; however, a single level flight path was used in some runs.

6. Other parameters varied were:

a. Number of aircraft positions.

b. Flight path pattern and position (straight line, triangle, etc.)

c. Number of Unknown Stations.

d. Base Station Configuration (triangles of different sizes, placement and orientation of triangle, etc.).

e. Number of Base Stations.

f. A priori sigma X, Y and Z of air positions.

g. A priori sigma X, Y and Z of Unknown Stations.

VI. Results of Simulation.

Some sample results are given next. Since one parameter at a time is varied, the early results show the trend of varying a parameter rather than the ultimate magnitude of the solution. From this trend a reasonable value which helps optimize the parameter is selected for use in future runs where other parameters are varied. As the parameters become better optimized, the magnitudes of the standard deviations of the solution will become smaller.

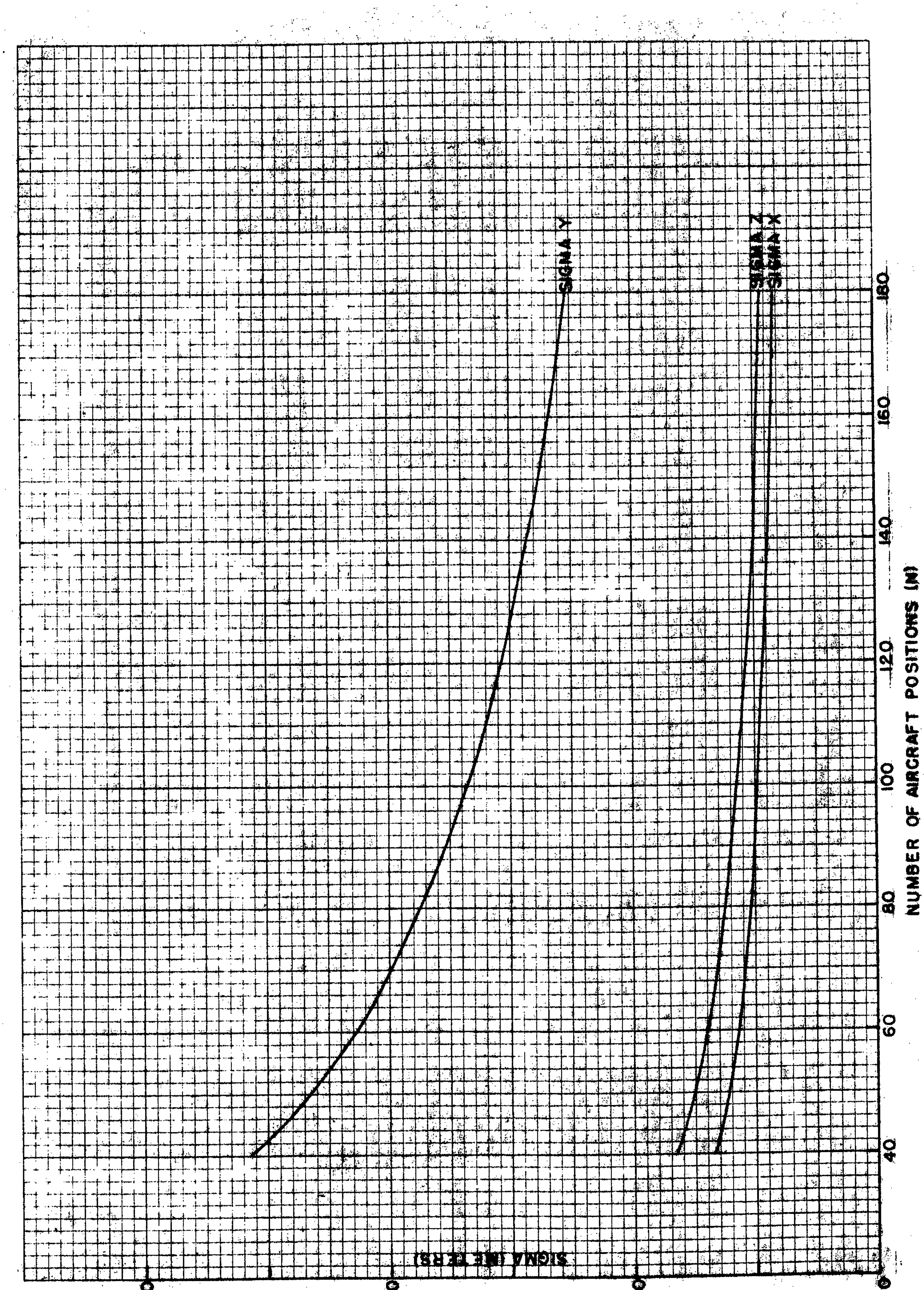
1. Number of Aircraft Positions.

Graph 1 shows how the standard deviations in X, Y and Z of Unknown Station 3 vary as a function of the number of aircraft positions (N) from which measurements are made. Since the curve starts leveling out more around N = 100, this was chosen for use in future runs.

2. Base Station Survey Accuracy. Graph 2 shows how the standard deviations in X, Y and Z of Unknown Station 3 vary as a function of the Base Station survey accuracy. One part in 10,000 was chosen for future runs based both on the requirements and the fact that the curve is starting to level out there.

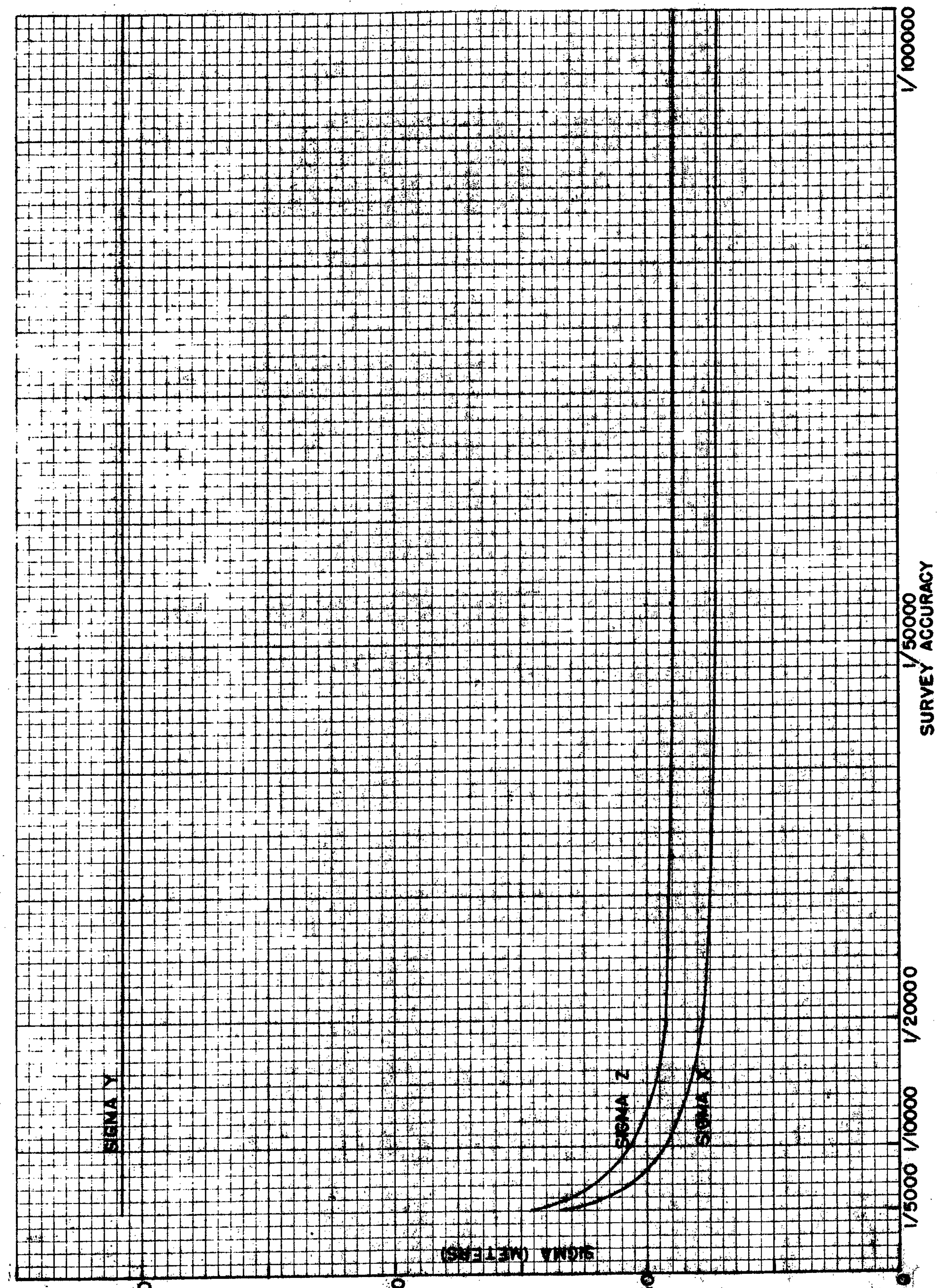
3. Number of Unknown Stations. Graph 3 shows how the standard deviations in X, Y and Z of Unknown Station 3 vary as a function of the number of Unknown Stations. From the graph it can be seen that going from 6 to 9 Unknown Stations gives an improvement in all sigma values, but the really significant improvement is in sigma Y; however, in going from 9 to 12 Unknown Stations, the improvement is small. This shows that to get better results, a certain minimum number of Unknown Stations are necessary. This minimum number would be determined be geometry and the degrees of freedom of the system and will vary from survey to survey. This illustrates one of the advantages of doing a simultaneous solution as compared to a step-by-step solution where first the aircraft position is solved for and then the Unknown Station.

VII. Conclusion. Based on the results of this computer simulation, it is concluded that it is definitely advantageous to perform a computer simulation before building the hardware of a system. It was determined that after the optimization of certain parameters, the system will meet the requirements. This optimization specifies certain minimum values for some of the parameters (such as the number of aircraft positions, etc.). This also served as a guide to the weak areas of the system. The cost of this simulation was only a fraction of the cost of the hardware and is serving now as a useful tool in helping to monitor the contract.

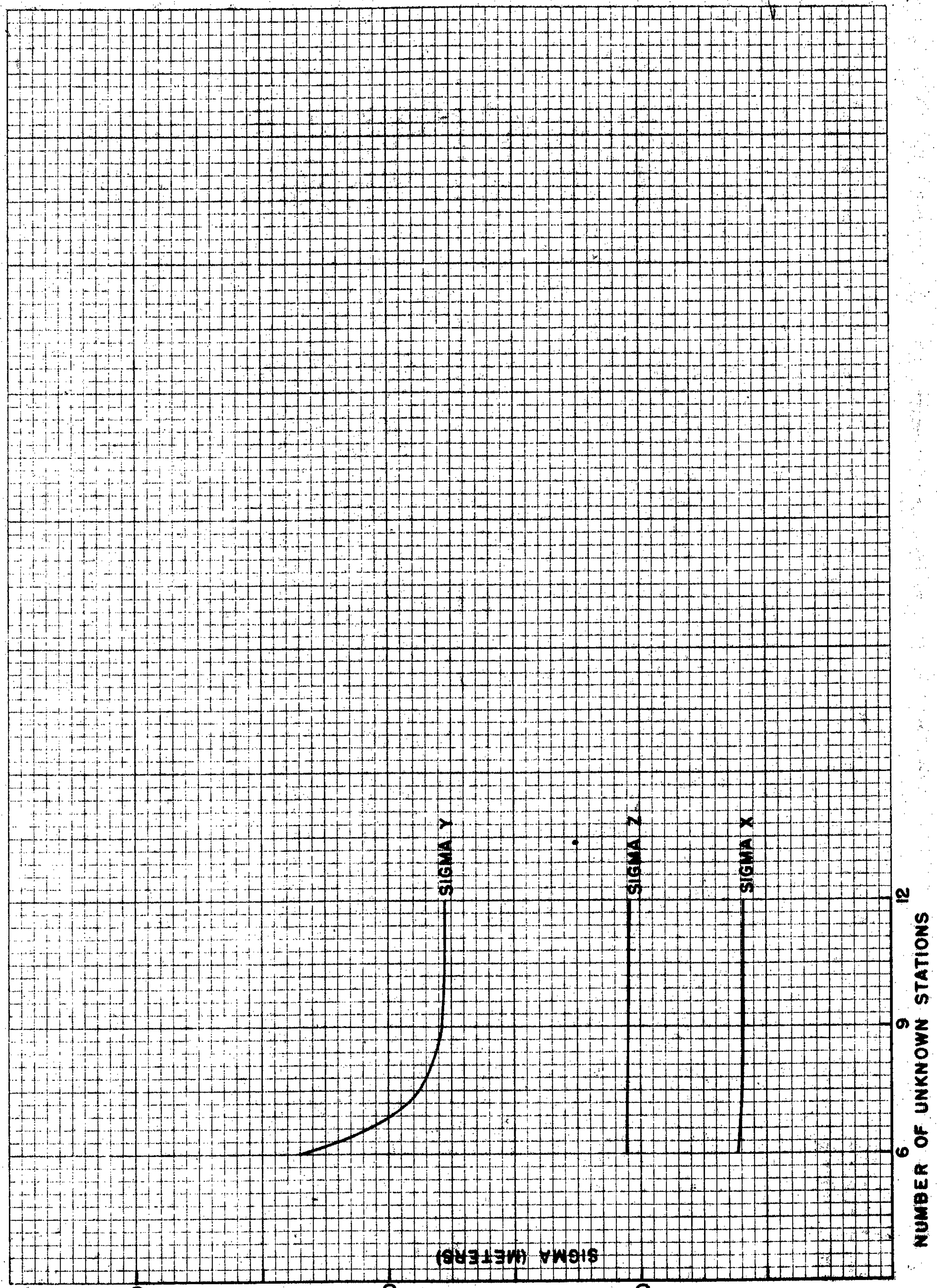


SIGMA Y
SIGMA Z
SIGMA X
NUMBER OF AIRCRAFT POSITIONS (N)
0
40
60
80
100
120
140
160
180
SIGMA (METERS)
100
200
300

GRAPH I


SIGMA Y
SIGMA Z
SIGMA X
SIGMA (METERS)
150
100
50
0
1/5000
1/10000
1/20000
1/50000
1/100000
SURVEY ACCURACY

GRAPH 2


SIGMA Y
SIGMA Z
SIGMA X
6
9
12
NUMBER OF UNKNOWN STATIONS
SIGMA (METERS)
150
100
50

GRAPH 3

Performance Analysis of Proposed Materiel Options
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1. Introduction. The Directorate of Military Technology, Institute of Land Combat, USACDC, has developed the Compendium of Plausible Materiel Options (CPMO). The purpose of this paper is to present the procedures to be used in conducting a performance analysis of proposed Materiel Options. The result of the performance analysis is to be the ranking of the proposed Materiel Options within three separate but correlated categories called Military Worth, System Effectiveness, and Cost Effectiveness. These categories are functions of three performance analysis factors called the Military Worth factor, the Technical Attainability factor, and the Cost factor (paragraph 3b(3)). In addition, a fourth ranking of Materiel Options is contained in the final report. This ranking is based on the judgment of the group performing the analysis and reflects the group's reconciliation of Materiel Option ranking differences among the three categories. Four specific rankings are presented, therefore, to provide the most meaningful input to the CPMO, to permit easier identification of factors of special interest that may otherwise become hidden in one composite ranking figure, and to enable the evaluators to effectively identify pivotal materiel unknowns.

2. Scope. The performance analysis is designed to permit complete flexibility in evaluating and ranking Materiel Options. The procedures allow either vigorous treatment of complete and quantified input data, or simplified treatment of incomplete and qualitative input data. The procedures to be used are chosen to obtain the most significant and nondeceptive ranking of Materiel Options. The choice is based upon the professional judgment of the individuals who are to perform the analysis.

3. Methodology.

a. Performance Evaluation Group.

(1) Purpose and number of members. The performance evaluation group (PEG) is a group of selected individuals whose purpose is the evaluation and ranking of Materiel Options proposed to satisfy a special Functional Objective. The PEG must also identify any pivotal materiel unknowns associated with a particular Functional Objective. Studies concerning the number of members to be used for this group have not rendered precise conclusions. As a general rule, the number of PEG members should be large enough to promote deliberation and include the breadth of expertise required for the job, but not so large as to waste time and/or create management problems. A historical review of size of panel studies indicates a range of from four to 16 persons. Time, place, purpose, and cost impact on the number of people to be selected. Considering all the constraints, a group of five appears to be appropriate, with one alternate member also selected to offset possible absenteeism.

(2) Status and qualifications. Since Materiel Options are oriented toward the military, the composition of the PEG should have a predominance of military personnel. In considering all the qualifications and criteria necessary, however, it is apparent that the PEG should have civilian representation also, because civilian experience and expertise, in many cases, is more highly specialized than that of the military. Furthermore, civilians have a continuity of job experience that is not found in military personnel. After considering the selection criteria, it was determined that a proper mix for the PEG would be three military and one civilian. The members should have broad general experience, in addition to qualification in specific areas, as indicated below:

(a) The technical will be represented by scientists, engineers, or analysts who are technically qualified to evaluate the specific Materiel Options in question.

(b) The operational will be represented by personnel from the field/operational community who are experts in the utilization of the Materiel Options in question.

(c) The organizational will be represented by personnel whose experience and/or skills relate to broad policy decision making, rather than to any specialty.

b. Application of Performance Analysis Factors to Materiel Options.

(1) General. The PEG conducts the analysis by first determining numerical values for three derived performance analysis factors (paragraph 1). These factors, i.e., Military Worth, Technical Attainability, and Cost, are composed of primary factors and subfactors as shown in Figure 1. A partial list of subfactors is contained in Figure 2. This list is intended to guide the PEG in its development of a complete list applicable to the specific Functional Objective in question.

(2) Computation. For each Materiel Option, one numerical value is computed for each of the three performance analysis factors as follows:

(a) Military Worth.

1. Military Worth factor = v_i, where v_i is the score given to a subfactor by an individual PEG member.

$$\sum_{i=1}^{n} v_i = 100. \quad (n = \text{numbered subfactors.})$$

2. The PEG selects, weights, and scores the subfactors which comprise Military Worth to obtain a Military Worth value for each Materiel

PERFORMANCE ANALYSIS FACTORS	PRIMARY FACTORS	SUBFACTORS
Military Worth:	Operational Readiness Performance Capability Mission Reliability Manpower Characteristics	Subfactors
Technical Attainability:	System Attainability Subsystem Attainability	Subfactors
Cost:	Research Development Production Training Operating Maintenance	Subfactors

Figure 1. Breakdown of performance analysis factors into primary factors and subfactors.

Option. The primary factors are not weighted or scored. They exist merely to facilitate the selection and weighting process. Military Worth is assigned a total weighted value of 100. The selected subfactors will be proportionally weighted so that their total summed value is 100.

3. Since, by definition, all selected subfactors are essential to the evaluation and ranking of the set of Materiel Options, the objective of the weighting procedure is to proportionally score these subfactors with regard to their relative importance. (For a more detailed discussion, see reference 1 on listing of references attached to this paper.)

(b) Technical Attainability.

1. Technical Attainability factor = P_a, where P_a is the probability of attainment as computed by the originator of the Materiel Option.

2. The Technical Attainability factor is assigned according to the risk area, as follows:

PRIMARY FACTORS	SUBFACTORS
Operational Readiness - The probability that the materiel option, when used under stated conditions, shall operate or perform satisfactorily at any given time.	Time required to respond, take effect, or activate; susceptibility to natural environments; ease of transportability; degree of deprocessing required; resistance to enemy action; identification of self-correcting, recuperative features; degree of mobility, serviceability, supportability, and maintainability; whether accessibly configured, conveniently packaged, and modular.
Performance Capability - The ability of the Materiel Option to successfully accomplish its mission, given a system that is operating within design specifications.	Maximum operating speed, time and range, depth forded, gap crossed, obstacle cleared, grade climbed, and/or fuel consumed; maximum ground drawbar pull, thrust, and/or angle of approach; minimum turning radius and/or ground clearance; maximum operating altitude and/or maximum depth limitations; maximum length, height, and weight; maximum payload; controllability; maneuverability; adaptability; compatibility; mobility; maximum capability to inflict casualties; rate of fire; degree of accuracy; capability to interdict, disrupt, canalize, and/or delay; identify, communicate, and/or control; capability to intercept and display data; and/or capability to warn.
Mission Reliability - The probability that the Materiel Option will give specified performance for the duration of a mission, when used in the manner and for the purpose intended.	The extent of use of proven processes, parts, and components; the compromise in design in achieving simplified procedures, system simplification, volume and weight reduction, producibility, and/or logistic support; durability; survivability; and redundancy.
Manpower Characteristics - The probability that operating personnel will perform their assigned tasks under specified conditions without error that causes mission failure.	Ease of operation, use, and application; ease of maintenance; vulnerability to human error; operator skill level required; safety features; and/or habitability and cultural acceptability.

Figure 2. Partial listing of performance analysis subfactors for Military Worth factor.

High risk -- $P_a = 0.30$

Medium risk -- $P_a = 0.60$

Low risk -- $P_a = 0.90$

(c) Cost. Cost factor = $\frac{R + D + (P)(n)}{10n} + (T + O + M)$, where R, D, P, T, O, M are respectively the costs of research, development, production, training, operation, and maintenance, as computed by taking the sum of the initial cost uniformly distributed over 10 years of operation; and where n is the number of systems to be produced for a specified timeframe, as estimated by the PEG.

(3) Ranking. After the values of the performance analysis factors have been determined, the PEG arithmetically relates these values and ranks the Materiel Options in terms of the factors. One ranking is presented in terms of Military Worth. A second ranking is presented in terms of System Effectiveness, a derived quantity which is a function of Military Worth and Technical Attainability. A third ranking is presented in terms of Cost Effectiveness, a derived quantity which is a function of System Effectiveness and Cost. A fourth ranking is presented which is not statistically based. This is a judgmental ranking by the PEG, and it attempts to reconcile any differences which may exist among the rankings.

(4) Final report. The PEG prepares a final report which contains all rankings, lists pivotal materiel unknowns which have been identified, lists all assumptions made, and presents comments and recommendations pertaining to the performance analysis.

4. <u>Materiel Option Evaluation Procedures</u>.

a. In group session, under the direction of the chairman, the PEG accomplishes the following actions:

(1) The chairman familiarizes the members with the objectives and the general technique of performance analysis.

(2) The PEG examines the Materiel Option data presented and assesses the need for additional data. If the information is not available within 1 working day, the PEG will make all assumptions necessary to enable it to proceed with the analysis. The assumptions will be recorded in the final report.

(3) Based on the data received and the subfactor guides (similar to those contained in Figure 2), the PEG selects the set of subfactors to be evaluated for the Functional Objective in question. The total set of selected subfactors (including those given in Figure 2) defines

the Military Worth factor for the Materiel Options proposed to satisfy the Functional Objective.

(4) The PEG determines a weighted value for each selected subfactor. For example, with regard to Military Worth, the weighted value is based on the relative importance of each subfactor within the set to total Military Worth. The total weighted value of the Military Worth factor is 100.

(5) The PEG determines the functional relationships between subfactors for each Materiel Option.

(6) The PEG establishes scoring criteria and threshold values for each subfactor. Threshold value is the minimum value which constitutes a boundary for determining the acceptability of the Materiel Option.

b. After the group actions (a. above) have been accomplished, the PEG members individually evaluate the proposed Materiel Options.

(1) Evaluation is based on the professional judgment of the member, within the framework of the scoring criteria, weighting factors, and threshold values previously determined by the PEG.

(2) Each individual evaluation produces one numerical value (between 0 and 100) per Materiel Option for each of the three performance analysis factors. This is the value of the performance analysis factor concerned, and is a function of the values assigned its subfactors.

5. Materiel Option Ranking Procedures.

a. Statistical Procedures. After the individual evaluation sheets have been completed, the PEG determines the statistical procedure to be used for averaging the data.

(1) Alternative procedures that normally may be used for averaging the data are the simple average, the weighted average, and the weighted majority rule.

(2) The procedure to be used is determined by the PEG. The decision is one of professional judgment, and is guided by the degree of completeness and quantification of the original input data, the consistency of the values computed by the individual PEG members, and the qualifications of those individuals.

b. Ranking of Materiel Options. The Materiel Options are ranked in three categories (termed Ranking A, Ranking B, and Ranking C) as follows:

(1) Ranking A.

(a) This is a ranking of the Materiel Options in terms of the Military Worth Factor. Also listed on the ranking format are the corresponding Technical Attainability and Cost factors obtained or computed from data provided. The subfactors which were most heavily weighted are also identified on the Ranking A format, which is illustrated in Figure 3.

FUNCTIONAL OBJECTIVE CODE:
MILITARY WORTH RANKING

Simple average ○
Weighted average ○
Other (specify) ○

a	b	c	d	e	f
MATERIEL OPTION	SCORE	CRITICAL SUBFACTORS	TECHNICAL ATTAINABILITY FACTOR	PRIMARY COST FACTORS	COST FACTOR
Rank ____:					
Rank ____:					
Rank ____:					

Figure 3. Format for performance evaluation group Ranking A Military Worth.

(b) Military Worth (Ranking A) = $k\sum v_i$, where k is specified by the PEG-determined procedure for normalization of the indiviual Military Worth factors. Normalization is accomplished by weighted average technique (see reference 4). Using their collective professional judgment, the PEG would assign a numerical weight to each member based on his experience and training. For example, if the materiel option to be evaluated is related to electronic equipment the member who has electronic training and experience should carry more weight than a non-electronic trained person.

(2) Ranking B.

(a) This is a ranking of the Materiel Options in terms of System Effectiveness. System Effectiveness is a derived factor and is a function of Military Worth and Technical Attainability, shown in Figure 4, which illustrates the Ranking B format.

FUNCTIONAL OBJECTIVE CODE:

SYSTEM EFFECTIVENESS RANKING (MILITARY WORTH X TECHNICAL ATTAINABILITY FACTOR)

a	b	c
MATERIEL OPTION	SCORE	MATERIEL UNKNOWNS (As a Function of Technical Attainability)
Rank ______:		
Rank ______:		
Rank ______:		

Figure 4. Format for performance evaluation group Ranking B, System Effectiveness.

(b) System Effectiveness (Ranking B) = Military Worth X Technical Attainability factor = $(k \sum v_i)$ (P_a).

(3) Ranking C.

(a) This is a ranking of the Materiel Options in terms of Cost Effectiveness. Cost Effectiveness is a derived factor and is a function of System Effectiveness and Cost. The Ranking C format is similar to that illustrated in Figures 3 and 4.

(b) Cost Effectiveness (Ranking C) = $\frac{\text{System Effectiveness}}{\text{Cost Factor}}$ =

$$(k \sum v_i) \; (P_a) \div \left[\frac{R + D + (P)\;(n)}{10n} + (T + O + M)\right].$$

(4) Ranking D.

(a) This ranking is to make a final check by the individual to see if he agrees with Ranking C. The individual is required to appraise his own ability to rank by assigning a confidence level, ranging from 1 to 10. The confidence level will be used to compute the consensus by using the weighted majority rule. (A detailed discussion may be found in reference 4 in listing of references attached to this paper.)

(b) This ranking is nonstatistical and is based on the judgment of the PEG in an effort to reconcile any differences which may exist between the statistical rankings.

(c) PEG Judgment (Ranking D) = Individual Judgment.

6. Final Report. The final report is designed to enable the PEG to present its final results and recommendations in a uniform, significant, and clear manner. The fourth ranking of Materiel Options (paragraph 5(b)(4)) is also a part of the final report.

7. Statistical Analysis of Results.

a. General. Evaluating Materiel Options provides a measure of the inconsistency in judging, and this can give a further indication of the reliance that should be placed on the final ranking. It must be repeated, however, that these are only indications, because a judge could be totally consistent and still be wrong. The definition of right or wrong cannot be given, as the concern is with subjective evaluation. If right or wrong could be determined explicitly, then only objective factors would be under consideration and judgment would not be required. Consistency in judgment is required; and in addition, it must be assumed that the judge is trying to conduct an honest, subjective evaluation.

b. Properties of Responses. The credibility of Materiel Option ranking by PEG members is directly related to the degree of completeness and organization of the information provided them, as well as the degree to which they are firm in their responses. Two properties of individual board member's responses are concerned: the Spearman's rank correlation coefficient, and the coefficient of concordance. The correlation coefficient is used to measure the consistency of the member. The coefficient of concordance indicates that there is high agreement among the judges in rankings.

(1) Spearman's rank correlation.

(a) Spearman's rank correlation coefficient is defined by

$$R = 1 - \frac{6 \sum d^2}{N^3 - n}$$

where Σd^2 is the sum of the squares of the rank differences, and n is the number of items ranked.

(b) When two rankings are identical, the rank correlation has a value of plus 1. When the rankings are as greatly in disagreement as possible, the correlation coefficient is equal to minus 1.

(c) Student's test is used to test whether the degree of agreement between the two observers is significant.

(2) Degrees of agreement between the evaluators.

(a) Assume k ranking of N concepts, and find whether the k rankings are in reasonable agreement with each other. In this case there are $k!/2!(k-2)!$ possible rank correlations obtained by taking all possible pairs of rankings. In many cases, it is desirable to have a single overall measure of agreement between the rankings.

(b) The measure is provided by the coefficient of concordance, denoted by the symbol, W. To find the value of W, we sum the k ranks for each individual and then subtract from each sum the mean value, $k\frac{1}{2}(N+1)$. Sum of the square of these deviations divided by the maximum possible value is the variance. The maximum will occur when each of the k rankings is identical. The sums of ranks will then be k, 2k, 3k, -- Nk. That means that k judges have perfect agreement and the deviation will be the difference between the sum of rankings and the mean value:

$$-\tfrac{1}{2}(N-1)k,\ -\tfrac{1}{2}(N-3)k,\ \text{--}\ \tfrac{1}{2}(N-3)k,\ \tfrac{1}{2}(N-1)k$$

so the maximum value of the sum squared of deviations is:

$$\tfrac{1}{2}k^2(N-1)^2 + \tfrac{1}{2}k^2(N-3)^2 + \text{--}) = (1/12)k^2(N^3-N).$$

Hence we have,

$$W = \frac{12\ (\text{sum of squares of deviations})}{k^2(N^3-N)}$$

W is a measure of the degree of agreement between the judges. This ratio is known as the coefficient of concordance. (For a detailed discussion, see reference 4 on listing of references attached to this paper.)

(c) The coefficient is designed so that it can vary from 0 (signifying complete randomness in the allocation of rankings) to 1 (signifying complete agreement among the judges). The significance of a coefficient of concordance may be tested by the use of a table developed by Kendall.

(d) A high or significant value of W may be interpreted as meaning that the observers or members are applying essentially the same standard in ranking the N designs. It should be emphasized that a high or significant value of W does not mean that the orderings assigned by members are necessarily correct.

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SURVIVAL EFFECTIVENESS FOR HARDENED FACILITY SYSTEMS

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1. Introduction

a. Two approaches can be used in the selection of a basic hardness level for a hardened facility system. Perhaps the most direct is to define hardness in terms of all nuclear effects which can be predicted to occur at a single overpressure level. The second approach derives from the threat. A probability distribution of all effects or loading conditions can be developed based on the postulated attack geometry and weapon sizes. Each results in an implicit definition of reliability/survivability which may be other than that intended.

b. The single overpressure level approach implies that all associated effects will be defined in terms of a functional descriptor to be associated at that level. No prediction is made as to the probability of various environmental conditions such as radiation from a low yield device or thermal load from a high yield device. The facility designer is forced to make a number of determinations as to resistance required for a series of worst case effects. This approach also requires that system vulnerability be related to a probability that the chosen overpressure level will occur at the appropriate set of distance/yield/height of burst (HOB) relationships.

c. The advantage of the second approach, in which a statistical description of environment is used, is that the facility designer is not forced to design for worst case conditions that are both extremely unlikely and extremely costly and do not impact the system vulnerability in a significant way.

Reliability-survivability of the system facilities can be established from information concerning the probability distribution of the attack loading.

2. System Effectiveness

a. The performance of the system can be described in terms of availability and dependability[1/].

$$E = AD$$

where E = A qualitative measure of performance

A = Availability of the facility system in a mechanical reliability sense

D = Dependability or the probability that the system will function as designed

b. Availability is a descriptor of down time required for maintenance and other support activities. It measures the degree of assurance that undetected subsystem failures are not present. The availability can be determined from

$$A = 1 - (Q_m + Q_f - Q_m Q_f)$$

where Q_m = Probability that the facility system will be in a vulnerable state of maintenance at a particular point in time.

Q_f = Probability that the facility system will contain undetected critical subsystems failures at a particular point in time.

[1/]Air Force System Command, Weapon System Effectiveness Industry Advisory Command (WSEIAC) Final Report of Task Group I, Requirements Methodology, AFSC-TR-65-1. Washington, D. C., January 1965.

If we assume that proper inspection reduces undetected failures to zero

$$Q_f \rightarrow 0$$

the availability becomes

$$A = 1 - Q_m = \frac{t_T}{t_T + t_{r/m}}$$

where t_T = Time during operational mode when equipment is operating

$t_{r/m}$ = Time for repair or maintenance

c. The dependability of a system is affected by structural survivability from attack loads at the design level and it is a function of probability of continual functional operation during attack, the severity of the attack with respect to the assumed, restoration of vital services after attack and assurance of pre-attack warning. Dependability can be evaluated from

$$D = P_s P_v P_L P_d P_o$$

where P_s = Probability of structure survival during attack

P_v = Probability of functional operation of critical equipment during attack

P_L = Probability that the weapon effect load is within bounds of predicted value

P_d = Probability of recovery from an attack condition

P_o = Probability that proper warning is given to the system

d. Redundancy plays an important part in the system effectiveness. Back-up or redundant mechanical and electrical equipment can be installed in a facility to provide greater assurance for vital equipment functioning throughout the attack mode. The functional operation probability is related to redundancy within the system as follows:

$$P_v = 1 - (1 - P_{vf}P_{cc}P_{vs})^m$$

where m = number of redundant elements

P_{vf} = probability of a single element functioning

P_{cc} = probability of external support such as electrical distribution functioning

P_{vs} = probability of a single element surviving from attack

e. Similarly, facilities can be duplicated to provide a more reliable/survivable functional capability. The probability of structural survival of a system consisting of a number of identical structures can be evaluated as follows:

$$P_s = 1 - (P_f + P_{vn} - P_fP_{vm})^{n/j}$$

where P_f = Probability of structural failure of a single structure

P_{vn} = Probability that the structure will be in a vulnerable maintenance/integrity status

n = number of structures to be used in the system

j = number of structures required in system

f. The maintenance/integrity status depends on the probability that blast valves and doors are down for maintenance or that the structure is in an otherwise down condition which can include moving weapon system or power plant equipment. These activities can be controlled in large measure by the system planner and operators. The probability of each structure being in a vulnerable maintenance status can be determined from

$$P_{vm} = \frac{t_T}{t_T + t_{vm}}$$

where t_T = Time during surveillance mode when in an up condition

t_{vm} = Time required to change modules or repair/maintain blast doors and valves, etc.

g. Figure 1 shows the probability of survival of a facility system as a function of the number of redundant structures for various combinations of single structure failure and integrity status. As the ratio of the total number of structures to number of structures required on a function basis approaches 1.5, significant functional survivability is achieved if all other factors remain unchanged. Figure 1 indicates that a rather high probability of single structure failure can be compensated by using additional structures. In accepting this conclusion, caution is in order because the probability of failure of a structure or, for that matter, a piece of equipment can be characterized in two ways (1) lack of confidence or precision in ones ability to handle the load-response relationship and (2) variability in the load description and/or material response. One cannot, in reality, achieve a compensation for lack of precision in a design problem through redundancy. It is only variability in the load descriptions and material properties that lends itself to improved survival probability through redundancy.

3. Factors of Safety

a. The achievement of an effectiveness goal in terms of survivability can be realized by consideration of the central factor of safety which is necessary to reduce the probability of failure to an acceptable maximum value. If the load and response of a system are defined in terms of a statistical distribution function (as shown in Figure 2), the separation of the mean values of each distribution determines the probability of failure. The probability of failure in

$$P_{vm} = \frac{\text{Down Time}}{\text{Total Time System Must Function}}$$

$$RF = \text{Redundancy Factor} = \frac{\text{Number of Structures}}{\text{Number of Structures Required}}$$

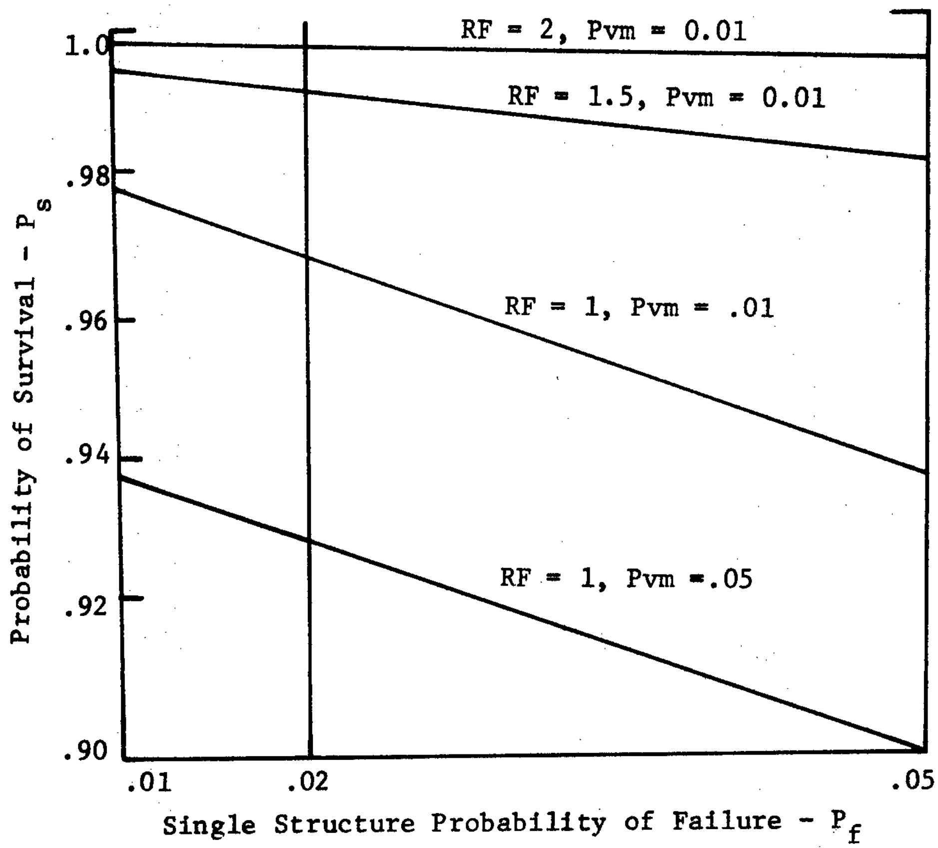

Figure 1

SURVIVAL VS. SINGLE STRUCTURE FAILURE FOR VARIOUS REDUNDANCY FACTORS

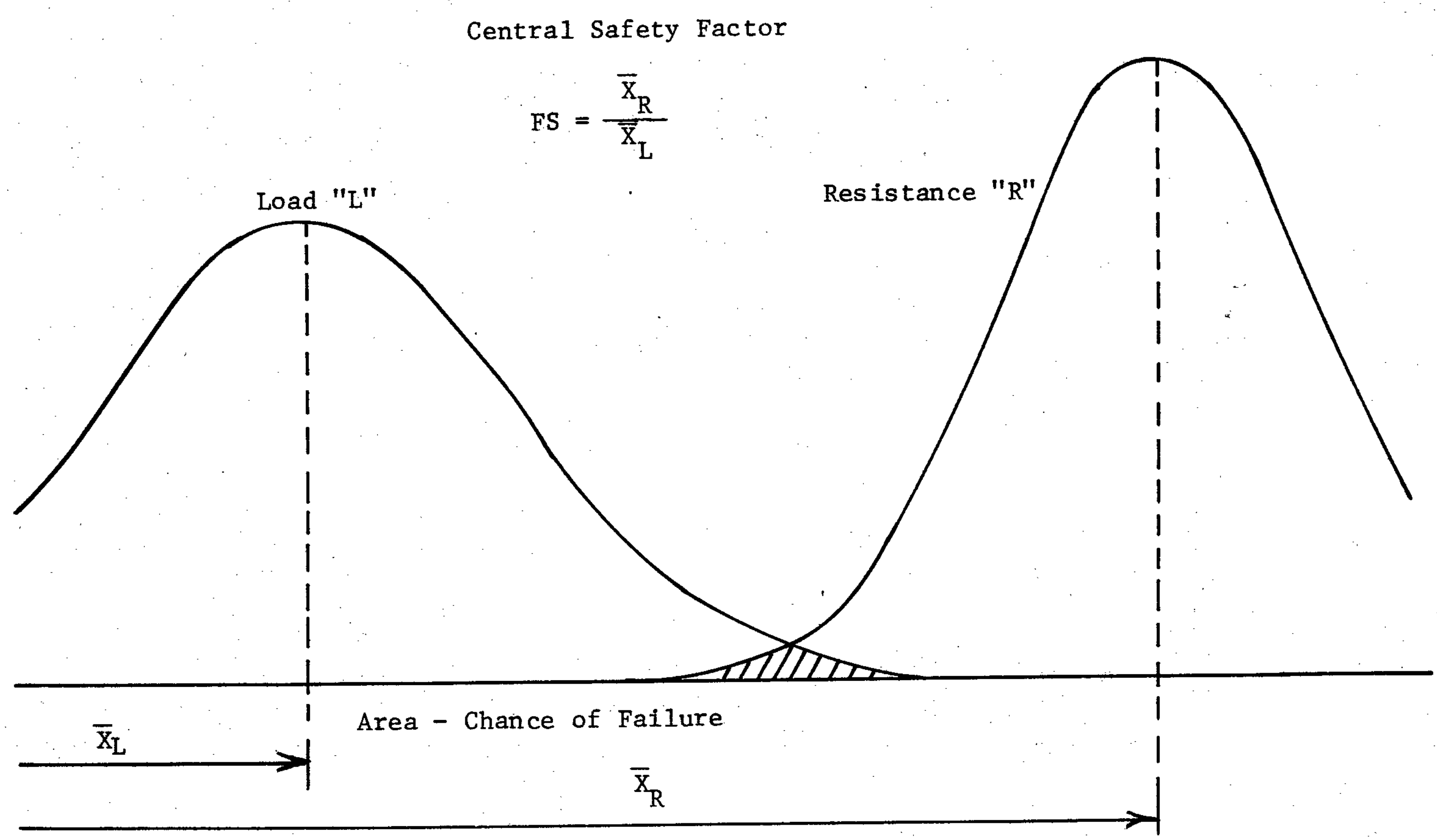

Figure 2

LOAD RESPONSE RELATIONSHIP

Figure 2 is shown as the shaded area bounded by the two distributions. The central factor of safety (FS) is the ratio of the mean values of the distributions. The central factor of safety for a normal distribution is given by[2/3/]

$$FS = \frac{1 + K_{pf}\sqrt{\delta L^2 + \delta R^2 - K_{pf}\ \delta L^2 \delta R^2}}{1 - K_{pf}^2\ \delta R^2}$$

where $K_{pf} = \phi^{-1}(1-P_f)$, $\delta_R = \frac{\bar{X}_R}{\bar{X}_R}$, $\delta_L = \frac{\bar{X}_L}{\bar{X}_L}$

P_f = Probability of failure which is defined as an effectiveness goal

$\phi^{-1}(1-P_f)$ = Value of the standard normal variate corresponding to a cummulative probability of $(1-P\ ) = \frac{\bar{X}_R - \bar{X}_L}{\sigma_R^2 + \sigma_L^2}$

σ_R = Standard Deviation for Resistance Distribution

σ_L = Standard Deviation for Load Distribution

$\bar{X}_R$ = Mean value of Resistance Distribution

$\bar{X}_L$ = Mean value of Load Distribution

b. The central safety factor represents the required overdesign level which must be used in order to achieve a probability of success equal to P_f. It, therefore, defines the design penalty to be incurred in order to achieve a desired vulnerability goal. A plot of central safety factor as a function probability of survival for various combinations of loading and response distributions is shown in Figure 3. The loading and response distributions are expressed in terms of the coefficient of

2/Ang, A.H.S., Probability Considerations in Design and Formulation of Safety Factors, JABSE Symposium on Concepts of Safety of Structures and Methods of Design, London, 1969.

3/Ang, A.H.S., Extended Reliability Basis of Structural Design under Uncertainties, SAE/AIAA/ASME 9th Reliability and Maintainability Conference, Detroit, Michigan, 20-23 July 1970.

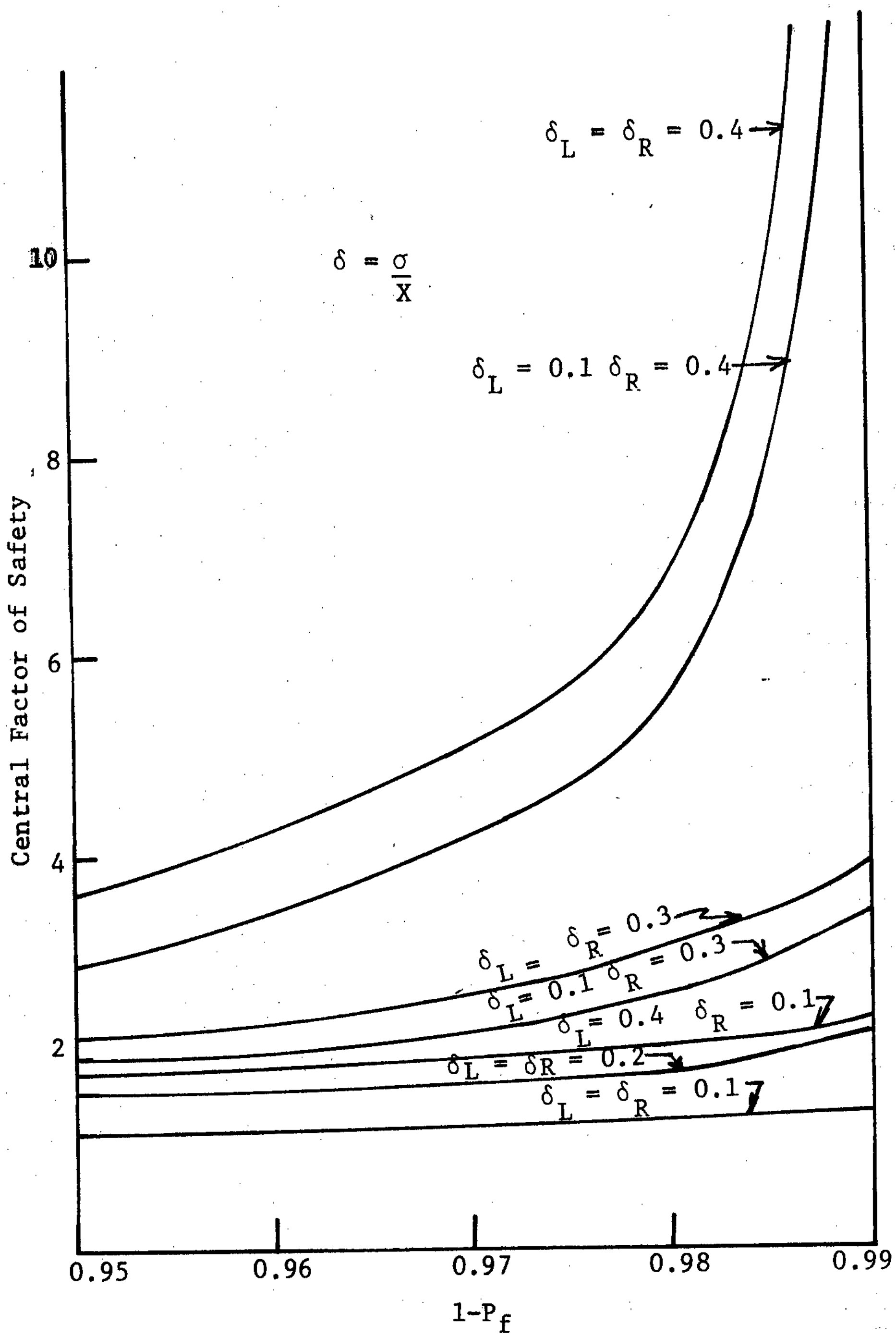

Figure 3

INFLUENCE OF COEFFICIENT OF VARIATION

variation which defines confidence factors as a percentage of the mean value.

c. It is significant to note that a slight penalty is imposed, in terms of an increased factor of safety, to achieve a high degree of survival probability if the confidence level of the loading data is poor. This is expressed as a large coefficient of variation for load (δ_L=0.4, δ_R=0.1). It is contrasted to a very severe design penalty for the case in which response is ill defined, i.e., the coefficient of variation for response is large (δ_L=0.1, δ_R=0.4). This is true for all normal distributions in which the factor of safety is expressed as a function of the mean value of the loading function. Normal distribution has been used in this example inasmuch as the failure probabilities for protective construction are on the order of 10^{-2} in a typical problem. As the failure probability goal is reduced significantly below 10^{-2}, the shape of the distribution function becomes important because the area in the tail of the distribution becomes critical. Figure 4 shows the sensitivity of the central factor of safety to the shape of the distribution. It is precisely this tail portion of the typical distribution function that lacks definition because of a paucity of test data.

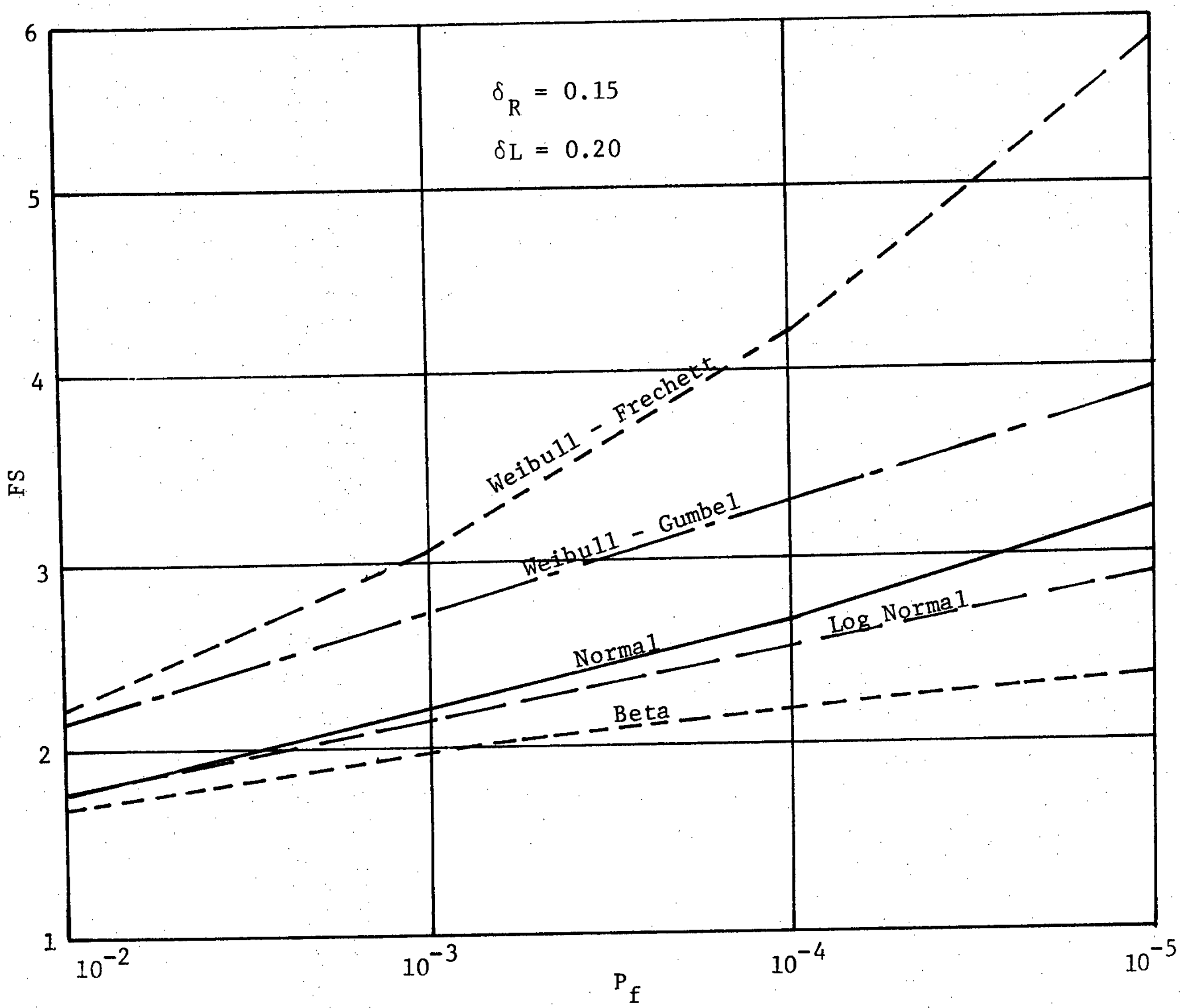

Figure 4

VARIATION OF CENTRAL FACTOR OF SAFETY
FOR VARIOUS DISTRIBUTIONS

SESSION V B. - DISCUSSION

Question:

What was the last point you made, I didn't appreciate that-the shape of the distribution?

Answer:

Well, if you cannot define the shape of a distribution-either the low function or the response function-and you're trying to get a survivability or an assurance in excess of say five ninths, you are working out of the shaded area in the two curves that relate response and load, it's way out on the tail and it is in the tail of the distribution function that you have the least good information. So you're deriving the problem in an area where you don't have another division of unit property, and what's sort of a classic problem right now in conventional structures as far as applying a statistical approach to your liabilities structures. In this case, we are dealing with survival goals that cause this problem to be moved towards the center of the distribution. So the closer you get to the center of the distribution, the less sensitive the result is to the shape of that distribution. On the other hand, you can fit a reasonable law of probability distribution to the data which you have.

NOTE: The comment included in this section is not necessarily complete. It was necessary to delete some remarks as they were unitelligible on the recording.

AN ANALYTIC MODEL OF GROUND COMBAT: DESIGN AND APPLICATION[1]

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1.0 INTRODUCTION

The importance of applying quantitative approaches to military planning activities is well recognized. Central to many of these activities, and of importance to weapons systems planning studies (selection, tactical doctrine, force mix, etc.) is the requirement for methods or models to predict the effectiveness of combat units when employing different mixes of equipment. This stems primarily from the fact that, in the planning phase, the systems of interest are not available so that their effectiveness cannot be experimentally determined. Even when experimentation is feasible, methods are needed to provide guidance in conducting the experiments, analyzing the data, and interpolating or extrapolating the data to systems and environments not considered in the experiment. When systems are not available for experimentation, it is particularly important that the effectiveness estimating methods be related to decision variables under the control of the military planner in a way such that the effect of their variations may be readily observed.[2]

The Army makes use of a broad spectrum of models or abstracting techniques, which includes war games, pure simulations, and analytic

[1]Methods described in this paper were developed by the Systems Research Laboratory, The University of Michigan, under the sponsorship of the Office, Assistant Vice Chief of Staff, U.S. Army (Contract DAHC15-68-C-0314) and the Office of Naval Research (Contract N00014-67-A-0181-0012). Application of the general methods to a set of tactical situations for comparison with existing procedures was conducted by Vector Research, Inc., under the sponsorship of the Office, Assistant Vice Chief of Staff, U.S. Army (Contract DAHC15-70-C-0151).

[2]See the discussion on different uses of models described by Bonder (1971).

models.[1] However, in weapon system studies at the tactical level, the Army has relied principally on high-resolution simulation models such as Carmonette (Adams, 1961), DYNTACS (Bishop and Clark, 1969), and Individual Unit Action (IUA) (USACDC, 1969). These simulations run completely without human intervention. In the development of this type of model, the military process is studied, decomposed into its basic events, and these events ordered in a logical sequence as they would occur in the actual process. In solving a simulation model, events in the different combat processes are essentially followed in sequence and decisions are based on predetermined rules which are programmed into the automated evaluation procedure.

The ground combat simulations noted above contain a significant number of stochastic or probabilistic routines in an attempt to capture the chance element associated with many combat processes. The models require probability distributions for many of the input variables and generate probability distributions for the output variables or results. In such a stochastic simulation, the model is solved by Monte Carlo sampling[2] 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 procedure 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.

An example of the detail included in the noted simulations is shown in Figure 1, which depicts a one-on-one duel, the basic combat activity in large-scale Monte Carlo simulations of ground combat. Random numbers are drawn to determine the time for each weapon system to fire its first round. Focusing on the Blue weapon system, additional random numbers are drawn to determine the flight time of the first round to the target,[3] if the first round hit the target, and if the round destroyed the target. This process is simultaneously accomplished for the Red weapon system. If Blue hasn't destroyed Red with his first round, and if he is alive himself, this process is repeated for Blue's second round, Red's second round, Blue's third round, and so forth. This process is continued until

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[1] Definitions and attributes of simulation and analytic models are discussed in succeeding paragraphs. Basically, the distinguishing feature of war games is the interface of players as military commanders in the model. The use of humans in this capacity allows combat decisions to be realistically based on the complete state of the process (friendly and threat forces, resources available, environmental conditions, etc.) and on an overall strategy.

[2] The reader is referred to Wagner (1970) for a discussion of Monte Carlo sampling procedures.

[3] This is usually treated as a range-dependent constant and thus not sampled by Monte Carlo procedures.

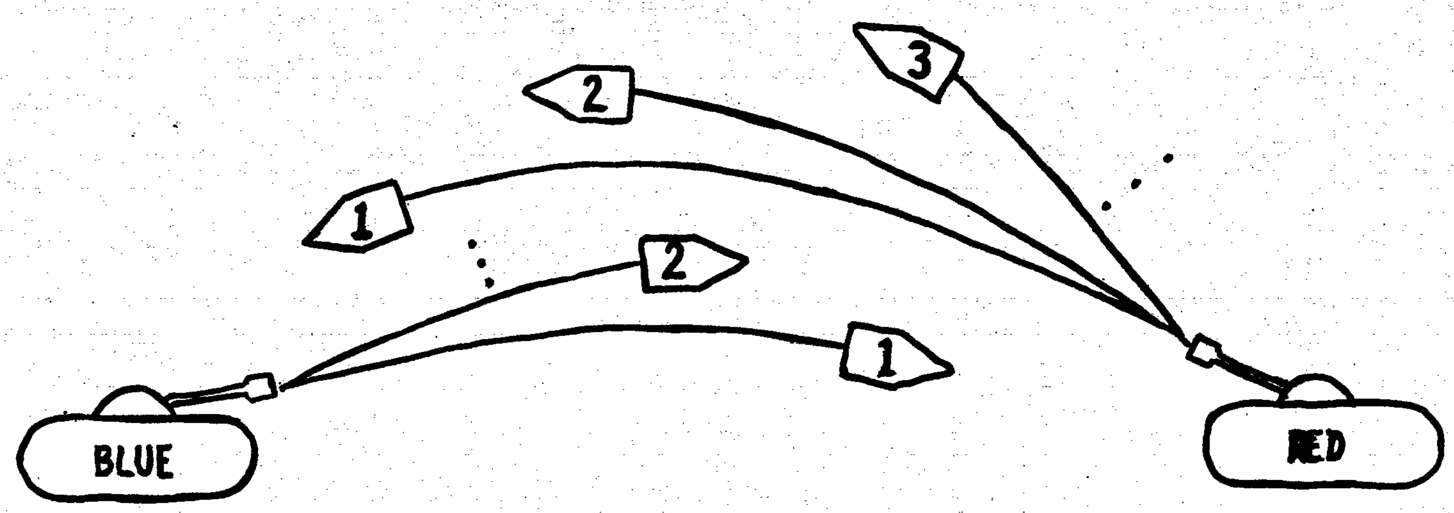

FIGURE 1 THE DUEL PROCESS IN A MONTE CARLO SIMULATION

one of the duelists is killed or the duel is terminated based on engagement rules built into the simulation. This activity, and others, of every system are recorded during the course of the battle and eventually analyzed.

Although Monte Carlo simulations are heavily employed in Army planning studies at the tactical level, there exist some meaningful drawbacks to their use as effectiveness assessment tools. Monte Carlo simulation models usually 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 in just developing a simulation of combat such as Carmonette or DYNTACS. Additionally, it would not be unreasonable to expect each replication of the simulation to require 10-20 minutes of computer time,[1] 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 analysis over the simulation assumptions and input data. This is due to both the statistical experimental design problems and money constraints which prohibit the large number of replications needed to determine the distribution of outcomes. Finally, and perhaps most importantly, the large amount of detail contained in the simulation makes it difficult to use by itself as a tool for analysis, i.e., single out the weapon system capabilities and/or doctrine, which significantly contribute to the combat effectiveness.

In contrast to the Monte Carlo simulation and war gaming approach, a limited amount of effort has been devoted to developing and using analytic (mathematical) models in the military planning area. Analytic models are in a sense like simulations in that they also have no player involvement; however, they tend to be much more abstract. As in the development of simulations, the military process is studied and decomposed into its basic events. In analytic models, however, mathematical descriptions of all the basic events are developed and these event descriptions are then integrated into an overall assumed mathematical structure of the combat process. Solutions are obtained by consistent mathematical operations giving rise to relationships between independent variables and dependent ones of combat effectiveness.

Analytic models can be either deterministic or stochastic. In the former case, a single set of input values produces a single set of output results, while in the latter case, a set of input probability distributions produces a probability distribution over the output variables. In either case, no replications are required since a solution is obtained either by direct mathematical operations or by numerical computations on a computer.

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[1]Test runs with the Carmonette simulation require 2 minutes of computer time to simulate 1 minute of battle in a single replication (Adams, 1961, p. 35).

The analytic model approach has a number of obvious advantages, both in its own right and as a powerful supplement to Monte Carlo simulations. Although they are most difficult for nontechnical personnel to understand, when this disadvantage is overcome, they are usually simpler to use and both the time and financial resources for their utilization are usually markedly reduced. They are very efficient in conducting sensitivity analyses to examine the effects of errors in input data and assumptions about the combat process, and are efficient in making excursions from and interpolations between analyses performed with the more complex Monte Carlo simulations. Analytic models provide an ease in interpreting the results since the dynamics of the combat process are contained in readily examined equations. That is, one can develop an understanding of the cause-effect relationships between input parameters and the combat results. Finally, analytic structures are usually more general, thus facilitating more generalized use of the models across different combat organization levels and equipment.

It is for these reasons, and recognition of them by military analysts and DOD decision makers, that some research effort has been devoted to the development of analytic models of different defense processes. In this paper we will describe recent work that has been performed in the development and application of an analytic model of battalion-level ground combat activities to supplement detailed Monte Carlo simulations such as the IUA, DYNTACS, and Carmonette.[1] Analytic models to describe ground combat processes have been developed in the past but, because of a number of critical deficiencies, have rarely been used in defense planning studies. The most prominent of these are the Lanchester theories and the theory of stochastic duels. These are both well documented in the literature, primarily in *Operations Research* and the *Naval Research Logistics Quarterly*. The research reported in this paper is, in a sense, a blending of these theories.

The following section of the paper describes the overall mathematical structure of the analytic model and the structure and variables included in the mathematical descriptions of the basic events and activities contained in the model. Section 3.0 presents comparisons of the analytic model predictions with those of the IUA Monte Carlo simulation results over a set of combat scenarios. The results and insights obtained when the model was used by the Army in context of some recent

[1] An analogous analytic model development project was presented at the Twenty-fourth Military Operations Research Symposium and will be published in the forthcoming issue of the *Journal for Defense Analysis*. The analytic model, which describes the engagement between an advanced air defense gun system and a high-performance aircraft, was favorably compared to a Monte Carlo simulation of the same process, which, in turn, was favorably tested against firing data of a Vulcan air defense gun system (Bonder and Farrell, in press).

tank and antitank weapons systems studies are described in Section 4.0. Section 5.0 contains some theoretical research results on the process of allocating weapons to targets, the effect of maneuver in combat, and the significance of terrain modeling in predicting results of combat engagements--all of which were obtained by analysis of simplified forms of the general analytic model.

2.0 MATHEMATICAL STRUCTURE OF THE ANALYTIC COMBAT MODEL

In a broad sense the primary objective of the research was the development of analytic structures that could be used to predict the *results* or an artificial history of combat. Essentially, this would be a trajectory or trace of time, space, casualties, and resources expended for both forces.[1] Ideally, there exists some functional relationship between these results of battle and the initial number of forces, types and capabilities of the weapons systems, the doctrine of employment, and the environment. Thus, we would like to specify the function f shown below:

$$\begin{pmatrix}\text{Results}\\ \text{of}\\ \text{Battle}\end{pmatrix} = f\left\{\begin{array}{l}\text{Numbers of Forces}\\ \text{Types of Weapon Systems}\\ \text{Weapon Capabilities}\\ \text{Doctrine of Employment (Tactics,}\\ \quad\text{Organization)}\\ \text{Environment}\end{array}\right.$$

Unfortunately, we don't know how to hypothesize such a function directly nor is there sufficient data to develop it empirically. Because of this, we attempt to approximate what happens in a small period of time during the battle. That is, for each side, we hypothesize that in a short period of time

(a) locations change due to tactical movement,

(b) weapon systems are attrited by enemy activity,

(c) resources are expended, and

(d) personnel become casualties due to enemy activity.

For purposes of this discussion, we have neglected the possibilities of arrivals and resupply during the small interval of time which can readily be included.

Let us concentrate on the loss of weapon systems and personnel. It is assumed that, if we know the state of the battle at the beginning of the small interval, we can predict the *rate* at which weapons systems and personnel are attrited during this small interval.[2] It is because of this rate focus that the mathematical structure we employ to model the combat activity is that of differential equations.

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[1] It is important to recognize that what is being developed is a descriptive theory of combat activities and not a normative one which specifies an optimum force structure, although some optimization methods have been examined.

[2] This essentially is the concept of measurable attrition rates formulated by F. W. Lanchester (1916).

For convenience, we assign names to the numbers of different groups of systems in each force. Let

m_i - the number of surviving Blue units of the i^{th} group ($i = 1, 2, \ldots, I$),

n_j = the number of surviving Red units of the j^{th} group ($j = 1, 2, \ldots, J$).

Different groups are determined by their ability to attrit weapons systems of an opposing group. Therefore, a missile weapon system and a rapid-fire machine gun form different groups since the rate at which they can attrit targets of an opposing group are different. Additionally, similar weapon system types can form different groups if they are at different ranges to the target and this range difference affects their ability to attrit it. Thus, a tank platoon at 1,000 meters to the target forms a different group than another tank platoon at 3,000 meters from it.

We assume that

(a) the rate of loss of units in the j^{th} Red group due to the i^{th} Blue group is proportional to the number of units in the i^{th} Blue group with a proportionality factor called the *attrition coefficient*, and

(b) the rate of loss of units in the j^{th} Red group *in total* is the sum of the rates of losses due to different i^{th} Blue groups.

Mathematically, these assumptions take the form of the following coupled sets of variable-coefficient differential equations to describe heterogeneous-force battles:[1]

$$\frac{dn_j}{dt} = -\sum_i A_{ij}(r)m_i \qquad \text{for } j = 1, 2, \ldots, J, \qquad [1]$$

$$\frac{dm_i}{dt} = -\sum_j B_{ji}(r)n_j \qquad \text{for } i = 1, 2, \ldots, I, \qquad [2]$$

[1]Battles in which at least one of the forces has more than one group.

where

$A_{ij}(r)$ = the utilized per system effectiveness of systems in the i^{th} Blue group against the j^{th} Red target group at range r. This is called the Blue attrition coefficient.

$B_{ji}(r)$ = the utilized per system effectiveness of systems in the j^{th} Red group against the i^{th} Blue target group at range r. This is called the Red attrition coefficient.

Although the variable r is used to designate the range between the firing weapon group and the target group, it should be noted that, in application of the model, actual time trajectories and positions of each group are considered. Additionally, although not explicitly shown, resources expended are included in the development of the A_{ij}, and can be determined directly from the model.

It is noted that this formulation is a deterministic one which treats the numbers of surviving forces (m_i and n_j) as continuous variables, while clearly the actual battle activity is a random phonomena and m_i and n_j are integer-valued variables. Although many probabilistic arguments are contained in this formulation (as will be seen later), the output of the model is a deterministic trajectory of the surviving numbers of forces. The reasons for this deterministic formulation, instead of a stochastic one of the same process, will be discussed briefly later in the paper.[1]

The attrition coefficients (A_{ij} and B_{ji}) are, as one would expect, complex functions of the weapon capabilities, target characteristics, distribution of the targets, allocation procedures for assigning weapons to targets, intelligence, etc. The model attempts to reflect these complexities by partitioning the total attrition process into four distinct ones:

(1) the effectiveness of weapons systems while firing on live targets,

(2) the allocation procedure of assigning weapons to targets,

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[1] Research done on comparing the deterministic and stochastic formulations for the homogeneous-force case (only one force group on each side) indicates that the deterministic formulations are reasonably good approximations to the expected number of survivors if there is a small probability that either side is annihilated. Additionally, it is noted that in many defense studies that employ Monte Carlo simulations, typically only the expected results are considered in the decision-making process.

(3) the inefficiency of fire when other than live targets are engaged, and

(4) the effect of terrain on limiting the firing activity due to loss of acquisition capability and on mobility of the systems.

The latter is discussed later in the paper in the section which describes the computerized solution procedure used by the Office, Assistant Vice Chief of Staff.

The first three effects are included in the attrition coefficient as

$$A_{ij}(r) = \alpha_{ij}(r)e_{ij}(r)I_{ij}(r) \tag{3}$$

$$B_{ji}(r) = \beta_{ji}(r)h_{ji}(r)K_{ji}(r) \ , \tag{4}$$

where

$\alpha_{ij}(r)$ = *the attrition rate.* The rate at which an individual system in the i^{th} Blue group destroys live j^{th}-group Red targets at range r when it is firing at them.

$e_{ij}(r)$ = *the allocation factor.* The proportion of the i^{th} Blue group systems assigned to fire on the j^{th}-group Red targets which are at range r.

$I_{ij}(r)$ = *the intelligence factor.* The proportion of the i^{th} group firing Blue weapons allocated to the j^{th} Red group which are actually engaging live j^{th}-group Red targets at range r.

Similar definitions exist for the components of the Red attrition coefficient, B_{ji}. Methods developed to predict these components of the model are described in Sections 2.1-2.3.

2.1 The Attrition Rate

Basic to the differential model or theory of combat is the attrition rate, which is the rate at which a weapon system can destroy live targets when it is firing at them. In the classical Lanchester theories, the attrition rate has been assumed constant or state-dependent (dependent on the numbers of surviving Red and Blue forces). The ability to obtain, other than by hindsight, a satisfactory estimate of the attrition rate for future engagments has limited the use of classical Lanchester theories for planning.

The concept of the attrition rate formulated in this research program is described in the Appendix to this paper. Simply, it is assumed to be dependent on a multitude of physical parameters of a weapon system which describe its capabilities in such areas as acquisition, firing accuracy, delivery rate, and warhead lethality. This dependency gives rise to two distinct variations in the attrition rate--variation with range to the target and chance variation at any specific range.[1] A mathematical structure of heterogeneous-force combat which includes the range and chance variations explicitly cannot be analytically solved with existing mathematical techniques. It is for this reason that we have suppressed the explicit chance variation and use essentially average attrition rates. This leads directly to the combat formulation given by equations 1 and 2 (see page 8). In this formulation we can consider the range variation of the attrition rate explicitly and somewhat independently of the chance variation at each specific range to the target.

Based on some logical and mathematical renewal theory[2] arguments, it has been shown that the appropriate average value of the attrition rate to use (for a specific range) with equations 1 and 2 is

$$\alpha_{ij}(\text{at range } r) \stackrel{d}{=} \frac{1}{E[T_{ij}|r]}, \qquad (5)$$

where

$E[T_{ij}|r]$ = the expected time for a single Blue system of the i^{th} group to destroy a passive j^{th}-group Red target, given the target is at range r.

This definition for an average value of the attrition rate at range r is equivalent to the harmonic mean of the attrition rate when it is viewed as a random variable at range r. This definition also leads naturally to defining the range variation of the attrition rate as the variation in the reciprocal of $E[T_{ij}|r]$ as the range to the target changes. This range variation is called the *attrition-rate function* and is denoted by $\alpha_{ij}(r)$, as used in equation 3. Explicit continuous mathematical attrition-rate functions are used in some of the theoretical studies (see Section 5.0) where closed-form mathematical solutions are derived and

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[1]For clarity of discussion, variations in the attrition rate due to changes in target posture, environmental effect, etc. which are inluded in the model are not presented in this section.

[2]The interested reader is referred to Parzen (1962) or Feller (1950) for a discussion of renewal theory and, in general, the theory of stochastic processes.

in some of the simpler computational forms of the model. The computational form of the model used in the comparisons with Monte Carlo simulations (Section 3.0) and study applications (Section 4.0) compute and use the attrition rate directly at discrete ranges.

Based on the above discussions, research on attrition rates focused primarily on the development of *time-to-kill* probability distributions and their expected values for a spectrum of weapon systems. These developments rely heavily on some mathematical renewal theory arguments to model the component processes (acquisition, firing, accuracy, lethality) which lead to destruction of a target, the fundamental renewal event. The mathematical structures are beyond the scope of this paper but can be found in (Bonder and Farrell, 1970). Essentially, what is done is to take part of the physical process of the duel that is basic to the Monte Carlo simulations and model the dynamics of this process mathematically. The distributions and expected values of the time-to-kill random variable explicitly include the number of rounds expended to achieve the kill. Thus, the amount of ammunition resources expended can be obtained directly for a specific combat activity.

To ensure that the attrition rates developed are general, a taxonomy of weapons systems that is not dependent on physical hardware characteristics (such as caliber) was developed. This taxonomy is shown in Figure 2 and reflects characteristics of weapons systems that would affect the methods used in predicting the attrition rates. For example, methods used to predict attrition rates for indirect-fire systems with projectiles having a lethal area would be appreciably different than direct-fire systems, which require that the projectile impact upon the target to produce damage. The effect of firing doctrine on the procedures used to predict the attrition rates is also very significant. For example, an attrition-rate model to describe single-shot firings with the same aim point for each round in the sequence (doctrine 1-A) could reasonably consider that the hit probability and the time to fire each round in the sequence were identical. However, if an adjustment based on the result of the immediately preceding round (doctrine 1-B) is made on each round in the sequence, then the attrition-rate model should consider different hit probabilities and firing times for the condition of a hit or a miss on the immediately preceding round. Adjustments made on a complete past history of the sequence of firings (doctrine 1-C) would require modeling that considered different parameters for every round in the sequence. It is felt that the taxonomy shown in Figure 3 is sufficiently general to describe a broad spectrum of existing or conceptualized weapon systems.

Methods have been developed to date that allow the prediction of attrition rates for many of the weapon systems shown in the taxonomy. For example, a completely general time-to-kill probability distribution

LETHALITY MECHANISM:

1. IMPACT

2. AREA

FIRE DOCTRINE:

1. REPEATED SINGLE SHOT:

   A) WITHOUT FEEDBACK CONTROL OF AIM POINT

   B) WITH FEEDBACK ON IMMEDIATELY PRECEDING ROUND (MARKOV FIRE)

   C) WITH COMPLEX FEEDBACK

2. BURST FIRE:

   A) WITHOUT AIM CHANGE OR DRIFT IN OR BETWEEN BURSTS

   B) WITH AIM DRIFT IN BURSTS, AIM REFIXED TO ORIGINAL AIM POINT FOR EACH BURST

   C) WITH AIM DRIFT, RE-AIM BETWEEN BURSTS

3. MULTIPLE TUBE FIRING: FEEDBACK SITUATIONS (IA, B, C)

   A) SALVO OR VOLLEY

4. MIXED MODE FIRING:

   A) ADJUSTMENT FOLLOWED BY MULTIPLE TUBE FIRE

   B) ADJUSTMENT FOLLOWED BY BURST FIRE

Figure 2 Weapon System Classification for the Development of Attrition Rates for Markov fire systems has been developed.[1] Weapon system factors explicitly included in the distribution are shown in Figure 3. Methods of predicting these factors from basic hardware considerations are well known. The time factors are usually considered as input parameters (constants) in the distribution but can themselves be random variables with associated probability distributions. It is important to note that acquisition is considered serially with firing and destruction in this distribution. That is, a target is acquired, fired upon, destroyed, then a new target is acquired, fired upon, etc. The mothod of including a parallel acquisition process (targets acquired while firing is in process) is described in Section 2.4.

A means of predicting the attrition rate for indirect-fire systems that employ projectiles with area lethality mechanisms has been developed. The method considers a weapon system which, perhaps not knowing the exact location of targets, fires indirectly into an area with a projectile that delivers damage-producing effects over part of the area. The weapons systems considered may fire multiple volleys at the target, where a volley is a number of rounds fired from a group of identical weapons systems. A multivolley target coverage methodology[2] has been developed and extended to determine the attrition rate as a function of relevant weapon system and target parameters. The parameters included in the method are shown in Figure 4. As one would expect, the attrition rate for this type attrition process is also functionally dependent on the number of surviving targets. Each of these parameters can be predicted from basic hardware characteristics of weapons systems and targets.

2.2 The Allocation Factor

As noted earlier, the allocation factor is the proportion of the i^{th} Blue group systems assigned to fire on j^{th}-group Red targets. This is included since only those systems directing their fire (or other lethal effects) on the j^{th} group or its area are likely to cause attrition of the target. The allocation factor may be input by military judgment reflecting the assignment strategies deemed most appropriate to the tactical situation. This factor may be input directly or determined from a priority or target worth scheme.

In addition to the use of military judgment to assign weapon groups to target groups (the procedure employed in the model currently in use by the Army), our research results on allocation strategies (described

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[1] Markov fire is defined as a firing doctrine in which adjustment is made on each round fired based on the results of the immediately preceding round.

[2] Usually the target coverage problem is used to denote the one-shot problem.

TIME TO ACQUIRE A TARGET

TIME TO FIRE THE FIRST ROUND

TIME TO FIRE A ROUND FOLLOWING A HIT

TIME TO FIRE A ROUND FOLLOWING A MISS

PROJECTILE FLIGHT TIME

PROBABILITY OF A HIT ON FIRST ROUND

PROBABILITY OF A HIT ON A ROUND FOLLOWING A HIT

PROBABILITY OF A HIT ON A ROUND FOLLOWING A MISS

PROBABILITY OF DESTROYING A TARGET GIVEN IT IS HIT

PROBABILITY OF DESTROYING A TARGET GIVEN IT IS MISSED

FIGURE 3 FACTORS INCLUDED IN ATTRITION RATE FOR DIRECT MARKOV FIRE WEAPON SYSTEMS

WEAPON AIMING AND BALLISTIC ERRORS

TARGET LOCATION ERRORS

WEAPON FIRING RATE

VOLLEY DAMAGE-PATTERN RADIUS

TARGET DISTRIBUTION

TARGET RADIUS

TARGET POSTURE

PROBABILITY THAT THE TARGET IS DESTROYED GIVEN
IT IS COVERED BY DAMAGE PATTERN

FIGURE 4 FACTORS CONSIDERED IN ATTRITION RATE FOR INDIRECT, AREA-FIRE WEAPONS in Section 5.1) have given rise to an approximate optimal[1] priority ordering rule which is used in some simpler versions of the model. The rule is

"Blue weapon group i should engage live Red target group K if the product

$$\alpha_{iK}\beta_{Ki} > \alpha_{ij}\beta_{ji} \qquad \text{for all } j$$

and Red weapon group j should engage live Blue target group K if the product

$$\beta_{jK}\alpha_{Kj} > \beta_{ji}\alpha_{ij} \qquad \text{for all } i."$$

This rule is used over all eligible targets, which consist of those targets within range which are not externally prohibited.[2] If all eligible target groups are unable to return fire, then all of the above products will be zero. In this case, Blue group i is assigned to fire on that target group j for which α_{ij} is maximum and an analogous rule is used for assignment of a Red weapon group.

2.3 *The Intelligence Factor*

As noted earlier, the intelligence factor is the proportion of the i^{th} group firing Blue weapons allocated to the j^{th} Red group which are actually engaging live j^{th}-group Red targets. This factor is included to consider the loss in efficiency (effectiveness) of a firing weapon when it is firing on either targets already attrited or on areas that are void of targets. Our research in this area suggests that the intelligence factor should be predicted as

$$I_{ij}(r) = \frac{p_L\bar{T}_L}{p_L\bar{T}_L + p_D\bar{T}_D + p_V\bar{T}_V}, \tag{6}$$

where

p_L = the probability of firing on a live target,

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[1]Optimal with respect to linear end of battle measures such as the difference (Blue minus Red) in survivors.

[2]Externally prohibited targets for a weapon group are those for which the attrition rate is zero, e.g., a rifle against a tank target.

p_D = the probability of firing on a dead target,

p_V = the probability of firing on a void area,

$\bar{T}_L$ = the expected or average time to fire on a live target before switching fire,

$\bar{T}_D$ = the expected or average time to fire on a dead target before switching fire, and

$\bar{T}_V$ = the expected or average time to fire on a void area before switching fire.

At the present time, only the parameter $\bar{T}_L$, which is equal to the expected time to defeat a live target,[1] can be predicted as input. Accordingly, this factor has bben set to unity (perfect intelligence) in all application studies.

2.4 Computation and Terrain Interactions

As implied throughout this paper, there exist a number of operating versions of the differential ground combat analytic models varying in degrees of complexity and simplifying assumptions. At one end of the continuum are simplified models (homogeneous forces, constant attrition-coefficient heterogeneous forces, no terrain effects, only terrain LOS, etc.) which succumb to closed-form mathematical solution techniques. These are used principally for theoretical research. At the other end of the continuum are more realistic complex versions that include more terrain effects and larger dimensionality in the input data (i.e., kill probabilities, which depend on the target type, cover status, movement status, aspect angle, etc.). These models usually require the use of numerical solution procedures and are used principally for anlaysis in weapon system studies. A modularized computer program has been developed for ease in applying the methodology to a spectrum of ground combat situations and for the conduct of sensitivity analyses.[2] In this section we shall briefly summarize the computational procedure employed and the way that terrain effects are included in one of the initial versions of the model used by the Directorate, Weapon Systems Analysis, Office, Assistant Vice Chief of Staff.

In the computational program, the basic differential equations are approximated by the difference equations

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[1]That is, $\bar{T}_L$ is equivalent to what was previously referred to as the expected time to kill a target.

[2]The program is described in (VRI, 1970).

$$m_i(t + \Delta t) = \max \left\{ 0,\ m_i(t) - \sum_{j=1}^{J} B_{ji}(t) n_j(t) \Delta t \right\}$$

$$\text{for } i = 1, 2, \ldots, I$$

$$n_j(t + \Delta t) = \max \left\{ 0,\ n_j(t) - \sum_{i=1}^{I} A_{ij}(t) m_i(t) \Delta t \right\}$$

$$\text{for } j = 1, 2, \ldots, J ,$$

where Δt is the computational time step. A 10-second time step is usually used. In applications of the model to battalion-level task force engagements with weapon systems currently under study it was observed that smaller time steps did not alter the solution, while larger steps led to significant errors (overkills, failure to switch assignments, etc.). Clearly, the time step must be appropriately selected depending on the capabilities of the systems involved and the scenario activity.

The correspondence between battle time and the spacial distribution of forces during the battle is obtained from knowledge of predetermined movement patterns of all Red and Blue groups which are input to the model. These movement patterns are obtained from a terrain preprocessor developed for the IUA Monte Carlo simulation. Routes of advance and movement tactics (sections leapfrog, sections advance and provide covering fire, etc.) are input to the preprocessor, which then considers the terrain characteristics (soil type, roughness, grade, etc.) along the routes and maneuver capabilities of the weapon systems (speeds, accelerations, etc.) to generate the time-sequenced movement patterns.

The effects of terrain which limit the firing activity due to loss of acquisition capability are also included in this model. For this purpose the terrain is currently incorporated in the model as if it were a map with digitized properties of concealment, cover (line-of-sight), etc. associated with each or pairs of locations. The model considers these terrain effects (which are also obtained from the IUA preprocessor) in conjunction with an acquisition submodel which considers that the acquisition process occurs *in parallel* with the firing and movement processes.[1] Since the analytic model considers *groups* of weapon systems, the parallel

[1] The reader is reminded that serial acquisition can be included in the attrition-rate submodel.

acquisition submodel is designed to determine the percentage of observers in a group who have detected a target in an opposing group. Detections occur due to either visual stimuli of nonfiring targets or pinpointing the flash of a firing target. The terrain effects of visibility (fully exposed, partially exposed, not exposed) and line-of-sight (exists, does not exist) are interfaced with the visual detection and pinpointing capabilities by the following computational formulas:

$\bar{F}_{ij}(t + \Delta t)$ = percentage of i^{th}-group survivors who have *failed* to detect a target in j^{th} target group at time $(t + \Delta t)$

$$= \begin{cases} 1 & \text{if no LOS} \\ \bar{F}_{ij}(t)\bar{V}_{ij}(t, t + \Delta t)\bar{P}_{ij}(t, t + \Delta t) & \text{if LOS exists,} \end{cases} \quad (6)$$

where

$\bar{V}_{ij}(t, t + \Delta t)$ = percentage of i^{th}-group survivors who have *failed* to visually detect a target in j^{th} target group in the interval $(t, t + \Delta t)$

$$= \begin{cases} 1 & \text{if visibility does not exist} \\ e^{-\lambda_{ij}(t+\Delta t)\cdot\Delta t\cdot n_j(t)} & \text{if visibility exists} \end{cases} \quad (7)$$

$\bar{P}_{ij}(t, t + \Delta t)$ = percentage of i^{th} group surviving who have *failed* to pinpoint a target in j^{th} target group in the interval $(t, t + \Delta t)$

$$= \begin{cases} 1 & \text{if no LOS} \\ (1 - p_{ij})^{\frac{\rho_{ij}(t,t+\Delta t)}{n_j(t)} n_j(t)} & \text{if LOS exists} \end{cases} \quad (8)$$

and

$\lambda_{ij}(t)$ = the detection rate at time t, which is a function of range between the i^{th} and j^{th} groups and exposure;

$n_j(t)$ = the number of surviving j^{th}-group targets at time t;

p_{ij} = probability of i^{th}-type observer pinpointing a j^{th}-type weapon when it fires *one round*. This is considered dependent on range between i^{th} and j^{th} groups, the weapon type, observer type, and movement status;

$\rho_{ij}(t, t + \Delta t)$ = the number of rounds fired by the j^{th} target group in the interval $(t, t + \Delta t)$.

The formulas assume a Poisson visual detection process when visibility exists and a geometric pinpointing process when LOS exists. They assume no back correlations on losses in the firing and enemy forces.

The percentage of i^{th}-group survivors *who have detected* a target in the j^{th} target group at time $(t + \Delta t)$, $F_{ij}(t + \Delta t)$, is obtained directly from $\bar{F}_{ij}$ $(t + \Delta t)$ for all j. Using this information, and an input military worth on target priority rule, an appropriate part of the i^{th}-group survivors are assigned to fire on different target groups.

The general flow of calculations in the numerical solution procedure is given in Figure 5. Details regarding data storage requirements, running time, etc. are contained in (VRI, 1970). It is of interest to note that computation time is on the order of 1 minute for 15 minutes of combat time in a battalion task force battle with about 100 weapon systems (tanks, personnel carriers, antitank missiles, etc.) aggregated in approximately 40 weapon groups. This ratio of 15:1 combat-to-computer time was obtained on The University of Michigan 360-67 time-sharing system, which includes time associated with the time-sharing overhead. It is faster in some modes on the Pentagon's computer, which is not time-shared.

Output of this version of the model at each time step is a status listing of all weapon groups which are involved in firing events (firer or target). The listing contains the group numbers, their locations, range separations, movement status, visibility status, percentage of the firing group allocated, round-type used, attrition rate, and amount of attrition. A summary output is also provided each 10-second time step. This summary lists the cumulative number of losses of each weapon *type* by the *types* in the opposing force which caused the attrition.

MODULE SETUP
1. Read weapon system data and command 2. Modify data as commanded 3. Go to MODULE UPDATE for new time step 4. If scenario finished, end combat simulation 5. Go to MODULE ATTRIT 6. Go to MODULE OUTPUT

MODULE UPDATE
1. Read new locations, covers, concealments, etc. 2. Compute current acquisitions 3. Compute current survivors 4. Go to MODULE SETUP, Step 4.

MODULE ATTRIT
1. Consider next group 2. Allocate group fire 3. Compute attrition rates, coefficients, and losses 4. If all groups have been considered, go to MODULE SETUP, Step 6 5. Otherwise, go to MODULE ATTRIT, Step 1

MODULE OUTPUT
1. Display requested outputs for this time step 2. Go to MODULE SETUP, Step 3

Figure 5 Computational Flow Chart for the Differential Model

3.0 COMPARISON OF ANALYTIC AND MONTE CARLO SIMULATION MODEL RESULTS

The previous section described the underlying differential equation structure of the analytic model of combat, procedures used to predict inputs to the structure, and the numerical solution procedure initially implemented on the Pentagon computers. Conceptually, one may view outputs of this methodology as hypotheses or theories that need be verified against actual data, or at least compared to the results of detailed Monte Carlo simulations.

Under a follow-on contract with the Directorate, Weapon Systems Analysis, Office, Assistant Vice Chief of Staff, U.S. Army, a study was conducted to compare the combat predictions generated by the analytic model of combat to those predicted by more detailed Monte Carlo simulation methods.[1] Under this study, the computational version of the model described in the previous section was applied to a set of tactical situations used in the TATAWS-III study and the Producibility/Cost Reduction (PCR) study, which were part of the overall Main Battle Tank (MBT-70) study program. Some of the results of these comparisons are presented in this section of the paper. These studies had been, or were in the process of being, conducted using the Individual Unit Action (IUA) Monte Carlo simulation of ground combat.

3.1 TATAWS-III Comparisons

Figure 6 depicts one of the tactical plans considered in the Main Battle Tank program to which the analytic model of combat was applied. The tactical plan shown is a Blue attack engagement against a fixed Red defensive position. The attack is conducted along three major axes with four individual routes of advance per axis. Each route consists of individual main battle tank candidates and/or supporting armored personnel carriers equipped with rapid-fire weapon systems. In addition to these maneuver units of main battle tanks and personnel carriers, the Blue attack force had long-range missiles and short-range missiles, as shown in the figure. The defending force is comprised of tanks, missiles, and armored personnel carriers equipped with rapid-fire weapons systems.

The Monte Carlo simulation of this engagement considered the movement, acquisition, and combat activity (duels) of each and every unit in the battle.[2] Maneuver, in terms of attack speed and accelerations, over different portions of the terrain were considered for each weapon based on preprocessed terrain analysis. The existence or nonexistence of line-of-sight between weapons systems for each route to all other weapons

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[1] This study was conducted by Vector Research, Inc., whose principals developed the methods described in this paper.

[2] Some of the engagements considered as many as 100 individual weapon systems.

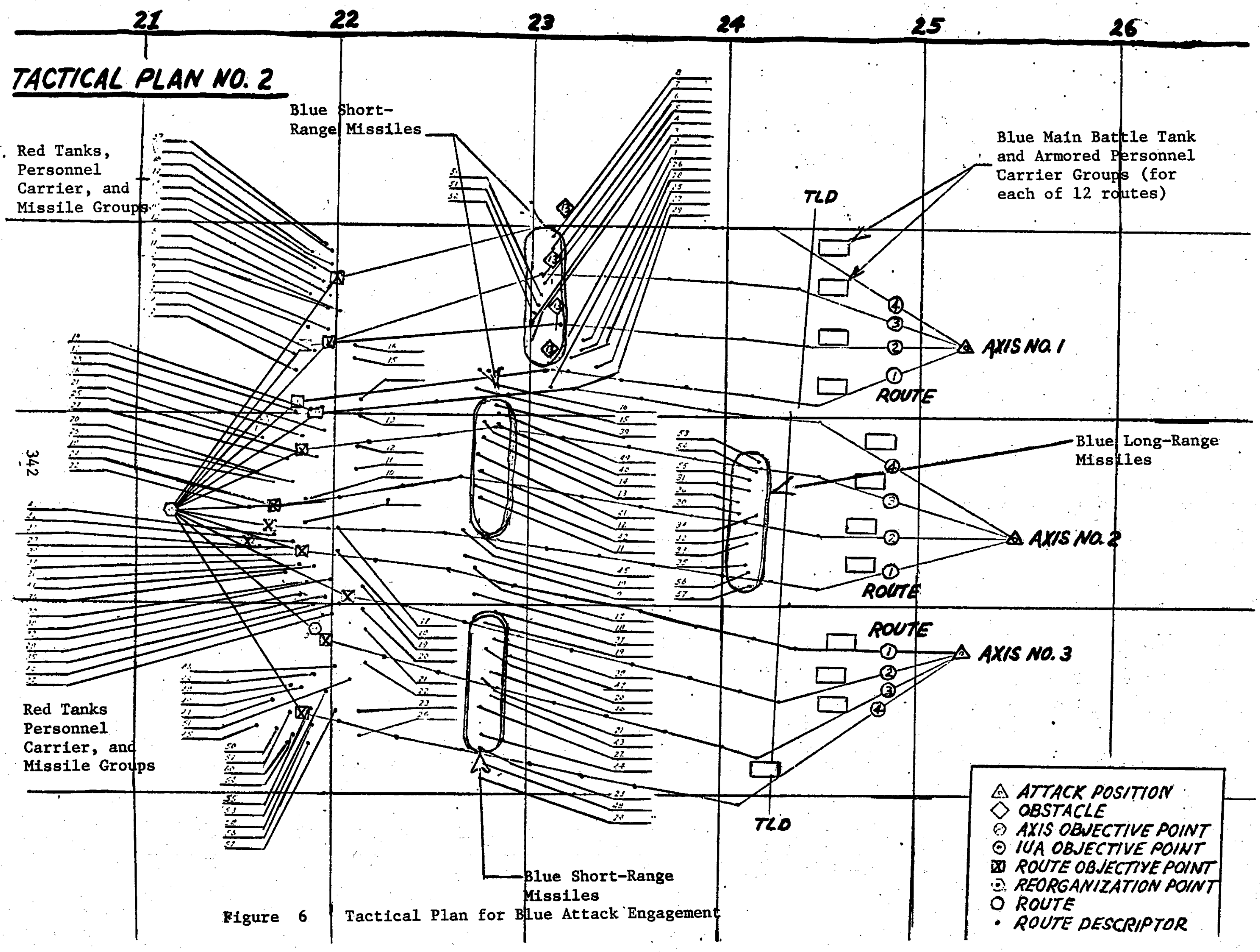

Figure 6 Tactical Plan for Blue Attack Engagement

systems was used as input. Preprogrammed target priority tables were used to specify the allocation of individual weapons to targets. A replication of the simulation consisted of moving each of the systems down their prespecified paths and evaluating, by Monte Carlo means, the acquisition and attrition processes (the fundamental duel event) for each weapon system during the course of the engagement. The engagement was replicated many times to obtain a level of statistical stability for the results.

The analytic combat model was applied to this and other TATAWS-III engagements by aggregating individual weapons systems into groups. Thus, for each route on an axis there were two separate groups of main battle tanks or armored personnel carriers. The long-range missiles were aggregated into one group and the short-range missiles were aggregated into three groups, one for each axis. The Red defensive force was aggregated by weapon type for each axis, thus producing nine Red defensive groups. Also included, but not shown in the figure, were indirect-fire artillery weapons systems for both forces.

Using the attrition-rate models discussed in Section 2.1, the attrition rates for each group on appropriate target groups were calculated using the same basic firing time, accuracy, and lethality data used in the simulation. Target acquisitions were determined with the parallel acquisition model (see Section 2.4) using the same detection rate and pinpoint probabilities used in the simulation. The allocation factors (e_{ij} and h_{ji}) employed were based on the priority tables used in the simulation. The intelligence factor was set equal to 1.0 since these effects were not considered in the simulation. Mobility and line-of-sight data from the preprocessor were considered in a deterministic manner similar to that employed in the simulation. Average speeds and line-of-sights over segments of the routes were input for each of the *aggregated* groups. Thus, a group was moved as a whole, and visibility did or did not exist to the group as as an entity. The differential equations were solved numerically using the computational procedures summarized in Section 2.4.

Using this approach, the model was applied to short-range defense and long-range attack scenarios considered in the TATAWS-III study program. With these engagement types, six separate runs involving different weapon systems and force structures were made for comparison with the simulation results. These comparisons are shown in Tables 1-3.

Table 1 presents a comparison of the results of one of the short-range defense engagements. The initial numbers of forces and the numbers of survivors at three analysis points as predicted by both Monte Carlo simulation and the analytic model are given. The analysis points are defined by the percentage of Red tank survivors: low equal to 70 percent, principal equal to 50 percent, and high approximately equal to

Table 1

COMPARISON OF SURVIVING FORCES

Run Number 7306
Short-Range Defense

Initial Numbers

16 Blue Tanks	40 Red Tanks
6 Blue Short-Range Missiles	0 Red Missiles
6 Blue APC	12 Red APC
3 Blue Long-Range Missiles	

ANALYSIS POINT	WEAPON	TATAWS SIMULATION	TIME	ANALYTIC	TIME
	Blue Tanks	13.90		15.1/13.9	
	Blue SR Missiles	5.10		6.0^{-}	
Low	Blue APC	5.93	242	6.0^{-}	240/250
	Blue LR Missiles	2.73		3.0^{-}	
(70%)	Red Tanks	28.00		30.4/24.4	
	Red Missiles	-----		-------	
	Red APC	11.70		11.0/10.6	
	Blue Tanks	12.23		12.6	
	Blue SR Missiles	4.57		6.0^{-}	
Prin-	Blue APC	5.73	263	6.0^{-}	260
cipal	Blue LR Missiles	2.27		3.0^{-}	
	Red Tanks	20.00		19.2	
(50%)	Red Missiles	-----		-------	
	Red APC	10.33		10.2	
	Blue Tanks	9.40		10.0	
	Blue SR Missiles	2.97		5.8	
High	Blue APC	5.20	327	6.0^{-}	290
	Blue LR Missiles	2.00		2.9	
(22%)	Red Tanks	8.90		7.2	
	Red Missiles	-----		-------	
	Red APC	4.27		7.0	

Table 2

COMPARISON OF SURVIVING FORCES

Run Numbers 7356, 7106
Short-Range Defenses

			LAP		PAP		HAP	
RUN NO.	WEAPON	INITIAL NO.	SIM.	ANAL.	SIM.	ANAL.	SIM.	ANAL.
7356	(Time)		(242)	(240)	(259)	(260)	(352?)	(280)
	Blue Tank	19	17.20	18.0	15.87	15.4	13.33	13.7
	Red Tank	40	28.00	30.4	20.00	17.6	8.0	8.8
7106	(Time)		(236)	(240)	(260)	(270)	(320)	(290)
	Blue Tank	27	20.13	18.27	15.1	11.6	9.37	6.7*
	Red Tank	40	28.00	26.00	20.00	19.2	11.07	15.2

*Red wins 60% of the time in the TATAWS game.

Table 3

COMPARISON OF SURVIVING FORCES

Run Numbers 7305, 7355, 7105
Long-Range Attack

			LAP		PAP		HAP	
RUN NO.	WEAPON	INITIAL NO.	SIM.	ANAL.	SIM.	ANAL.	SIM.	ANAL.
7305	(Time)		(206)	(260)	(411)	(440)	(512)	(470)
	Blue Tank	31	26.30	27.6	23.83	23.8	21.47	23.5
	Red Tank	13	9.00	9.1	7.0	7.0	2.0	1.4
7355	(Time)			(260)		(440)		(460)
	Blue Tank	37		32.6		29.2		29.2
	Red Tank	13		8.9		7.0		2.8
7105	(Time)		(415)	(340)	(477)	(480)	(610)	(540)
	Blue Tank	54	41.87	33.5	38.87	29.97	33.60	28.8
	Red Tank	13	9.0	9.0	7.0	7.0	2.0	2.4

20 percent. The times at which these analysis points are reached in each of the models also is given. Two sets of results at the low analysis point in the analytic model are shown since there was an appreciable attrition in the 240-250 time interval.

Table 2 presents the comparisons of tank survivors only at the three analysis points for the other short-range defense engagements, and Table 3 presents the comparisons of the tank survivors at the three analysis points for the three long-range attack engagements. The Monte Carlo simulation results for runs 7355 were not provided by the government for comparison. The relatively larger differences in tank survivors in runs 7105 and 7106 were attributed to the fact that the input vulnerability data for the Blue tank on the Red missile used in the simulation run was approximately twice that used in the analytic model run. This had the effect of destroying the Red missiles early in the simulation evaluation, thus eliminating their effectiveness against Blue tanks, a result obtained in the analytic model evaluations. This disparity highlighted another benefit of analytic models not mentioned in Section 1.0--their usefulness as aids in debugging simulations.

3.2 PCR Comparisons

Following the comparisons with the TATAWS-III study results, the model was applied to the six scenarios used in the PCR study--three defense and three attack engagements. These scenarios contained only tank systems in the forces. The program also was revised to accept the increased dimensionality of the input data used in the PCR version of the TATAWS-III IUA model.

Evaluations were to be made on five pure tank force structures, each to be run in the combat set of six scenarios. Because of the lack of sufficient input data for one run, only 29 evaluations and eventual comparisons with the PCR version of the IUA model were made. The results indicated favorable comparisons in approximately 60 percent of the runs and marked deviations in the remaining 40 percent. Figure 7 shows the results of six runs (1 tank force structure in the six scenarios) in which the loss ratios at the principal analysis point did not compare favorably.

An analysis was undertaken to determine the cause of these differences. Preliminary analysis of the assumptions contained in the two models and a detailed review of a single replication of the PCR version of the IUA simulation showed significant modeling differences in two areas. These were

(1) the IUA model assumed a "pop-down" effect which caused a defender to miss a firing turn after being hit or suffering a close miss. No counterpart of this effect existed in the analytic model, and

BOA-B9D		INITIAL		ANALYTIC			IUA
				Losses			
		Blue	Red	Blue	Red	Ratio	Ratio
Short Range	ATTACK	54	40	17.9	25.3	1.41	1.08
Medium Range		54	40	14.1	24.8	1.77	1.10
Long Range		54	27	7.45	15.62	2.10	0.72
Short Range	DEFENSE	46	72	30.3	39.3	1.30	2.10
Medium Range		48	72	28.1	36.2	1.29	1.95
Long Range		38	72	23.1	37.3	1.61	2.00

Figure 7 PCR Analytic and IUA Comparisons

(2) the fact that significant ganging-up of several attackers on a single defender occurred in the IUA, while a fundamental assumption of the differential combat model is that such ganging-up, if it occurs, has little effect on the results.

Analytical models of the pop-down and gang-up effects were developed. The concepts employed in developing these models can be included directly in the differential combat model; however, to preclude re-running all the PCR engagements, approximations for the pop-down and gang-up effects were applied directly to the results of the previous runs. The 60 percent of the cases which previously compared favorably were negligibly changed when the pop-down and gang-up corrections were applied. Significant changes occurred in the results of the eleven cases which had not compared favorably with the simulation output. Improvements in the results shown in Figure 7 are given in Figure 8, which depicts much more favorable comparisons.

The pop-down and gang-up corrections produced analytic model results for all 29 cases which compared very favorably with the IUA predictions of PCR pure tank results. It is of importance to note that in eight of the eleven improved runs, the change in results was due solely to the pop-down effect and in the remaining three runs, three-fourths of the change in results was due to the pop-down effect. This appears to substantiate a fundamental assumption of the differential combat model, that gang-up has little effect on the results.

The favorable comparisons between the analytic model predictions and those of the IUA simulation in 35 such tests strongly supported the hypothesis that both models were essentially describing the same combat process. This result gave credence to the model and its use in the PCR and other studies, as described in the next section of the paper.

BOA-B9D		INITIAL		ANALYTIC			IUA	POP-DOWN		
				Losses		Ratio	Ratio	Ratio	Losses	
		Blue	Red	Blue	Red				Blue	Red
ATTACK	Short Range	54	40	17.9	25.3	1.41	1.08	92	27.5	25.3
	Medium Range	54	40	14.1	24.8	1.77	1.10	1.10	22.5	24.8
	Long Range	54	27	7.45	15.62	2.10	0.72	96	16.2	15.6
DEFENSE	Short Range	46	72	30.3	39.3	1.30	2.10	2.1	17.4	36.0
	Medium Range	48	72	28.1	36.2	1.29	1.95	1.68	21.6	36.2
	Long Range	38	72	23.1	37.3	1.61	2.00	1.87	19.9	37.3

Figure 8 PCR Pop-Down Analytic and IUA Comparisons

4.0 ARMY UTILIZATION OF THE ANALYTIC MODEL

In Section 2.0 of this paper we described the mathematical structure of the analytic model for analyzing ground combat of small units and summarized the computational procedures used in numerically solving the model. In order to determine the validity and utility of the model, it was programmed against an existing simulation to determine whether both could generate comparable results. At that time, the Individual Unit Action (IUA) model, originally developed by Lockheed Corporation for the TATAWS series of tank/antitank studies, was chosen as the parent simulation for comparison purposes. The processes included in that simulation were examined in great detail and the analytical model was applied to describe those processes in an analogous manner. It is important to note that the analytic model was applied to replicate the processes, as they were described in the IUA simulation, and not as they might possibly be more realistically modeled.

This effort in developing a correspondence in model descriptions had an immediate benefit in that it led to a thorough understanding of the IUA simulation model and identification of numerous errors and deficiencies in the IUA simulation as used which were never before documented. The comparison test with both the TATAWS III and the PCR versions of the IUA simulation were presented in Section 3.0. These indicate good agreement between output results and suggest that both models essentially describe the same process.

After the comparison study, the model was transferred to the Office of the Assistant Vice Chief of Staff, the sponsoring agency, using the Department of the Army USAMSSA computer facility at the Pentagon. The model then was used to perform extensive sensitivity analyses to determine the capabilities of the model as well as to check the impact of variations in inputs, game rules, and assumptions used in the IUA simulation on results of the analysis.

Input parameters that can be changed readily in the analytical model, that is, in a matter of minutes or at most a couple of hours, include variations in the number of Red or Blue weapons, weapon types (for those weapons where characteristics are available, weapon selection routines, target priority assumptions, and other tactical rules. In addition, the model can readily test variations in weapon accuracy, round-to-round dispersion, weapon cycle time or rate of fire, target acquisition times and variations in kill lethality or kill probability.

Because of the fact that the analytical model in its currently programmed form still relies on terrain and mobility inputs developed by the IUA preprocessor program, it is more difficult to conduct sensitivity analyses on such factors as variations in attacker type, soil type, terrain roughness, concealment, fire and movement tactics, mobility characteristics, and such terrain factors as line-of-sight calculations, target size, etc.

4.1 PCR Sensitivity Analysis

The following discussions on analyses performed with the model are designed to indicate the utility of the analytical model.[1] The IUA simulation determines engagement outcome at three prescribed analysis points; generally the principal analysis point which occurs when 50 percent of the Red killed or 70 percent of Blue killed (Blue break) is chosen for comparisons. A standard set of runs includes three scenarios in which Blue is on the attack using different opening ranges and three scenarios in which Blue is on the defense using three opening ranges for the Red attacker. Results for a "standard" set of views are given in Figure 9. Analysis was then performed to determine, for example, the effect of using a less complex fire-control system which would result in increasing the dispersion by 50 percent. The comparison with a standard run also is shown in Figure 9. It is interesting that particularly in the defense situation, the poorer dispersion causes all Blue tanks to be lost before the enemy has reached this analysis point. Even in the attack, increasing the dispersion has a severe adverse effect.

In another analysis, the fixed cycle time between rounds was decreased by 50 percent, which, in effect, causes an increase in the rate of fire. In Figure 10 the results of this analysis were compared against the "standard" set. It is evident that increasing the rate of fire had the most pronounced effect in short-range attack and defense situations. It should also be noted that for the short-range attack situation, two sets of results are shown. These results illustrate variations in the results during the 10-second combat period used near the principal analysis point. It is evident that the vicinity of the analysis point attrition is very high, that is, a change from 19.7 tanks lost to 28.9 tanks lost during that 10-second interval.

Because of this large variation in attrition in the vicinity of the principal analysis point, advantage was taken of another property of deterministic models. That is, being able to represent the whole engagement as a result of a single run as compared to stochastic models, where the results have to be averaged over a number of replications. For example, in Figure 11 the results of a Blue defense situation for short and medium (Red 7) opening ranges are shown in terms of the number of Red and Blue tanks surviving at any time. Analogous results for a Blue attack situation are shown in Figure 12. In Figure 13 the results of a superior Blue attack situation shown probably would not be sufficiently sensitive to describe changes in weapon parameters. A more even situation was formed for sensitivity analyses using a reduced number of Blue tanks, as also shown in Figure 13. However, it appeared peculiar that despite a relatively small numerical superiority of Blue tanks, they were so decisive in defeating the Red tanks. Careful analysis showed that the cause for this peculiarity was a less than optimum choice of Red rounds to defeat Blue tanks on the move. A simple change in round

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[1] Actual input data used in the analyses and the results were not releasable at the time of writing this paper.

		INITIAL		STANDARD			DISPERSION INCR 50%		
				LOSSES		RATIO	LOSSES		RATIO
		BLUE	RED	BLUE	RED		BLUE	RED	
ATTACK	SHORT RANGE	54	40	11.4	21.1	1.85	19.3	22.9	1.19
ATTACK	MEDIUM RANGE	54	40	11.2	21.2	1.90	16.2	22.0	1.36
DEFENSE	SHORT RANGE	46	72	30.8	36.8	1.19	46.0	28.5	0.62
DEFENSE	MEDIUM RANGE	48	72	31.4	38.6	1.23	47.7	32.1	0.67

Figure 9

		INITIAL		STANDARD			CYCLE TIME DECR 50%		
				LOSSES		RATIO	LOSSES		RATIO
		BLUE	RED	BLUE	RED		BLUE	RED	
ATTACK	SHORT RANGE	54	40	11.4	21.1	1.85	10.70 8.65	28.9 19.7	3.65 2.25
	MEDIUM RANGE	54	40	11.2	21.2	1.90	11.1	25.6	2.30
DEFENSE	SHORT RANGE	46	72	30.8	36.8	1.19	21.1	36.2	1.7
	MEDIUM RANGE	48	72	31.4	38.6	1.23	27.4	41.2	1.50

Figure 10

BLUE DEFENSE

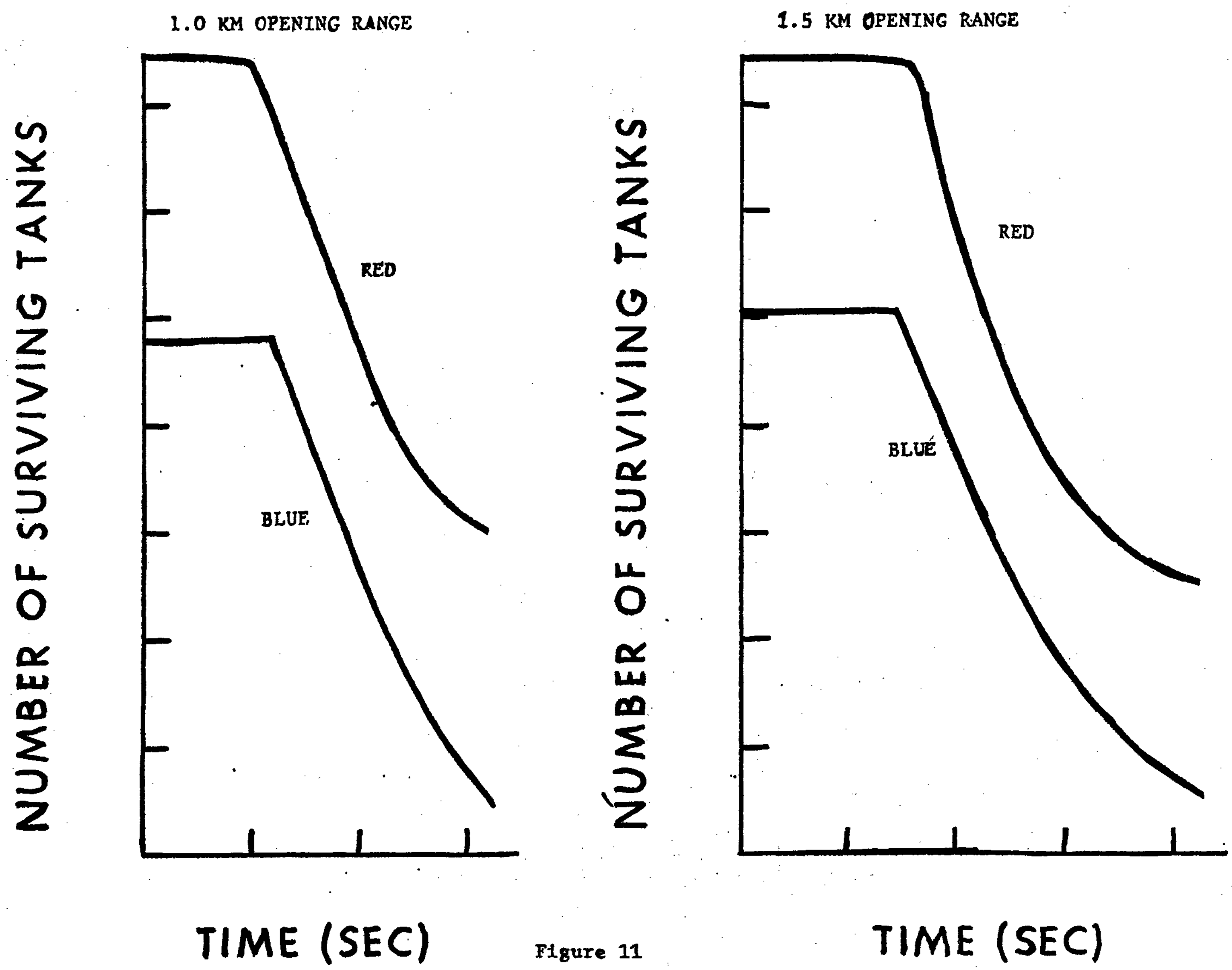


Figure 11

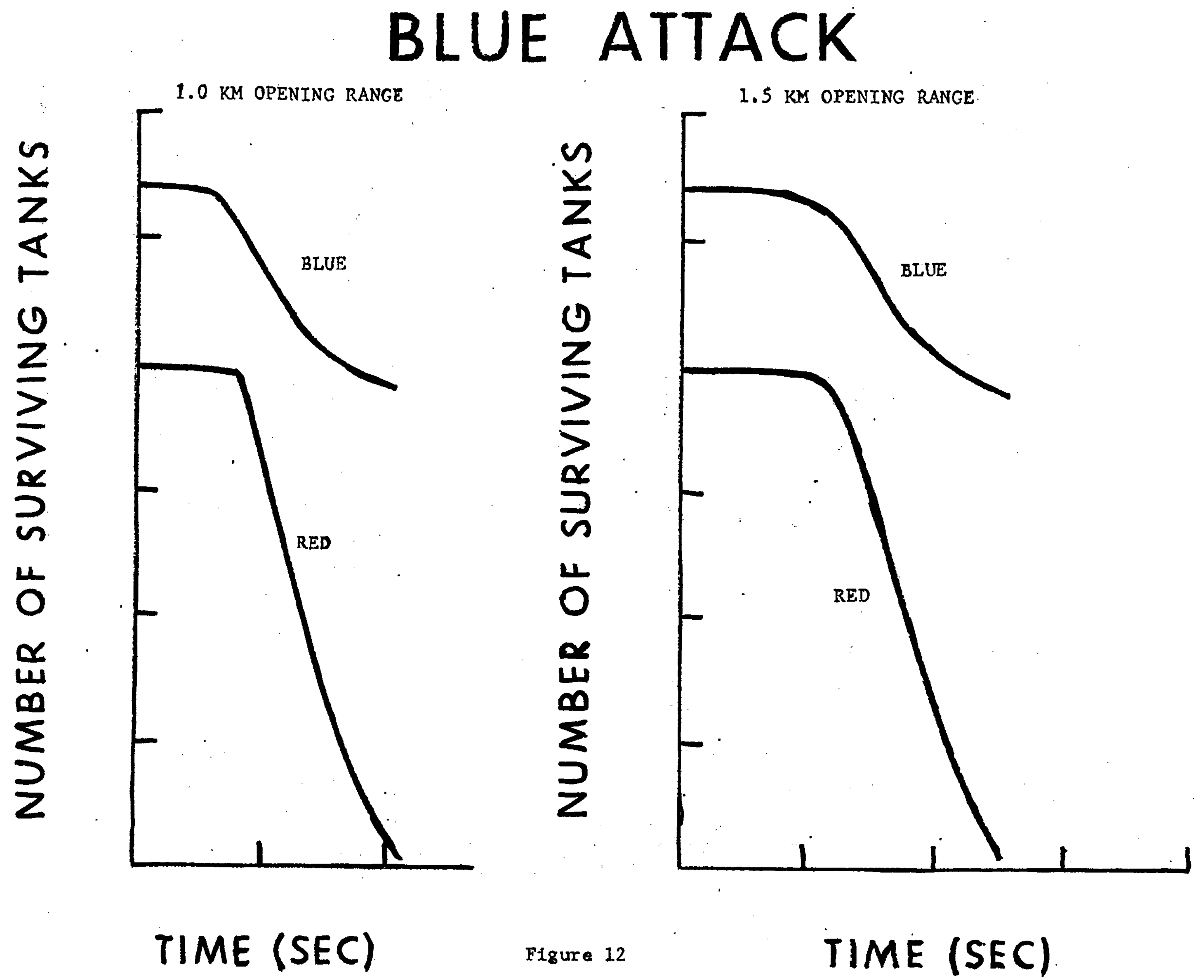

BLUE ATTACK
1.0 KM OPENING RANGE
1.5 KM OPENING RANGE
BLUE
RED
BLUE
RED
NUMBER OF SURVIVING TANKS
NUMBER OF SURVIVING TANKS
TIME (SEC)
TIME (SEC)

Figure 12

MED. RANGE BLUE ATTACK

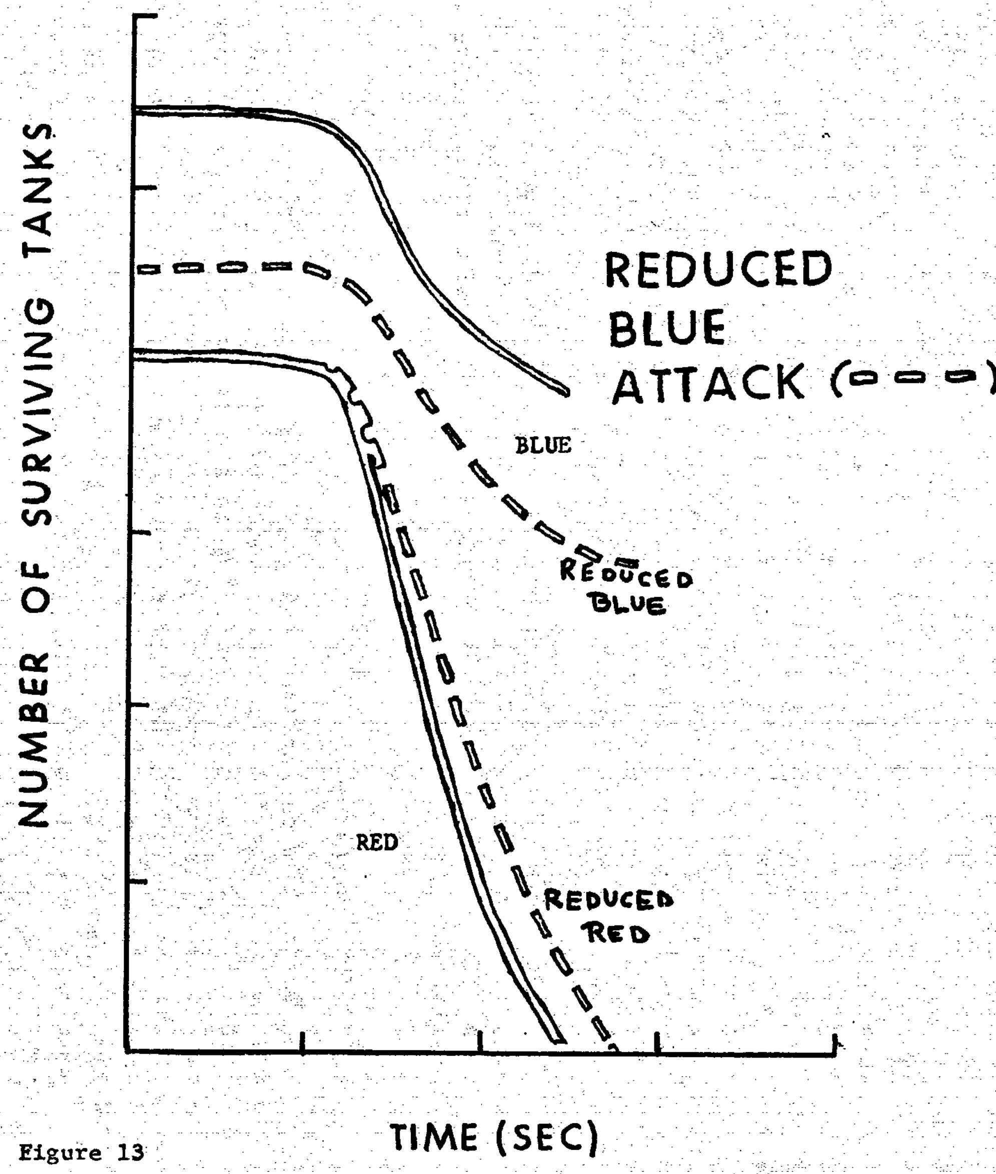


Figure 13

selection changed the outcome substantially (Figure 14). To illustrate changes in weapon characteristics, the effect of improving cycle time between rounds for a Blue attack situation is indicated in Figure 15. The standard run is in solid lines and the improvements in dotted lines. Also, the capability of an improved fire-control system which, in effect, would decrease dispersion by 30 percent is shown in Figure 16, where an original Red victory would become doubtful against the improved Blue tanks. The substitution of a current tank for the type under development, on an equal number basis, results in a more decisive defeat in a Blue short-range defense situation, as shown in Figure 17. (The standard run with the developmental tank is in solid lines.) This same short-range defense situation, even using our best developmental tank, can be severely affected when Red uses antitank missiles in an overwatch role to provide fire support for his attack (Figure 18).

The replacement of a current US tank for the US developmental tank even in a long-range defense situation, shown in Figure 19, also results in a Red expected victory as compared to a successful Blue defense with the better tank.

4.2 ATMIX Analyses

During the period that analyses such as the ones above were performed a version of the IUA simulation model was reprogrammed to analyze the effectiveness of mechanized infantry in a defense against a Red armored assault. This reprogramming required sizable resources and time to accomplish. Some time during this reprogramming effort it was decided to perform analogous changes in the analytical model in order to be able to perform parallel analyses. The changes included the introduction of new weapons data as well as changes in data formats, new algorithms for vulnerability, calculations, new rules for selecting target priorities for firings, estimates of area kill effects against personnel targets associated with crew-served wapons, variations in pinpoint probabilities depending on firing weapon signatures, the suppression effect using direct-fire weapons, visual acquisition of stationary targets of short range, and an estimate of cumulative ammunition expenditures (Figure 20). All these changes were accomplished by an analytically trained, military officer in the Office of the Assistant Vice Chief of Staff, on a part-time basis.

When the results of the IUA simulation runs were received, many internal inconsistencies became apparent. Many of these were probably due to the relatively short suspense nature of the new study. In some cases, for example, weapon sizes were entered incorrectly. The sensitivity of the results to these errors was quickly checked using the analytical model. Peculiarities in target priorities, the use of the wrong analysis point, peculiarities in long-range attack situations and other results could be checked quickly using the analytical model. Additionally, the analytical model could determine the effect of Red overwatch weapons and similar factors which could not be run in the simulation.

MED. RANGE
RED ATTACK

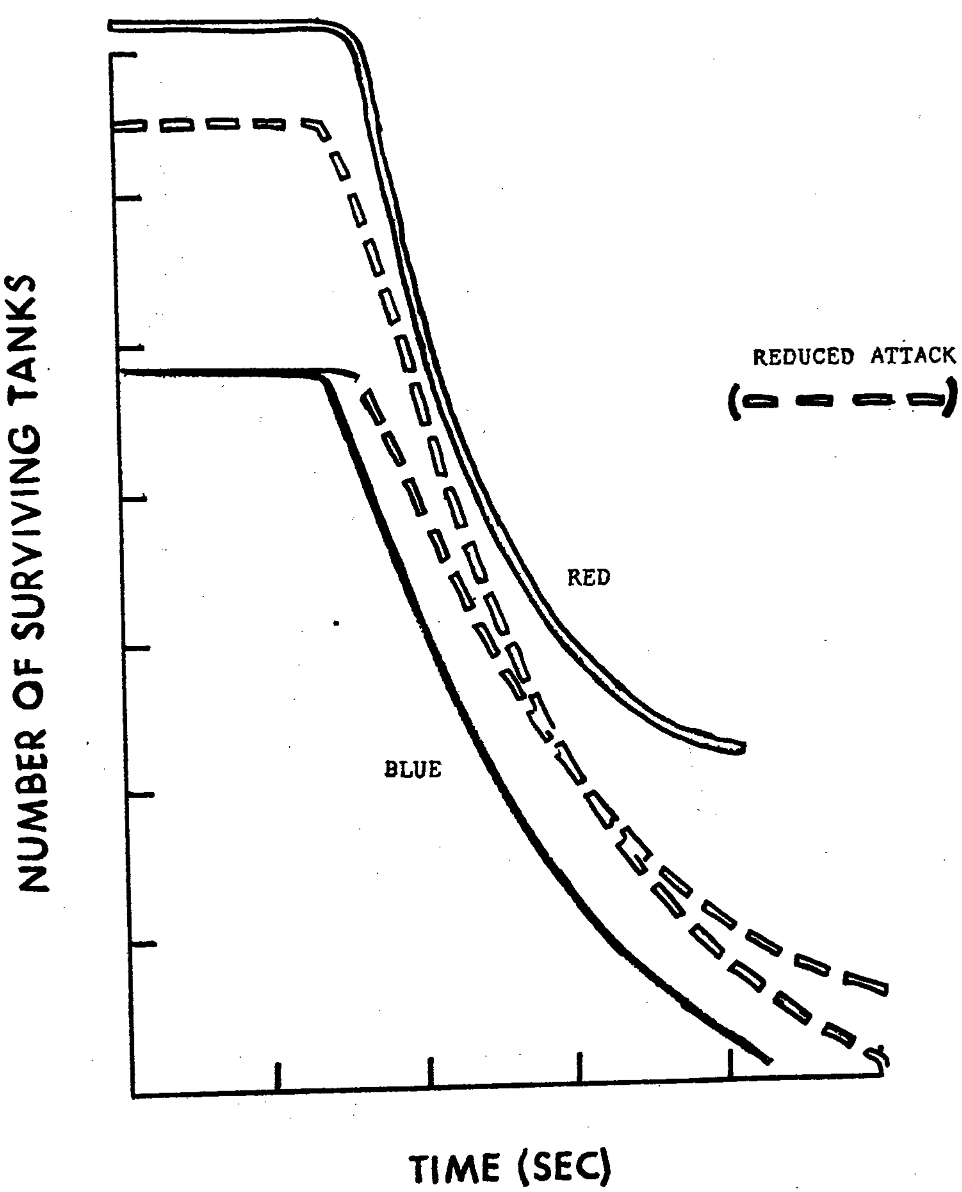
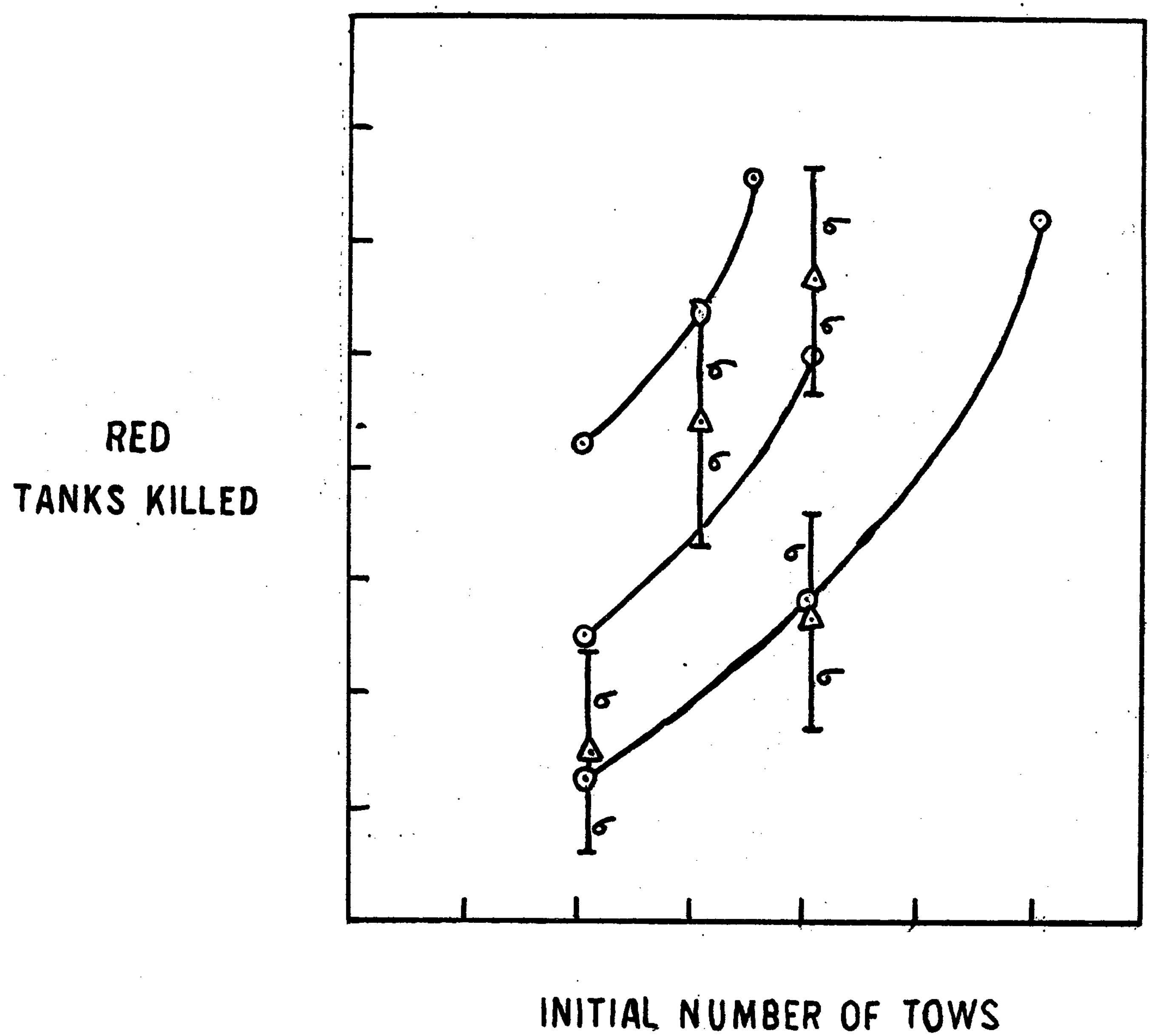


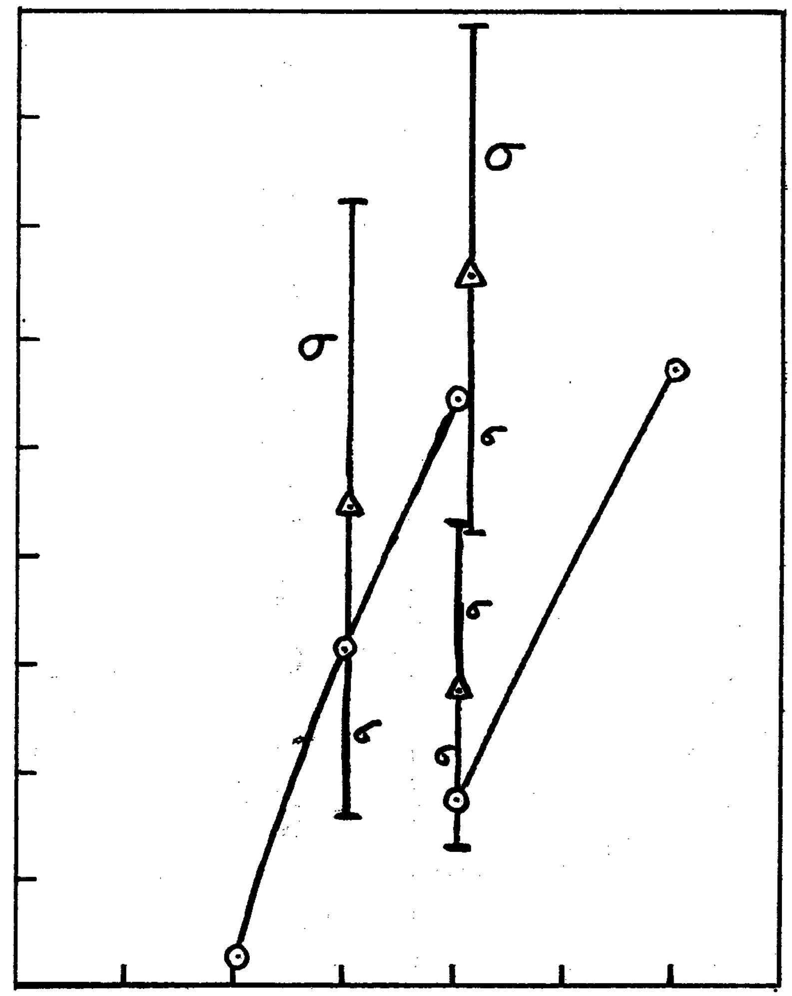
Figure 14

Figure 21



BLUE SURVIVORS VS BLUE INITIAL AT 50% RED TANKS KILLED

Figure 22



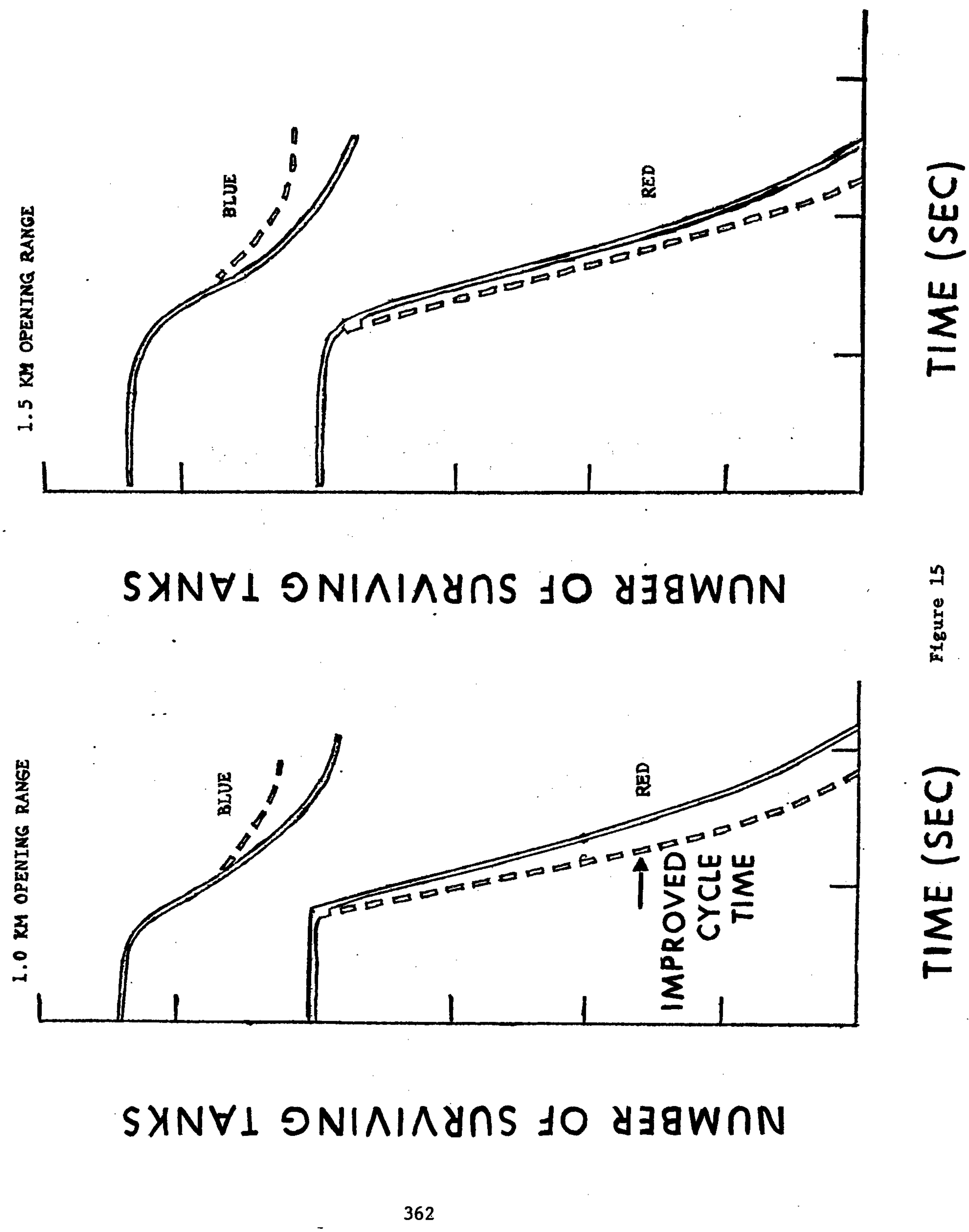

1.5 KM OPENING RANGE
BLUE
RED
NUMBER OF SURVIVING TANKS
TIME (SEC)
1.0 KM OPENING RANGE
BLUE
RED
IMPROVED CYCLE TIME
NUMBER OF SURVIVING TANKS
TIME (SEC)

Figure 15

MED. RANGE RED ATTACK

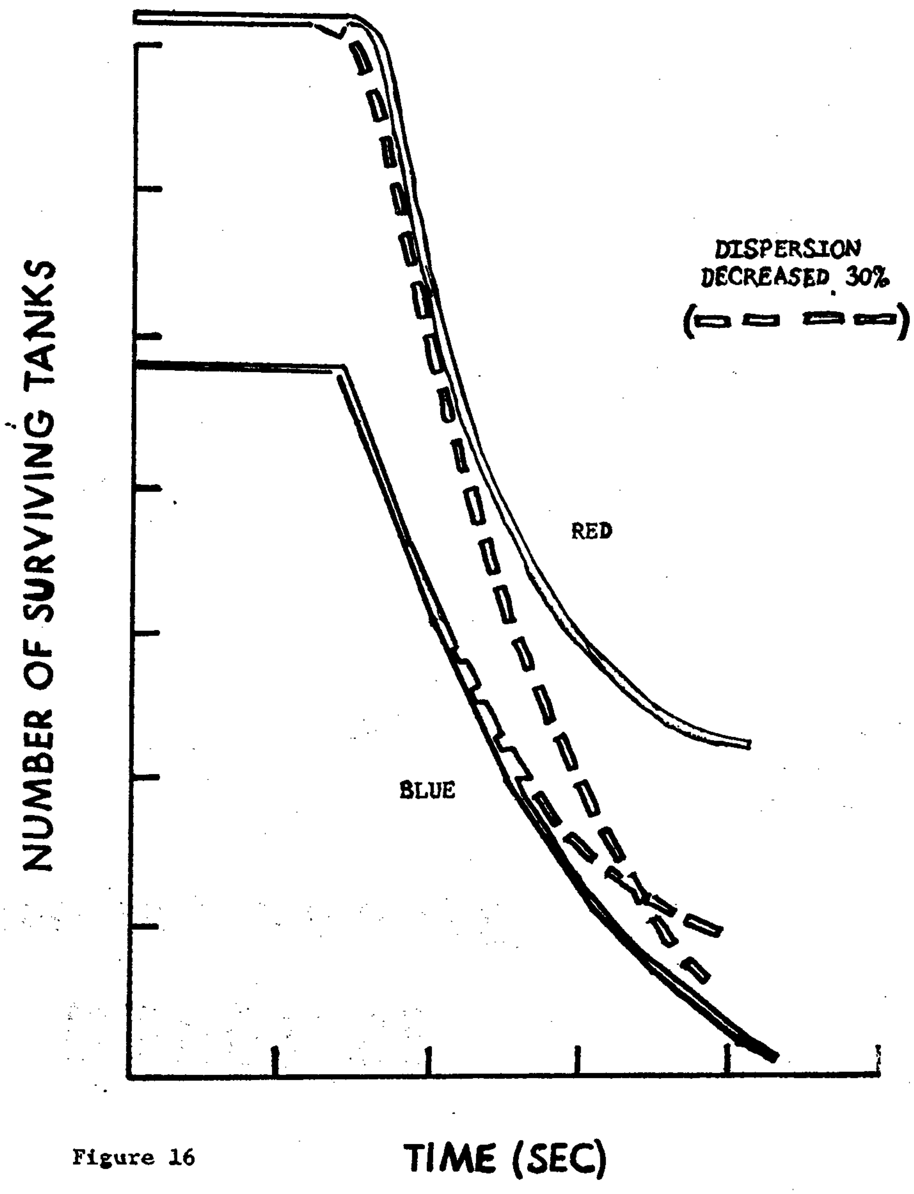


Figure 16

DEFENSE
(SHORT RANGE)

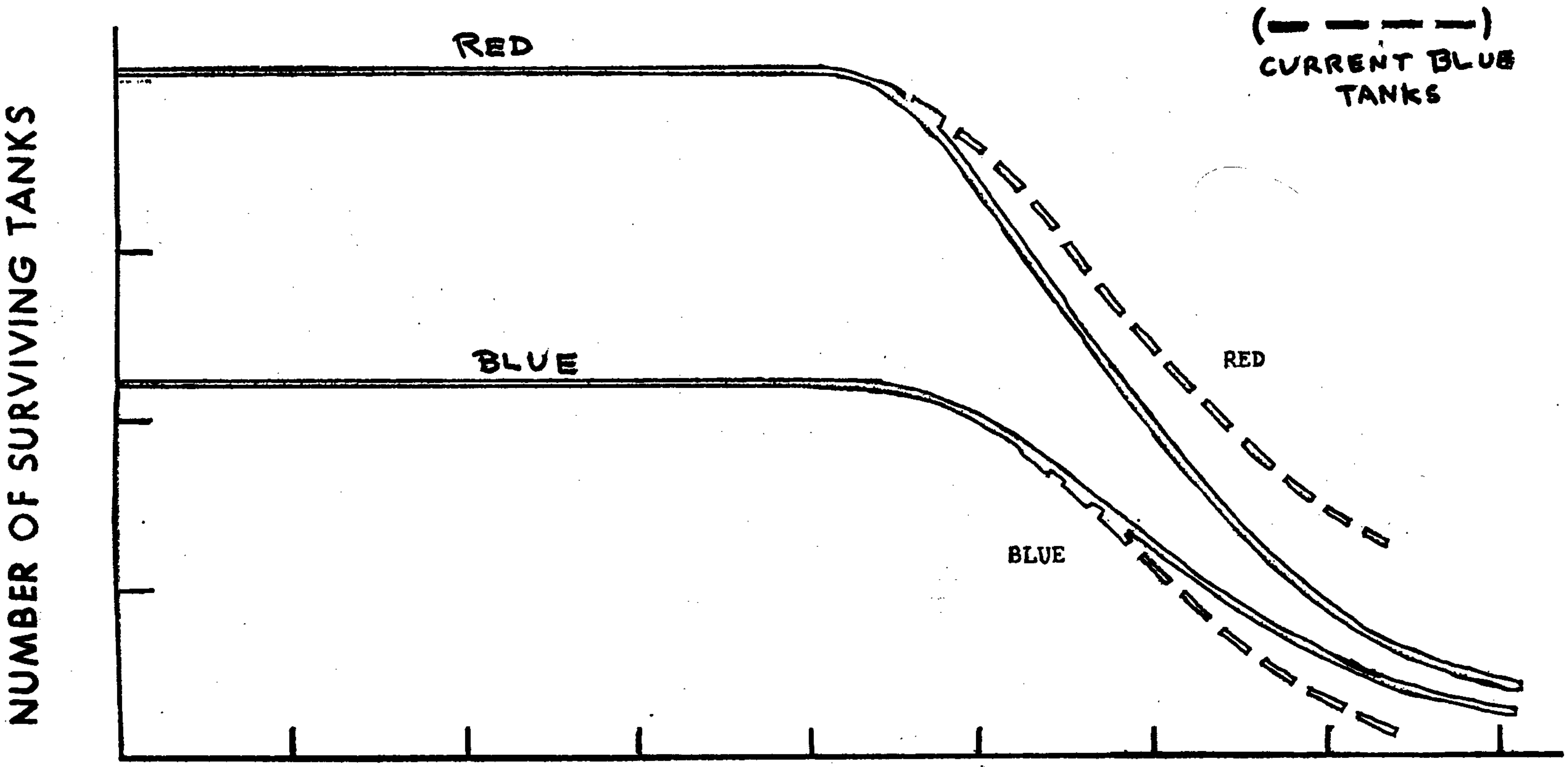


Figure 17

DEFENSE
(SHORT RANGE)

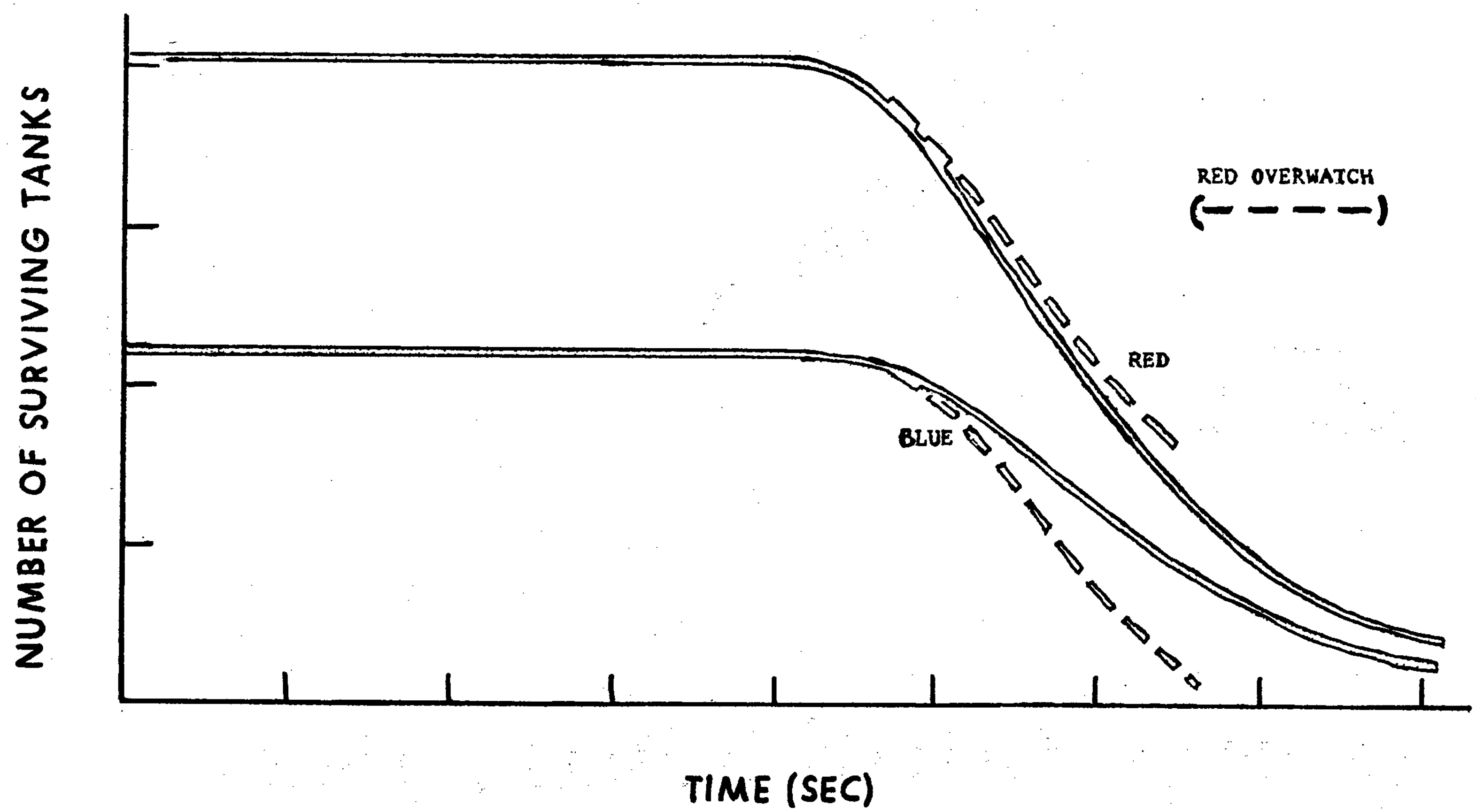


Figure 18

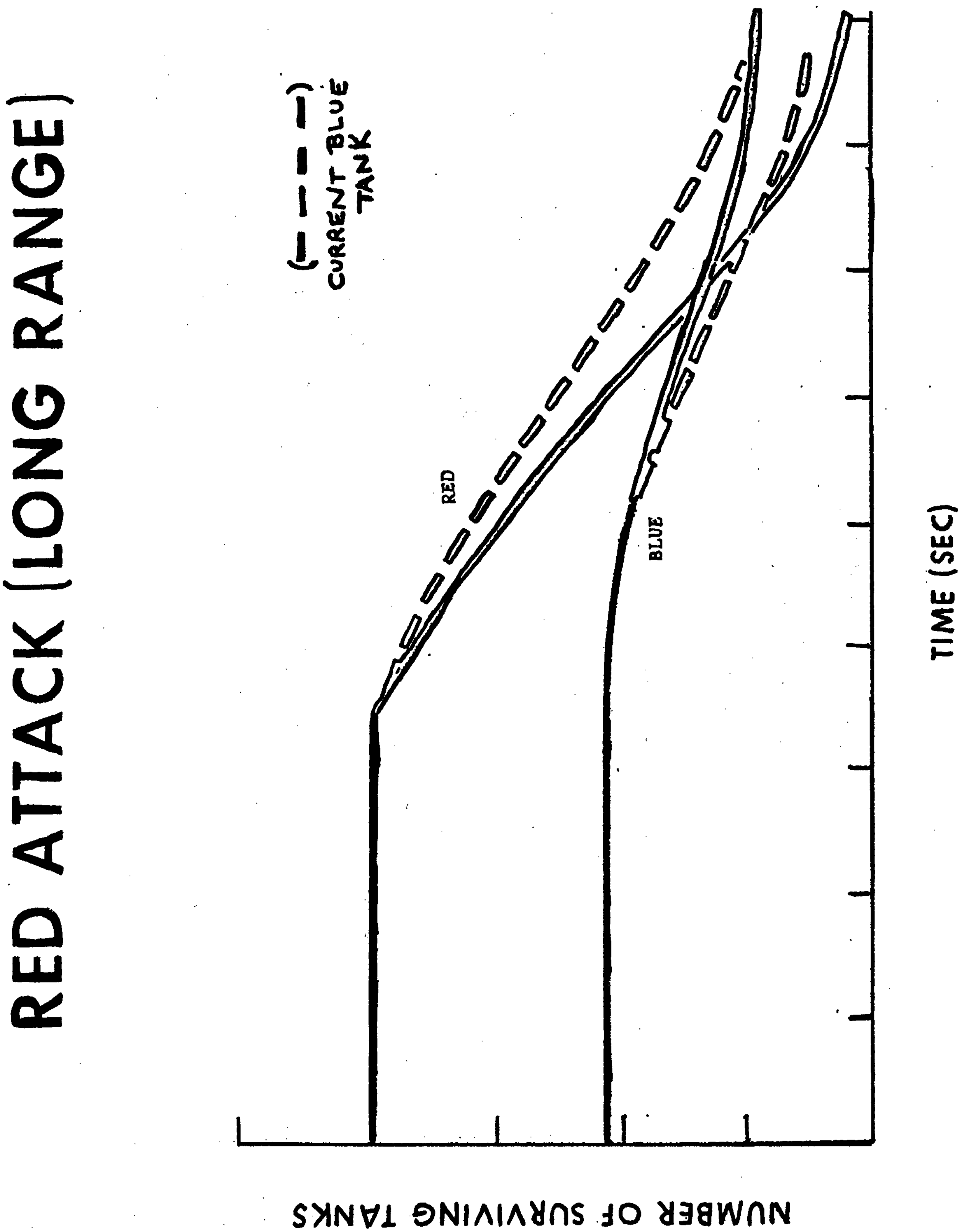

RED ATTACK (LONG RANGE)
CURRENT BLUE TANK
RED
BLUE
TIME (SEC)
NUMBER OF SURVIVING TANKS

Figure 19

In order to estimate better the effect of mixes of different types of infantry antitank weapons, response curves were generated using both the analytical and the IUA simulation models. In Figure 21, curves show the number of Red tanks killed as a function of different mixes of Blue antitank weapons, the bottom curve being the result of TOW missiles alone and the curves above showing the effect of additional weapons. Since the analytical model includes as an output the number of enemy weapons killed by firing weapon type, a synergistic effect could be demonstrated. It could be shown that the number of Red tanks killed as a result of only TOW weapon firings increased when other complementary weapons were presented also. On the same graph (Figure 21), IUA simulation results for various mixes are shown in triangles with the standard deviation about the simulation results shown by the vertical lines.

While the previous analyses showed the effect of TOWs and other weapons at the very end of the battle, similar curves (Figure 22) show the effect of TOWs and weapon mixes at the principal analysis point. In this case, since the number of Red tanks killed is fixed, the total number of Blue survivors is plotted as the measure of effectiveness. Again, IUA results and the corresponding standard deviations are shown.

In summary, it has been shown in the above examples how a simple analytical model has been used to check a complex simulation and to perform sensitivity analysis. The model has been particularly useful in performing the "what if"-type analysis to support high-level staff decisions in a very responsive manner.

The type of analyses that have been performed readily include changes in number of weapons, weapon types and weapon mixes on both sides, the effect of variations in weapon characteristics, and weapon employment, such as target selection routines. The effect of uncertainties in enemy weapon characteristics on employment also can be checked readily.

The program is very simple to use and could be reprogrammed significantly using relatively little effort. A number of versions are currently operational in the Headquarters, Departments of the Army, and are in actual use.

5.0 THEORETICAL RESEARCH RESULTS

Section 2.0 of this paper presented coupled sets of variable-coefficient differential equations as the underlying mathematical structure to describe heterogeneous-force ground combat activities and descriptions of mathematical procedures for predicting component inputs to the equations. Difficulties associated with obtaining useful closed-form solutions to these equations when the methodology is applied to realistic combat scenarios gave rise to the numerical solution procedure summarized in Section 2.4. This type of solution procedure was used in the comparison study described in Section 3.0 and extensive sensitivity analyses in the Army applications described in the last section.

Although the analytic model is markedly better than existing ground combat simulations for the conduct of sensitivity analyses (because of its rapid solution time, ease of modification, and ease in interpreting the results to understand why they occurred), ideally it would be desirable to have the solutions in simple closed form, which would explicitly portray the relationship between independent factors of the combat process (initial number of forces, firepower, mobility, tactics, etc.) and the surviving numbers of forces. Such solutions would greatly ease the conduct of sensitivity analyses and provide appreciable insight regarding variables which significantly contribute to combat effectiveness.

Over the past few years, attempts have been made to (a) obtain closed-form solutions for simplified cases of the equations (homogeneous forces, constant-coefficient heterogeneous forces) and (b) develop more interpretable numerical solutions, which could be used to analyze component parts of the combat process. Details of these efforts are contained in (Bonder and Farrell, 1970) and (VRI, 1970). In this section we will summarize some of the results of these theoretical analyses relative to the (a) weapon allocation process in heterogeneous-force combat, (b) effect of assault speed in ground combat, and (c) significance of of terrain modeling in predicting results of combat engagements.

5.1 Weapon Allocation Strategies[1]

It is clear that in a battle involving heterogeneous forces the number of survivors of each type depends on the manner in which weapon systems choose targets throughout the battle. This variation in combat results has been demonstrated using the differential models to describe such battles. Accordingly, some theoretical research was conducted to determine characteristics of good or optimal allocation strategies. In the research it was assumed that the battle dynamics of heterogeneous-force battles could be described by coupled sets of *constant* coefficient differential equations. It was further assumed that

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[1]Research in this area was conducted by Dr. S. Sternberg, Vector Research Incorporated.

(1) zero time is required to switch from one target group to another,

(2) projectile flight times are small, and

(3) the groups have perfect control and intelligence.

Results of the research indicate that, for linear payoff functions,[1] it is ineffective for individual weapon groups to distribute their fire over different target groups. That is, all i-group weapons should engage all j-group targets with no splitting of fire allocation within a group. The optimal assignment strategies are such that all weapons of a single group should be assigned to a single group in the opponent's arsenal. Mathematically,

$$e_{ij} = \begin{cases} 1 & \text{for } j = K \\ 0 & \text{for } j \neq K \end{cases} \qquad \text{for } i = 1, 2, \ldots, I \tag{9}$$

$$h_{ji} = \begin{cases} 1 & \text{for } i = L \\ 0 & \text{for } i \neq L \end{cases} \qquad \text{for } j = 1, 2, \ldots, J \, , \tag{10}$$

where K and L are specific weapon types in the Red and Blue forces, respectively.

It also has been shown that the choice of group to be fired upon is independent of the number of weapons in the firing or target group.[2] The class to be fired upon is selected by determining the maximum attrition rates on the marginal utilities of the opposing groups and not directly by the number of weapons in the opposing groups. Furthermore, although in previous research Snow (1948) employed the assumption that the allocation coefficients were constant throughout the battle, it has been shown that switching surfaces do exist, i.e., the optimal allocation strategy changes during the battle even though none of the Blue or Red force groups are annihilated.

Closed-form analytic solutions for the optimal allocation strategies (initial allocation and switching surfaces) have been obtained for the

---

[1]For example, the difference (Blue minus Red) in survivors at the end of the battle.

[2]This result is also contingent upon the above-noted assumptions.

two-on-one battle, i.e., two groups on one side and one on the other. The method used is applicable to higher-order battles; however, the mathematics gets extremely cumbersome.

The research also indicated that, to a first approximation, a simple, good allocation strategy is to assign Blue group i to that Red group j for which the product $\alpha_{ij}\beta_{ji}$ is a maximum, and vice versa for assignments of Blue groups. This rule was suggested by the solution of the two-on-one game of kind, for which it is identically the optimal allocation strategy. The usefulness of this simplified strategy was demonstrated in an allocation experiment which evaluated[1] the battle containing five Blue groups and nine Red groups. Two types of Red allocation strategies were programmed. The first was a target lookup subroutine from a list of target priorities prepared by an experienced military officer, and the second, the simplified allocation strategy mentioned above. Experimental results from the limited number of cases run indicated that the simplified allocation strategy was at least as good as the target priority table lookup allocation strategy, and in some cases, was significantly superior.

5.2 *Effect of Assault Speed*

The importance of maneuver in a tactical engagement has long been recognized by the military (Clarke, 1962). A simplified battle situation was modeled with the differential methodology to study one dimension of maneuver--the effect of assault speed.

We considered the simplified case of homogeneous-force battles with unity intelligence coefficients. The coupled variable-coefficient, heterogeneous-force equations [1] and [2] reduce to

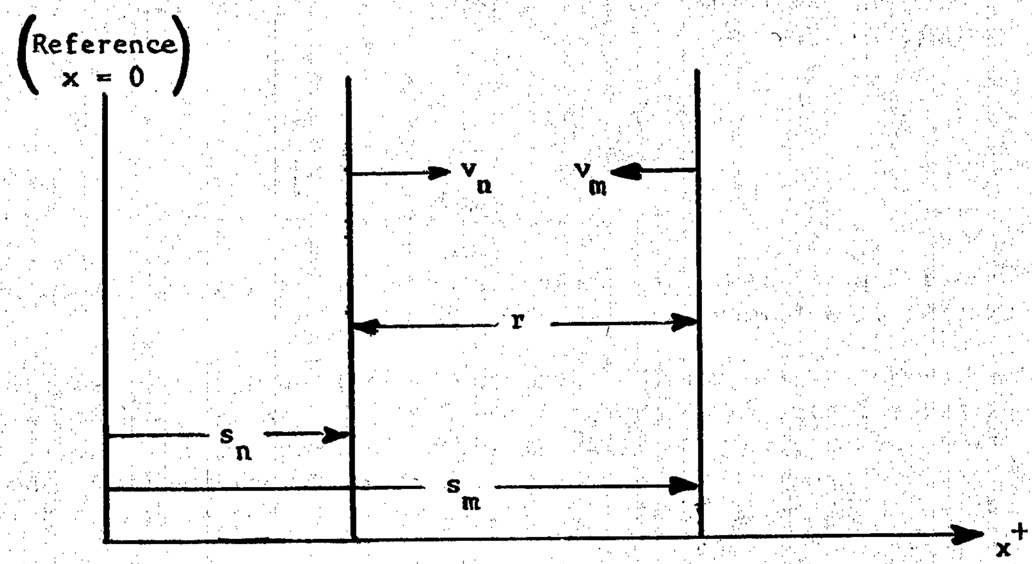
$$\frac{dn(t)}{dt} = -\alpha(r)m(t) \tag{11}$$

$$\frac{dm(t)}{dt} = -\beta(r)n(t) \ . \tag{12}$$

Since there is only one group on each side, the allocation factor is also equal to unity for each force. In these equations explicit notation showing the time and range dependencies are given.

It was assumed that the forces engage "on line" in the one-dimensional battlefield coordinate system shown in Figure 23. Relevant range

[1]The evaluation was conducted in the PEACE version of the differential model, which describes a simplified attack scenario. This version of the model is described in (Bonder and Farrell, 1970).



s_n (s_m) = the distances of the Red (Blue) forces from some common references,

r = force separation,

v_n (v_m) = speed of the Red (Blue) force,

v = relative speed between the Blue and Red force $(v_m - v_n)$.

Figure 23 One-Dimensional Battlefield Coordinate System and speed notations are shown in the figure. The above equations can be converted to the space domain depicted in Figure 23 in order to include explicit consideration of some dimensions of maneuver in the mathematical formulation. Finally, assuming that the relative acceleration (rate of change of the relative closing velocity v) is zero, results in the following variable-coefficient differential equation for the number of surviving Red forces:

$$\frac{d^2n}{dr^2} - \left(\frac{\dot{\alpha}(r)}{\alpha(r)}\right)\frac{dn}{dr} - \left[\frac{\alpha(r)\beta(r)}{v^2}\right] n = 0 \quad , \tag{13}$$

where $\dot{\alpha}(r) = d\alpha/dr$. An analogous equation exists for the number of surviving Blue forces.

The solution of this equation requires explicit knowledge of the attrition-rate functions $\alpha(r)$ and $\beta(r)$ for the Blue and Red weapons systems, respectively.[1] If it is known that the ratio $\alpha(r)/\beta(r)$ is not range dependent, then a general solution of equation 13 can be obtained. This condition is fulfilled, for example, if the following pair of attrition-rate functions are used.

$$\alpha(r) = \begin{cases} \frac{\alpha_o}{R_e}(R_e - r) = K_\alpha(R_e - r) & r \leq R_e \\ 0 & r > R_e \end{cases} \tag{14}$$

$$\beta(r) = \begin{cases} \frac{\beta_o}{R_e}(R_e - r) = K_\beta(R_e - r) & r \leq R_e \\ 0 & r > R_e \end{cases} \quad . \tag{15}$$

These linear attrition-rate functions with slopes K_α and K_β are shown in Figure 24a.

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[1] It was noted in Section 2.1 that the attrition-rate function is defined as the variation in the reciprocal of the expected value of the time-to-destroy a target. Data for some representative weapon systems (main tank guns, VRFWS, etc.) against different targets was used to estimate this parameter for different ranges. Plots of these results suggested some explicit mathematical forms for the attrition-rate functions which were used in theoretical research activities.

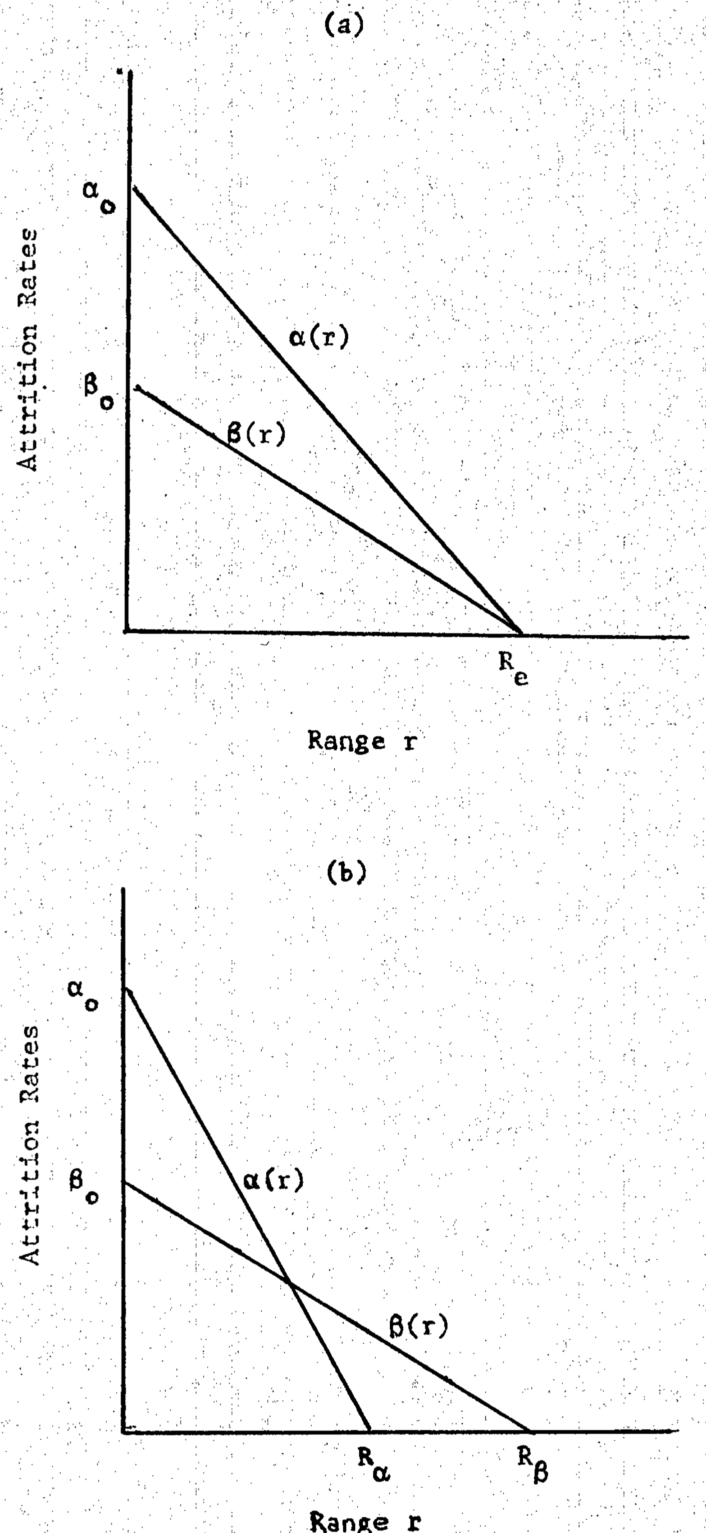


Figure 24 Linear Attrition-Rate Functions

Even with these overly simplified restrictive assumptions, solutions to the variable-coefficient differential equations give rise to some interesting insights and comparisons with existing theories. In particular, the classical constant-coefficient Lanchester formulation of this problem suggests that a Blue force will lose a battle when

$$\alpha M^2 < \beta N^2 ,$$

where M and N are initial numbers of Blue and Red forces, respectively. Loss in this classical criterion is synonomous with complete annihilation. Analysis of the variable-coefficient solutions indicate that this win or lose condition is completely misleading. In fact, annihilation may not be a meaningful concept since forces can be overrun or withdrawn before annihilation occurs. Instead, analysis should focus on some other "end of battle condition" such as the difference (m - n) at r = 0 or the ratio m/n at r = 0. When these conditions are considered, the results of the battle are highly dependent on the assault speed and the relationship between the *initial*, *linear*, and *quadratic* conditions defined as follows:[1]

Initial Condition:

$$M \begin{Bmatrix} < \\ = \\ > \end{Bmatrix} N$$

Linear Condition:

$$\alpha_o M \begin{Bmatrix} < \\ = \\ > \end{Bmatrix} \beta_o N$$

Quadratic Condition:

$$\alpha_o M^2 \begin{Bmatrix} < \\ = \\ > \end{Bmatrix} \beta_o N^2 ,$$

where α_o and β_o are the attrition rates for Blue and Red weapons, respectively, when their force separation is zero. The effect of these conditions and the use of mobility as measured by the assault speed are shown

[1]Complete analysis of the effects of these conditions is given by Bonder and Farrell (1970).

in Figures 25 through 28. The symbol R_o is the range at which the battle is initiated (open-fire range). The figures show the effect of the assault speed on the difference and ratio of surviving forces at the end of the battle (i.e., $r = 0$). Each point on a graph is the result of a single battle where the attacker advances with a different assault speed.

The conditions shown in Figures 25 through 28 suggest, by classical Lanchester analysis, that the Blue force will be annihilated. This is true if their assault speed is less than 4 mph. However, increasing their assault speed to approximately 20 mph will result in their arriving at the defended position with a superiority of 14 units (where the initial superiority was 20) or a ratio of 2.9 to 1, where the initial ratio was 3 to 1. These figures are suggestive of two phenomena:

(1) Attacking with sufficient speed is a means of conserving one's own force, i.e., get the enemy before he gets you. This we might term a saturation principle in that we saturate the enemy's retaliatory firepower capability with maneuver.

(2) Increasing the assault speed increases the saturation effect; however, this effect has a decreasing marginal benefit.

The decreasing marginal utility of increasing assault speed is evidenced in both Figures 25 and 26 ; however, it is more pronounced in the ratio measure of effectiveness.

In contrast to these results, the conditions of Figures 27 and 28 suggest, by classical Lanchester analysis, that the Blue force will annihilate the Red force. This will occur only if the Blue force assault speed is less than 13 mph. Increasing their assault speed above this will result in their arriving at the objective with a lower superiority measured by the difference and ratio of forces. It is interesting to note that when the measure of effectiveness is the force difference at the objective, there is a unique worst speed for the Blue force to attack; however, the ratio of surviving forces continues to decrease with increasing assault speed.

A general solution of equation 13 when the ratio $\alpha(r)/\beta(r)$ is a function of range has not been obtained to date.[1] In fact, even the apparently simple case of linear attrition rates given by

[1] A special situation, called the "fire-support" battle, in which the ratio $\alpha(r)/\beta(r)$ is range dependent, has been solved and is currently being analyzed. A description of the battle conditions and the solution are given by Bonder and Farrell (1970).

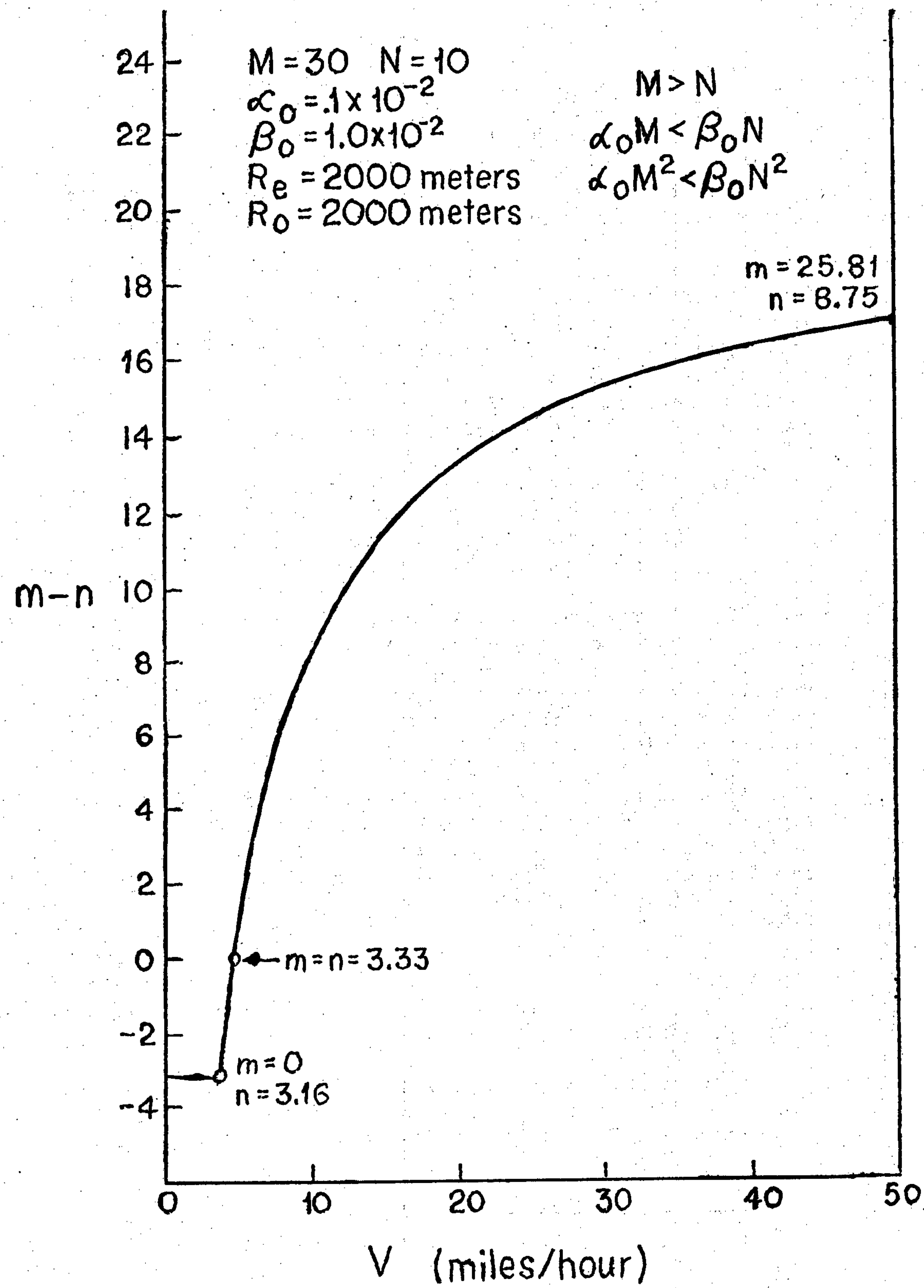


Figure 25 Force Difference at r = 0 (Constant-Ratio, Linear Attrition Rates)

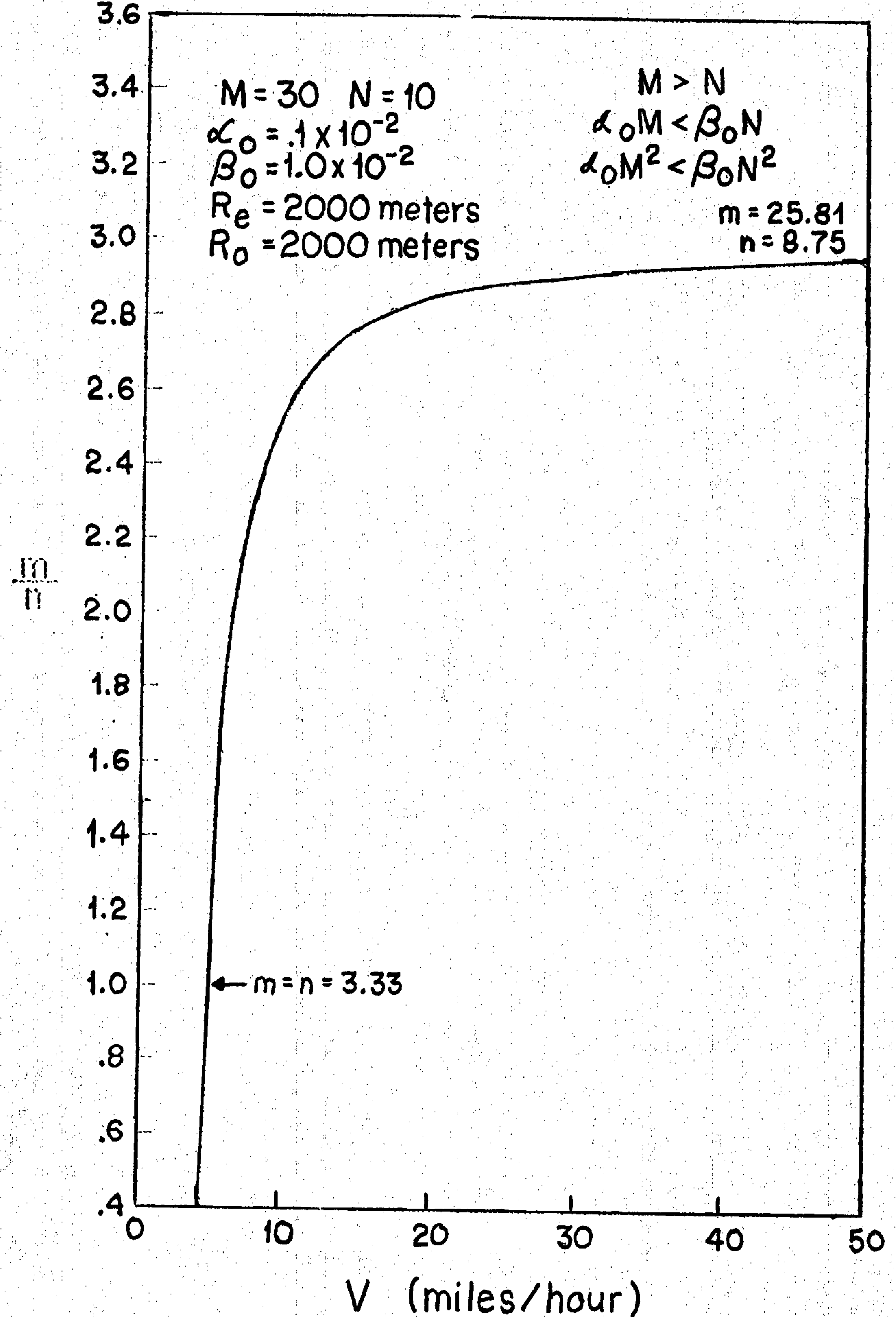


Figure 26 Force Ratio at r = 0 (Constant-Ratio, Linear Attrition Rates)

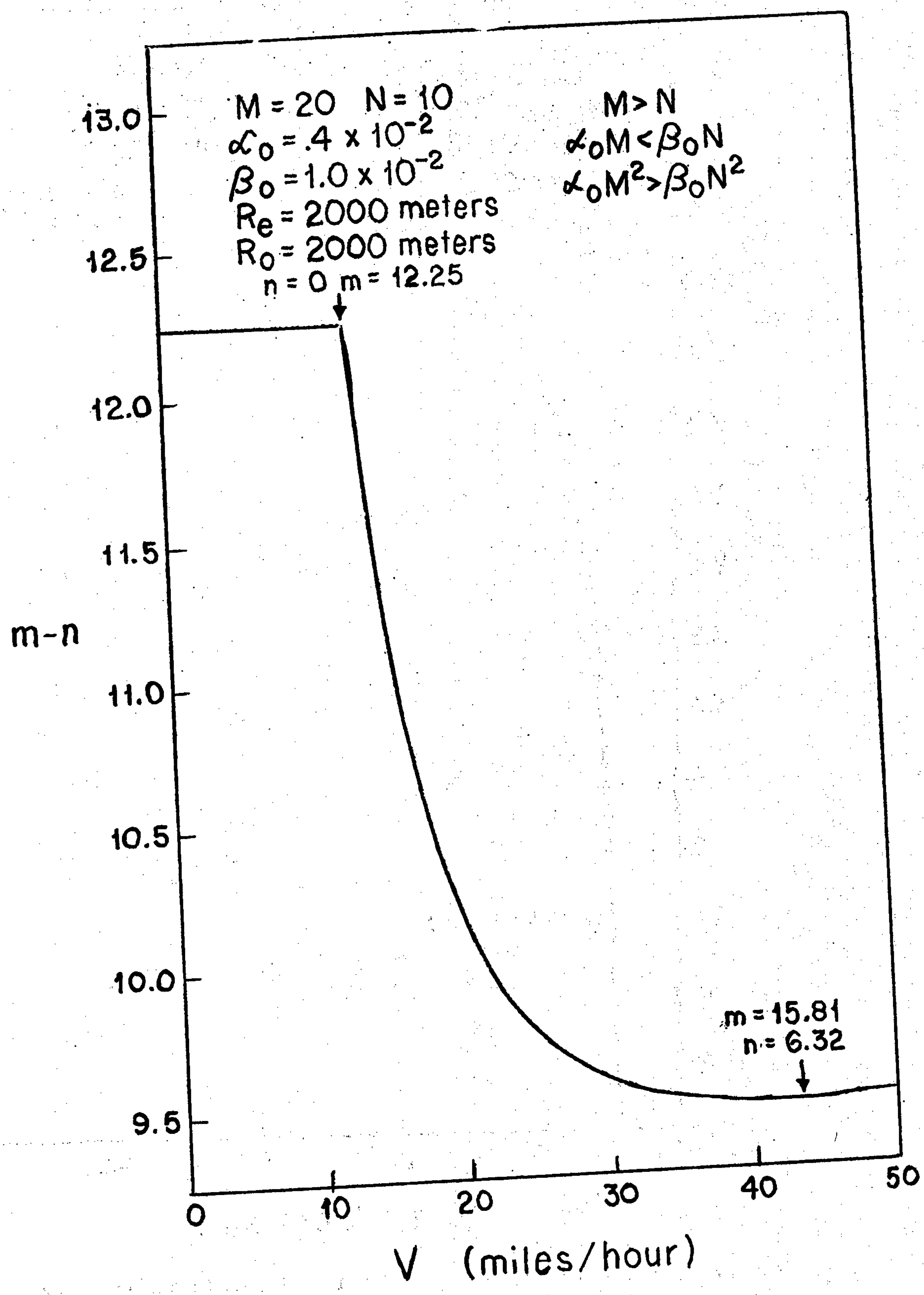


Figure 27 Force Difference at r = 0 (Constant-Ratio, Linear Attrition Rates)

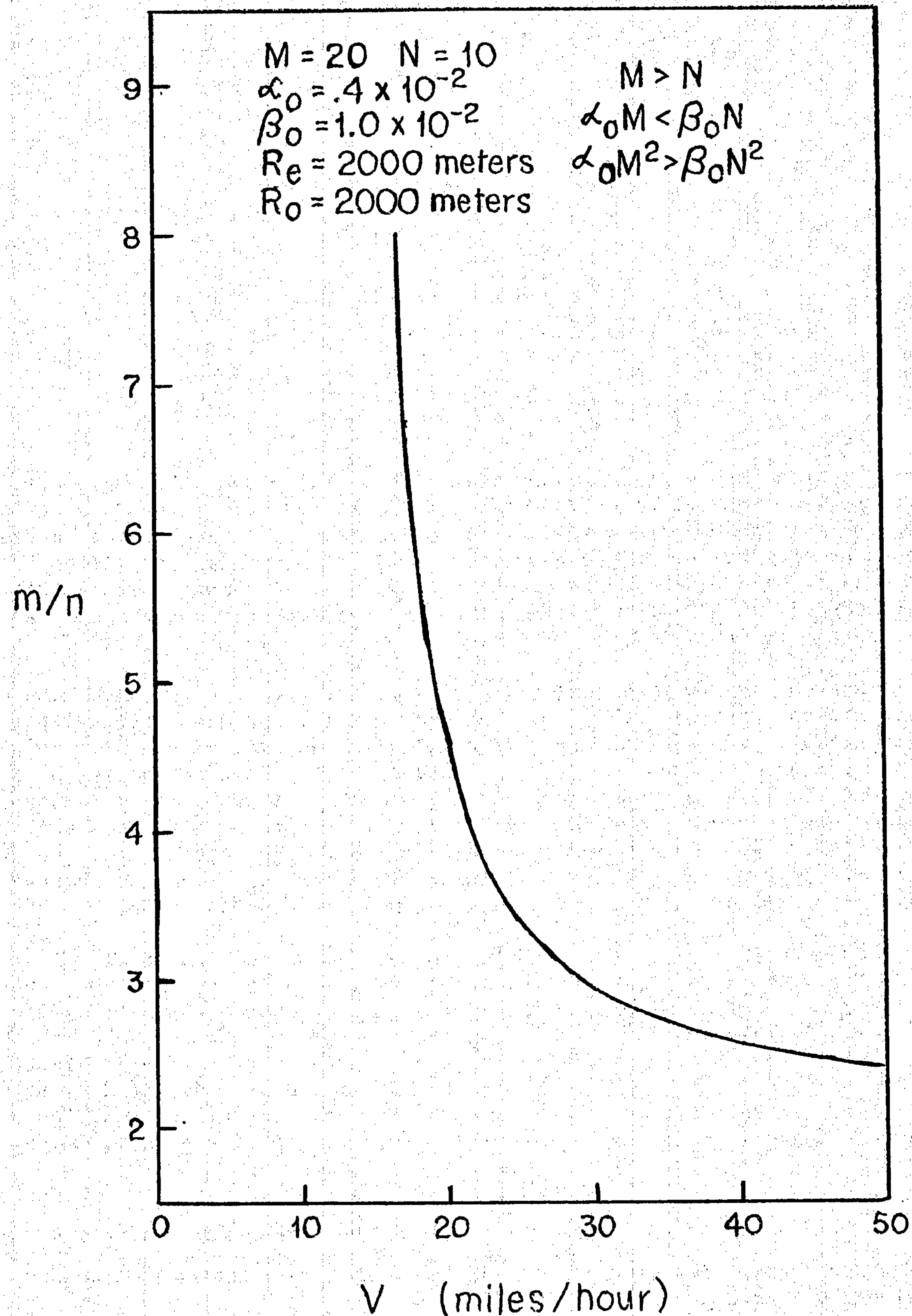


Figure 28 Force Ratio at r = 0 (Constant-Ratio, Linear Attrition Rates

$$\alpha(r) = \begin{cases} \frac{\alpha_o}{R_\alpha}(R_\alpha - r) = K_\alpha(R_\alpha - r) & r \leq R_\alpha \\ 0 & r > R_\alpha \end{cases} \tag{16}$$

$$\beta(r) = \begin{cases} \frac{\beta_o}{R_\beta}(R_\beta - r) = K_\beta(R_\beta - r) & r \leq R_\beta \\ 0 & r > R_\beta \end{cases} . \tag{17}$$

and shown in Figure 24b, has not yielded to closed-form solution. Research efforts have been directed to obtaining parity conditions (conditions leading to equal numbers of survivors on both sides at the end of the battle). Based on the work described above, it was felt that these conditions would depend not only on the force sizes[1] but also on the shape of the attrition-rate functions, effective ranges of the weapon systems, the range at which the battle is initiated, and the mobility of the attacking force.

Although approximate solutions to the parity conditions have been obtained analytically, they have not provided a great deal of insight to date. Analysis of parametric series solutions and analog computer solutions to the equations, however, have tended to support the above conjectures.[2] The analog computer provides a visual display of the solution space when parameters such as initial number of forces, assault speed, effective range of the weapons, opening range of the battle, etc. are varied. Systematic variations of these parameters were made to observe the trajectory of the parity conditions ($m = n$ at range $r - 0$).

Some typical plots of the solutions are shown in Figures 29, 30, and 31 for the absolute number of survivors, the difference in survivors, and the ratio of survivors, respectively, at the end of the battle (i.e., $r = 0$). Again, each point on a graph is a result of a battle when the attacker advances with a different assault speed. The parity points for variations in the initial numbers of the Red force are indicated by solid circles. Immediately obvious from these figures is the fact that the assault speed is an integral factor in predicting parity points. More

[1]The principal factors in the classical Lanchester parity conditions.

[2]The parametric series solutions and the analog computer solutions are given by Bonder and Farrell (1970).

Figure 29

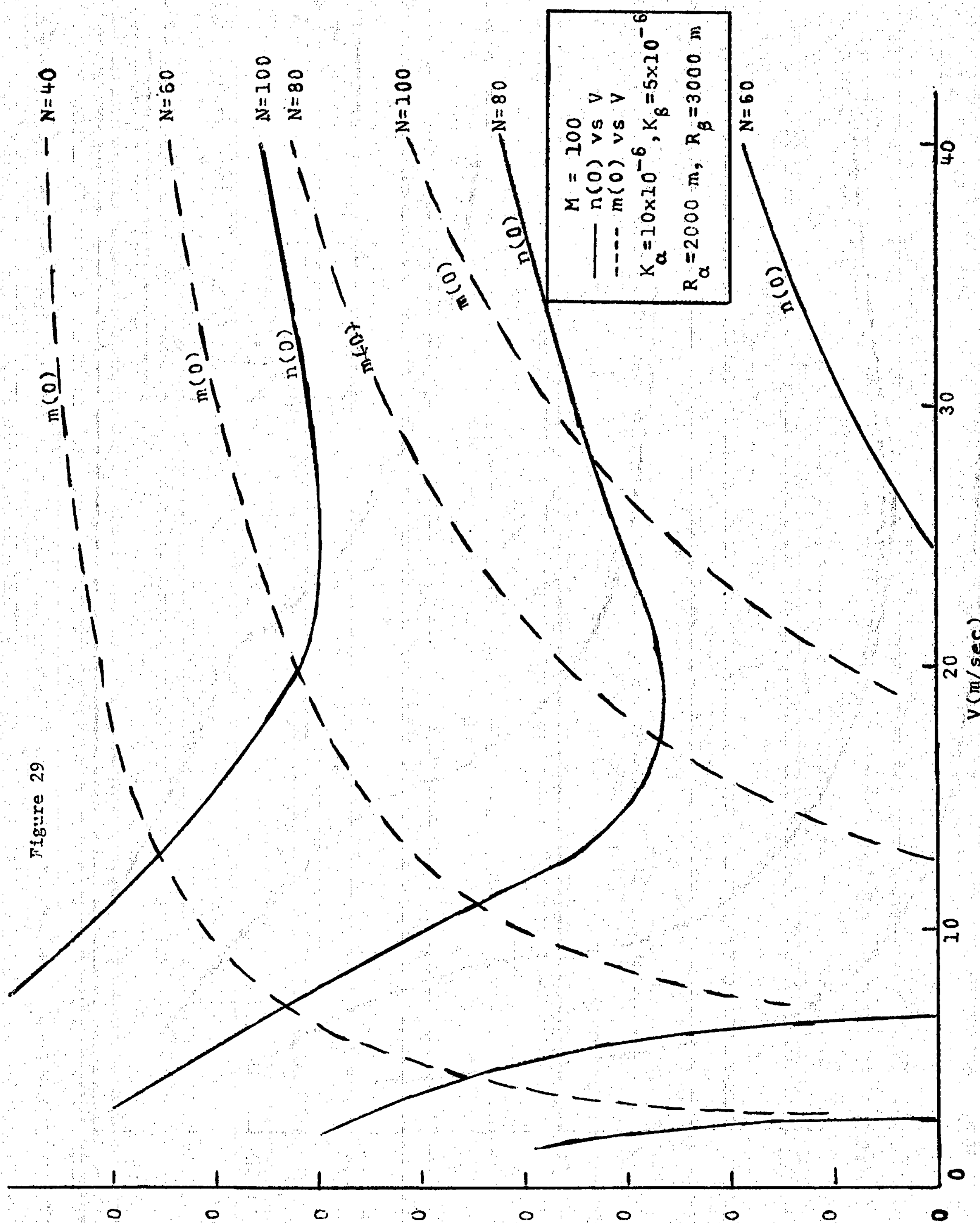

M = 100
—— n(0) vs V
- - - - m(0) vs V
$K_\alpha=10\times10^{-6}$, $K_\beta=5\times10^{-6}$
$R_\alpha=2000$ m, $R_\beta=3000$ m
N=40
N=60
N=100
N=80
N=100
N=80
N=60
m(0)
n(0)
m(0), n(0)
V(m/sec)
0
10
20
30
40
50
60
70
80

Figure 30 Force Difference at Range $r = 0$ (Linear Attrition Rate $R_\alpha \neq R_\beta$)

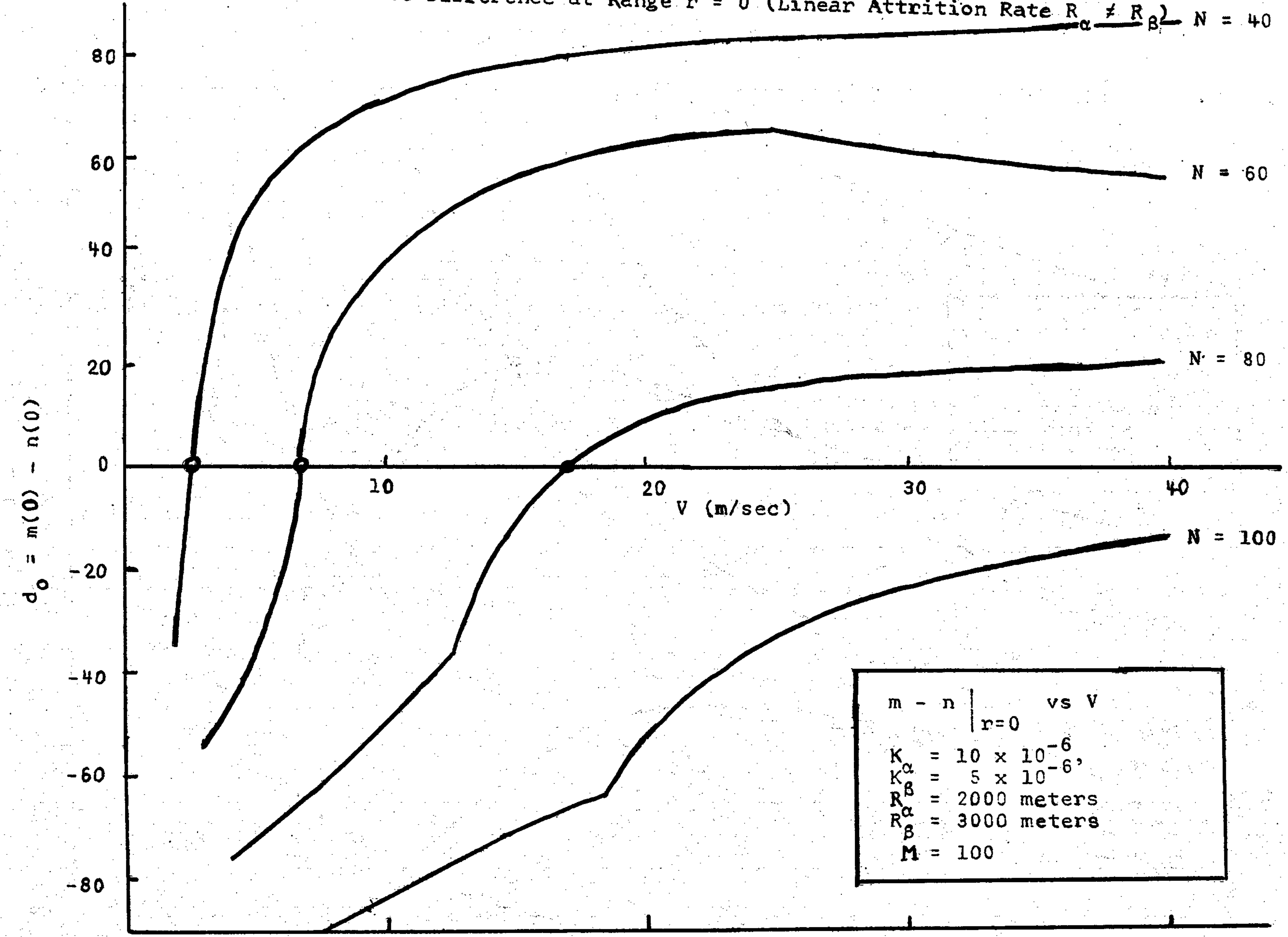
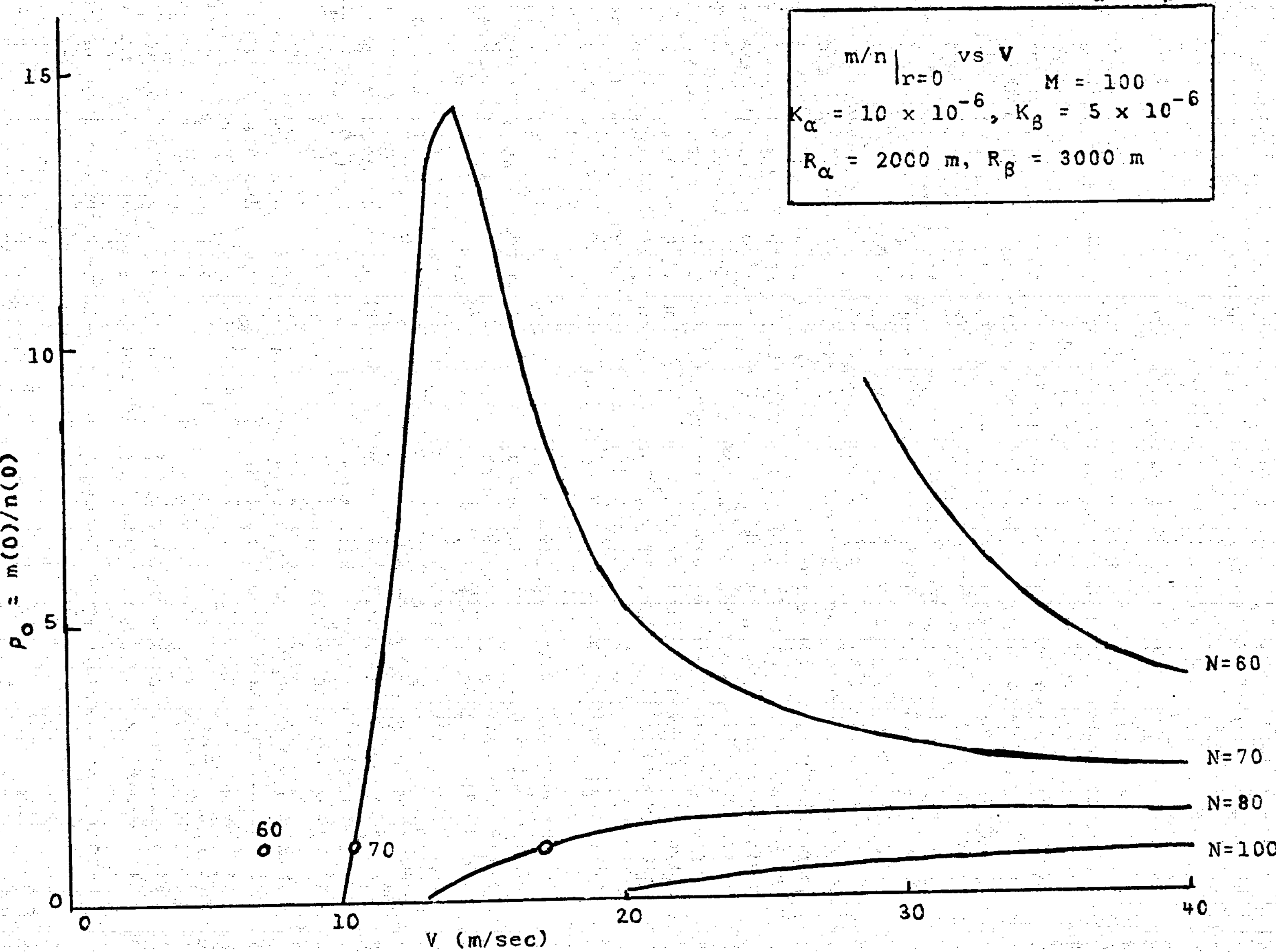


Figure 31 Force Ratio at Range r = 0 (Linear Attrition Rate $R_\alpha \neq R_\beta$)



importantly, there appear to be optimal assault speeds such that deviations from this optimal can have significant effects on the battle results. This point is highlighted in Figure 31, where for an initial number of 70 Red units, an assault speed of 15 meters/second produces a final ratio of forces of 14.5 to 1. A reduction of only 5 meters/second to approximately 10 meters/second assault speed would produce a final ratio of Blue to Red forces of less than 1.0.

5.3 The Effect of Terrain Line-of-Sight (LOS)

The version of the differential combat model used by the Army is particularly useful in analysis studies in which the principal items varied (as in a sensitivity analysis) are the force compositions and the basic performance descriptors of acquisition, lethality, and vulnerability for different weapon systems in each of the forces. The model was not designed to perform as usefully if the elements which were to be extensively varied are tactical rules or underlying parametric descriptors of the mobility capabilities of the weapon systems. This is principally a result of treating terrain in the model as if it were a map with digitized properties of concealment, cover (LOS), terrain roughness, etc. associated with each or pairs of locations.[1] For this reason a study was conducted[2] to determine the feasibility of developing and incorporating an analytic representation of LOS into the differential combat models with a view toward increasing their capability for sensitivity analysis on tactics and mobility. The LOS dimension of terrain was selected for study (in lieu of roughness, cover, etc.) since (a) it is the largest component of the terrain and mobility data base, and (b) we believe it is the most difficult environment dimension to realistically model analytically. In this section of the paper we will summarize the activity and present a theoretical research result which, if true, has broad implications for many current and future Army weapon system studies.

Discussions with experienced Army officers indicate that the specific location of a battle in an area and the actual routes of advance during a battle are, in some sense, pseudorandom phenomena.[3] Thus, it appeared reasonable to model the LOS process as a stochastic one[4] and hope it would

---

[1]Use of predetermined mobility capabilities and detailed movement patterns over a specific terrain which must be determined by the IUA preprocessor is the other principal reason.

[2]This study was conducted by Vector Research, Inc., under the sponsorship of the Directorate, Weapon Systems Analysis, Office, Assistant Vice Chief of Staff, U.S. Army (Contract DAHC15-70-C-0205). The reader is referred to (VRI, 1970).

[3]A pseudorandom process is one which, to the casual observer, appears in all aspects to have been randomly generated but, in fact, is deterministic.

[4]Deterministic models were, however, also considered but found to be unsatisfactory.

be a useful replacement for the digitized LOS model. The "usefulness" of a stochastic model of LOS for use with the deterministic differential models of combat is, of course, a subjective judgment on the part of the model user and management. The research examined the degree of variability in combat results caused by introducing a stochastic LOS into the differential model of combat. If the variability were low, with combat predictions clustering about some central value, then the LOS model would be deemed useful. Parameters of the LOS model could then be estimated from the digitized LOS data and the analytic LOS model used with the differential models of combat to predict the central-value combat results. In contrast, a large variability in combat predictions would indicate that LOS realizations from the same underlying stochastic LOS process might well produce dramatically different combat predictions. In our view this would make the analytic LOS model appreciably less useful as a replacement for the digitized LOS model currently in use. That is, use of the analytic LOS model with the differential models would clearly not generate combat predictions that were similar to Monte Carlo simulation predictions which used a digitized single realization of the LOS process.

Three stochastic LOS models were considered--nonstationary alternating[1] renewal process, nonstationary alternating Markov process, and a stationary alternating Markov process. This choice among these LOS models (and others) was dependent on the availability of data to ascertain which assumptions are reasonable and to estimate appropriate parameters. Some of the digitized LOS data used in comparing the differential model of combat to the IUA Monte Carlo simulation model[2] were analyzed for these purposes; however, the data was barely adequate to obtain rough estimates of the transition probabilities even under the assumption of stationary, exponentially distributed interval lengths.[3] Because of the lack of data, a stationary alternating Markov process model of LOS was used in most of the study.[4]

The stochastic LOS model was first incorporated into a homogeneous-force differential battle model and produced significantly large variances in the distributions of both the Red and Blue force survivors.

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[1]This assumes that LOS either exists between weapon groups or it does not exist, i.e., no partially exposed targets. This assumption was made to simplify analysis in the study. It is a straightforward matter to enrich the resulting structure to multiple LOS classifications.

[2]See Section 3.0.

[3]Property of the Markov assumption made.

[4]Information presented by the British at the Fourth Quadrapartite Meeting in October 1970 indicated that this LOS model, as well as parameter values used in the study, were quite reasonable.

This was perhaps to be expected since use of a stochastic line-of-sight process in a homogeneous-force battle model results in intervals of simultaneous fire of the opposing forces or no fire at all. It seemed reasonable to conjecture that, if a weapon group could alternatively direct its fire against any one of several opposing weapon groups (depending on the existence of LOS), then the extreme effects of not having LOS in the homogeneous-force battle, i.e., no fire at all, would be frequently avoided. It might further be postulated that the increase in time of fire and associated diversification of fire would serve to reduce the variance in the survivor fractions in a heterogeneous-force battle.

To evaluate this hypothesis some heterogeneous-force battles were run with the PEACE[1] analytical model of combat, which was modified to include stochastic line-of-sights among opposing weapon groups. The simplified battle situation considered is shown in Figure 32. Both Red and Blue are assumed to be positioned along straight-line fronts, these lines being parallel and separated by a distance r, decreasing uniformly with time as Blue attacks.

The simple Markov LOS model was again used but enriched to include the concept of correlation between adjoining lines-of-sight. Correlation was included so that the probability that weapon group i can "see" weapon group j is enhanced when group i can "see" weapon groups to the right and left of group j and diminished when the flanking weapon groups are hidden.

Five runs of the Blue battalion task force assault engagement shown in Figure 32 were made using the PEACE combat model and different realizations of the stochastic LOS process. The combat results of the five runs are tabulated in Tables 4 and 5. Table 4 compares the surviving weapon systems and percentage MBT survivors at range zero, i.e., when the attacking Blue force reaches the FEBA. Table 5 compares the five realizations of Blue and Red MBT survivors at the Red 33 percent and Blue 50 percent analysis points, respectively. Examination of these tables suggests that, similar to the homogeneous-force battles, there exists a high degree of variability in combat results caused by using different realizations of the same underlying stochastic LOS process.

Although somewhat limited in scope, the study implied that the stationary alternating Markov process LOS model did not seem appropriate for connection with the differential combat models. This conclusion was based on the result that the combat attrition predicted by the differential models was dramatically altered by small changes in the choice of LOS data.

[1] This version of the model is described in (Bonder and Farrell, 1970).

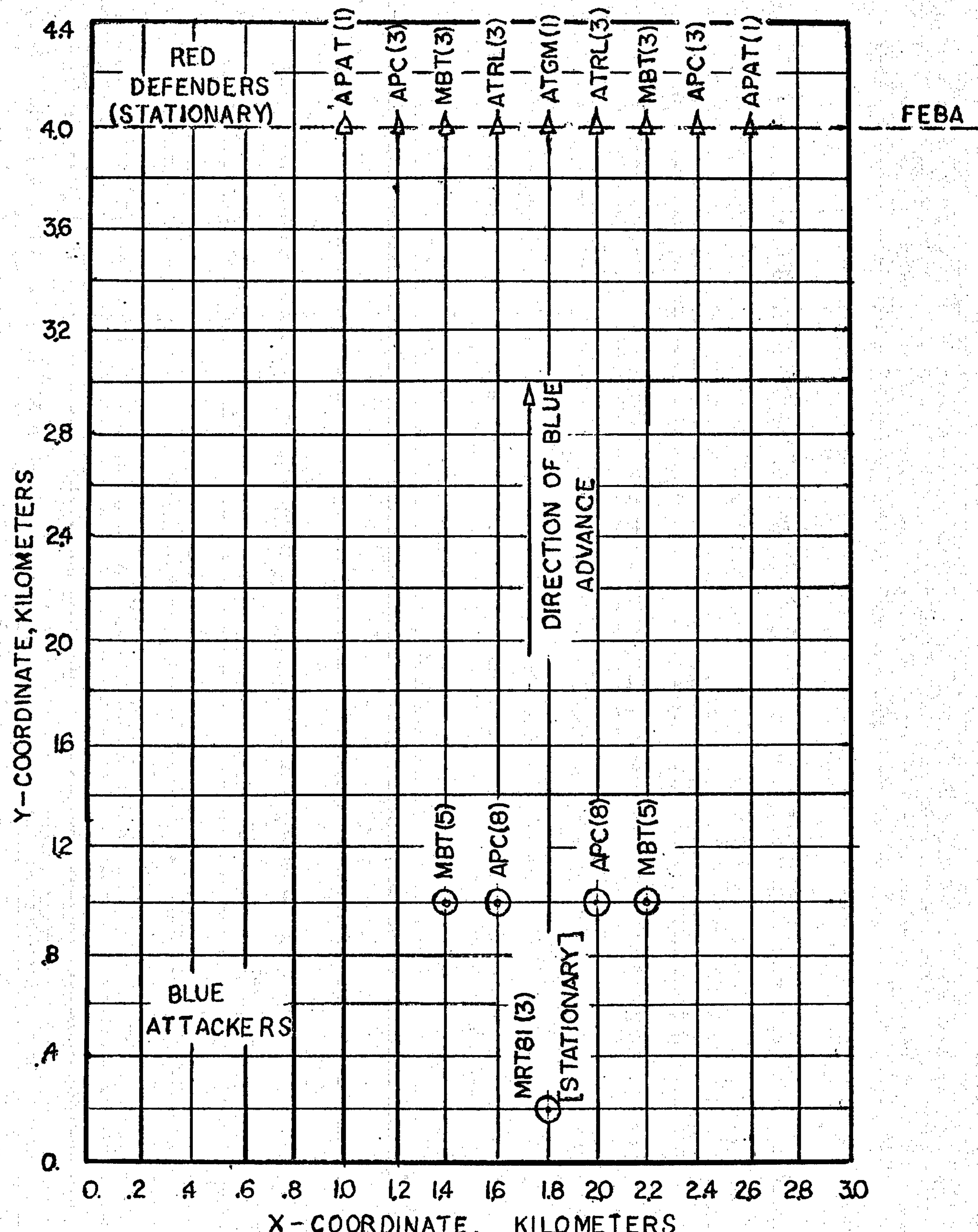

Figure 32 Simplified Blue Assault Engagement

NOTE: Initial weapon quantities are shown in parentheses.

Table 4

SURVIVING FORCES AT THE FEBA FOR FIVE LOS REALIZATIONS

Group	Weapon Type	Initial Number	1	2	3	4	5
Red							
1	APAT	1	0	0	0	0	0
2	APC	3	2.52	0	.40	1.65	1.13
3	MBT	3	1.74	1.11	.27	0	.41
4	ATRL	3	0	0	0	0	0
5	ATGM	1	0	0	0	0	0
6	ATRL	3	0	0	0	0	1.17
7	MBT	3	0	0.76	0	0.41	0.52
8	APC	3	0	0	1.83	0.63	0
9	APAT	1	0	0	0	0	0
		(%Red MBT Survivors) =	.29	.31	.045	.068	.155
Blue							
1	MBT	5	2.05	0.98	2.94	2.07	1.70
2	APC	8	7.46	6.71	6.43	7.02	6.47
3	MRT81	3	3.00	3.00	3.00	3.00	3.00
4	APC	8	5.89	5.63	6.55	4.93	6.41
5	MBT	5	2.57	0	2.01	1.88	0.77
		(Blue MBT Survivors) =	.563	.098	.595	.393	.247

Table 5

ANALYSIS POINT MBT RESULTS FOR FIVE LOS REALIZATIONS

Analysis Point	Realization Number	Surviving Red MBT	Fraction Surviving Red MBT	Surviving Blue MBT	Fraction Surviving Blue MBT
50% Blue MBT	1	2.33	.39	5	.50
	2	3.33	.55	5	.50
	3	0.33	.055	5	.50
	4	1.98	.33	5	.50
	5	2.99	.50	5	.50
33% Red MBT	1	2	.33	4.86	.486
	2	2	.33	1.44	.144
	3	2	.33	6.04	.604
	4	2	.33	5.02	.502
	5	2	.33	3.07	.307

Initial Number Red MBT = 6

Initial Number Blue MBT = 10

It is felt that these results have broader implications for current and future Army weapon system studies. Analysis of the models suggested that the observed large variability in combat results is due to the sensitivity of the differential combat models to changes in LOS and not a property of the specific LOS process used in the study. Coupling this observation with the comparison study which indicated that the differential models describe the dynamics of combat in essentially the same manner as the more largely used Monte Carlo simulations, casts serious doubt on the present technique of using a single realization of an environment (or small sets of such environments) in any combat effectiveness analysis, regardless of the specific combat model used. Thus the combat results of any study, using the differential models or Monte Carlo simulations of combat, might well be dramatically altered by small changes in the choice of environment data, even if this new data were drawn from the same underlying stochastic process as the old.

Appendix

CONCEPT OF THE ATTRITION RATE

The attrition rate for individual weapon systems is assumed to be dependent on a multitude of physical parameters of a weapon system which describe its capabilities in such areas as acquisition, firing accuracy, delivery rate, and warhead lethality. Experience with existing systems suggests that these characteristics are dependent on the range to a target and are stochastic in nature. That is, the attrition rate is functionally dependent on the range between combatants and, for any specified range, is described by a probability distribution. In the vernacular of the mathematician, the attrition rate may be viewed as a nonstationary stochastic process when forces employ mobile weapons. This is shown in Figure 1A, which depicts the two distinct variations in the attrition rate for a single weapon system type against one target type: (a) the stochastic variation at a specific range, which is described by the conditional probability distribution $f(\alpha|r)$, and (b) the variation in some function of the attrition-rate random variable with range, which is called the attrition-rate function, $\alpha(r)$.[1]

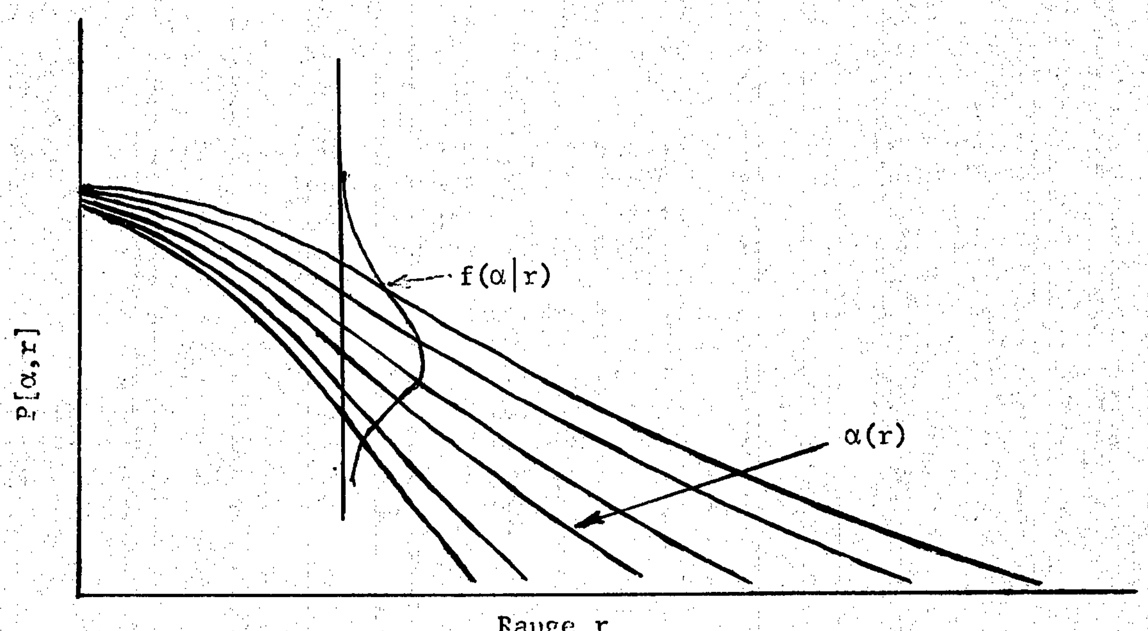

Figure 1A The Attrition-Rate Process

[1]For clarity of discussion, variations in the attrition rate due to changes in target posture, environmental effect, etc., which can be included in the model, are not presented.

The fact that armed conflict is stochastic is well recognized and is one of the reasons for conceptualizing the attrition rate itself as a nonstationary stochastic process, $P[\alpha, r]$. Assuming the process $P[\alpha, r]$ could be predicted, one would like to incorporate the range and chance variations of the attrition rate explicitly into a model of combat among heterogeneous forces. The rate concept suggested that such a model would be either a differential equation (continuous-state variables) or a difference-differential equation (discrete-state variables) structure in which the relevant coefficients were nonstationary stochastic processes, i.e., the $P[\alpha_{ij}, r]$ and $P[\beta_{ji}, r]$ for all weapon-target group pairs. Initial study strongly indicated that, in the foreseeable future, there was little hope of solving either of these structures even for simplified situations. A research decision was made to suppress the chance variation in the attrition rate and concentrate on structures of combat which explicitly involved the range variation in the rate when mobile weapons are employed.

Discrete-state stochastic process models were considered in which the transition rates are nonstationary, i.e., as varying with time. The literature indicated that discrete-state stochastic process formulations of combat have been difficult to solve even when the process is considered to be Poisson (Lanchester type) with stationary transition mechanisms. The few solutions obtained with homogeneous forces have been of such complexity as to delimit their usefulness for analysis purposes (Dolanský, 1964; Clark, 1968). Accordingly, it was felt that useful solutions for general discrete-state stochastic process formulations with nonstationary transition mechanisms could not be obtained in the near future.

Although the appropriate long-range objective is to develop stochastic formulations of heterogeneous-force armed combat such as those noted above, we felt that a more reasonable intermediate objective would be the development of deterministic formulations, and solutions, which included the nonstationary aspects of the attrition rate at the expense of explicit consideration of its stochastic elements. Accordingly, the coupled sets of differential equations 1 and 2 were chosen as the mathematical structure to model the combat activity. The nonstationary aspect of the attrition rates is included in the formulation as the variable coefficients in the differential equations, where the variable coefficients are appropriately defined as the attrition-rate function, $\alpha(r)$. Thus, there is one value of the attrition rate (for any firing weapon on a specific target group) at each range.

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Night operations in this model as in most models is simply modeled as a difference in acquisition or detection probabilities. This model like the other models, does not come to grips with the real problems of night fighting, the human problems, navigation problems, the coordination problems or anything else. We believe that this model like the other models are not truly representative of night operations.

John indicated the time to make the modification of the program. There is available now a modulerized computer program that'll allow you to apply this to different tactical situations and with some little programming changes to a whole host of them, I think. I've not seen anybody yet put this on the computers except me. I think Keith you're in the process of trying to do it now-to use the modulerized program. Is that correct? For those of you who'd like to use that, it would give you great flexibility in terms of running parametric analyses. You can just signal this thing to do a whole host of runs in very very small periods of time.

There seems to be no end to the number of this type problem. There are all kinds of things you haven't treated besides the variability and inadvisibility like the process we are talking about.

There are other things that he could treat besides the inadvisibility of this that are much more important than the range effect on kill probabilities. I am referring to the alertness of the crew, the human factors, and STOCASTIC processes that are involved. All of these things have much greater affect than the simple dispersion and hit probabilities versus range, which this whole model is built on.

Lets make a distinction, there's been no attempt, because we don't have any data, to test this model against the role. Both models may be predicting very badly and I think that is the important point and the point you are making.

That's right and there's no way to validate the model really. And so when you try to do an analysis like all these things you want to look at, exchange ratios and so forth, and make decisions based on these things, when the important concepts are not the things that are in the model; not the range dependent ones. There's the maneuvers, the alertness, the things that are not built into the model. You can't make a reasonable judgment on what the mixed ratio is based on-the type of analysis that you just showed-when you didn't even change the inadvisibility thing and you won't be able to in the next five years.

Well nobody's arguing the point. I think what we're trying to say here, what I've been trying to say with the development of this thing, is exactly the fact that we don't know what the right assumptions are. And I agree, we haven't handled all the elements of conduct very clearly. We've handled the ones that we've studied for 20 years and people think they can handle easily. I'm not arguing that point at all. I agree, we can't consider the fact whether the guy had a good breakfast or not and it may be important, I don't know. We can't do that, but we can vary the assumptions about the process readily here that we couldn't do in the other, and we can sit down and try to figure out why the results are occurring, which we couldn't do in the assimilation, based on the limited things we've included here. O.K. I have said at other times, in the absence of the good data and the ability to model things you're talking about, that's all we ought to do and then let the decision-makers argue about what the right assumptions are. If they can arrive at the right assumptions then maybe we can predict an output.

If I might say so, the model doesn't know that range is range. You might be able to enter the model with some of your criticisms through the range which is the parameter. They may be convertible. The model wouldn't know any difference, so it could well be tried.

Once you consider the driving forces in this battle study, I think that perhaps we're concentrating a lot of effort on things we know to do very well as you said. It's the human factor there which is really quite a driving factor in a battle; it is very important. I would think that perhaps some work should be done on how to decide an optimum mix. With this driving force behind the decision, like not considering your army as robotized, might have a considerably different effect as to what the optimum mix of weapons should be.

Yes, thank you Jay, you're cutting back to me for having made kind remarks about your model, I guess. I'm getting frantic signals from the organizers here and I would like to thank you very much for this large group who kept quiet so long and I hope it was a good session.

NOTE: The comment included in this section is not necessarily complete. It was necessary to delete some remarks as they were unitelligible on the recording.

THE VOLUNTEER DRAFT

A New Approach to the Problem of the Draft

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President Nixon, General Westmoreland, and other high ranking members of the government and armed forces have stated that the post-Vietnam army will be all-volunteer.[1] With this objective in mind, military salaries have been raised and conditions in the military service have been improved. However, considering the restiveness of the American taxpayer and the demands on government revenues, political realities would seem to rule out appropriation of enough funds for an immediate end to the draft.

The general taxpayer could be bypassed. If anyone desiring an exemption from the draft were required to pay the entire cost of the exemption, the taxes of everyone else would not have to be increased. This approach will be called the volunteer draft because only those unwilling to pay the cost of their exemption continue to be subject to the draft.

The first section of this paper demonstrates one way to let those who benefit from exemptions pay the cost. The second section develops a model and uses it to simulate the alternatives that would have been available in 1971 to nineteen year olds if the volunteer draft had been adopted in 1970. Subsequent sections discuss the advantages of the volunteer draft over the present system.

i. Choosing between Service, Taxation, or Draft

Male eighteen year olds, on registering with the selective service system, would take the physical and mental examinations used to determine acceptability for military service. Everyone eligible for military service would be asked to choose among three options: service, taxation, or draft.

Those who choose service would have to enlist in one of the branches of the armed forces for two years starting sometime when they were nineteen years old.[2] They would receive in return a fixed percentage, lifetime reduction in their income tax. They would retain the tax reduction after their two year obligation had been satisfactorily completed whether they became a career soldier or a civilian.

The military and veterans' tax reduction would be financed by a surtax imposed on the incomes of those who selected taxation at the age of eighteen. They would receive in exchange the complete certainty that short of a national emergency they will never be conscripted into the army.

Those who decided to remain under the draft at the age of eighteen would be subjected to a lottery draft at the age of nineteen. If conscripted they would serve two years without the tax reduction. If they were not drafted they would remain civilians without any surtax.

*The author is an assistant Professor in economics on leave from the State University of New York at Binghamton. The views expressed are those of the author and do not purport to represent the views of the United States Army. The author would, however, like to thank his colleagues in Electives and his students in AOAC 1-71, AOAC 501-71 and AOAC 2-71 for their many valuable comments.

The decision made at the age of eighteen does not have to be irreversible. A civilian accepted by the armed forces after he became twenty could stop paying whatever surtax had been imposed on him and receive a lifetime, percentage reduction in his income tax.3 But the percentage reduction would have to be the smaller of the percentage reductions received by his peers who elected to serve at eighteen and granted nineteen year olds when they volunteer.4

The volunteer draft could be designed so that the chance of being drafted in the lottery was independent of the numbers of eighteen year olds who selected the draft, taxation, or service options. Estimates would be made of the probability of being drafted next year if the lottery draft is used by itself with no exemption from the draft due to the surtax and no one receiving a tax reduction as an inducement to volunteer. The lowest reasonable estimate would determine the probability next year of being conscripted under the volunteer draft. Hence the number of nineteen year olds drafted next year would be equal to the number of nineteen year olds who selected the draft option at the age of eighteen, multiplied by the probability of being drafted.

This approach could also guarantee that military requirements would be met. Estimates would be made of the percentage tax reduction next year necessary for the number of volunteers to equal the required accessions less the number of nineteen year olds drafted. The highest reasonable estimate would determine the lifetime percentage tax reduction granted next year's nineteen year olds who select the service option this year.

The military requirements could be satisfied without increasing the general level of taxation. The percentage of the surtax of each group of civilians of the same age who had selected taxation when they were eighteen would be set high enough so that revenues lost due to the reduction of the taxes of those who had volunteered when these civilians were nineteen would equal the revenues gained from their surtax.

ii. <u>Feasibility</u>

If the volunteer draft had been adopted in 1970, would the percentages of the surtax and tax reduction for 1971 have been too large to administer?

Assume that in 1971 the Federal income taxes of nineteen year olds who had selected taxation when they registered with the selective service system were increased by s% in order to finance a reduction of r% in the Federal income taxes of nineteen year olds who chose service. Then s=r R where R is the sum of the income taxes that would have been paid by nineteen year olds who selected service had there been no surtax.

Since r remains constant, the value of s in t years will depend on R^t, the value of the tax ratio t years in the future or

(1) $S^t = R^t r$ for $t=0,\ldots\ldots,H$ where H is the time horizon.

In this model the choice between increased taxation or service will depend only on the difference between the present value of after-tax earnings as a civilian and a soldier.5 All taxes except the Federal income tax will be disregarded, since these taxes are unchanged by the surcharge and the tax reduction. In 1971 the difference between the present values of military after-tax income and after-tax civilian income for a typical nineteen year old would be

$$(2) \qquad D_{mc} = \sum_{t=0}^{H} (Y_m^t - T_m(Y_m^t)(1-r))(1+i)^{-t} + \sum_{t=n+1}^{H} (Y_v^t - T_c(Y_v^t)(1-r))(1+i)^{-t}$$

$- \sum_{t=0}^{H} (Y_c^t - T_c(Y_c^t)(1+s^t))(1+i)^{-t}$ where Y_m^t , Y_v^t and Y_c^t are respectively his earnings as a soldier, veteran and civilian t years in the future; $T_m(.)$ and $T_c(.)$ are the tax functions for military and nonmilitary incomes; i is his discount rate; n is the number of years he anticipates remaining a soldier; H is his time horizon.

Substituting for s^t from (1) the equation for D_{mc} can be rewritten as

$$(3) \qquad D_{mc} = \sum_{t=0}^{H} ((Y_m^t - Y_c^t) - (T_m(Y_m^t) - T_c(Y_c^t)))(1+i)^{-t}$$

$$+ (\sum_{t=0}^{n} (T_m(Y_m^t) + T_c(Y_c^t) R^t)(1+i)^{-t} + \sum_{t=n+1}^{H} T_c(Y_c^t)(1+R^t)(1+i)^{-t})r$$

Summing across the differences in the present values for those who volunteer in 1971 provides some indication of the cost of attracting these same volunteers with increases in military salaries.

If R^t is constant from (3)

$$(4) \qquad r = (C+A)/(B+RF)$$

where C is the present value of the sum of the differences between the volunteer's after-tax earnings as a soldier and veteran with the tax reduction and the earnings they would have had as civilians with the surtax; A is the present value of the sum of the differences between the earnings the volunteers would have had as civilians and their earnings as soldiers and veterans; F is the present value of taxes volunteers would have paid as soldiers and veterans without tax reductions; B is the present value of taxes they would have paid as civilians without the surtax.

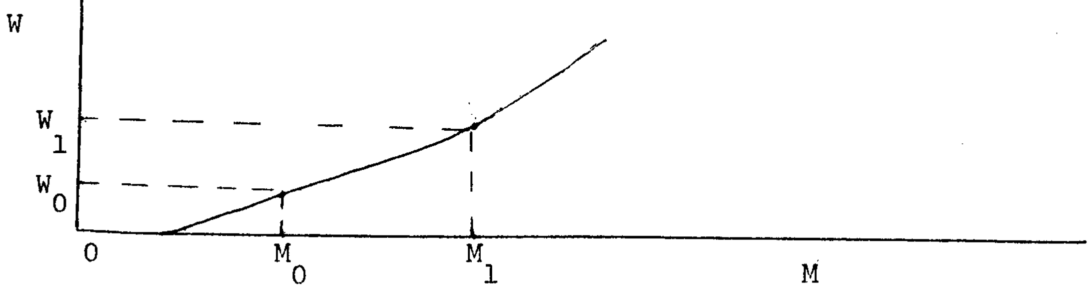
If C= $2.7 billion, A=$2 billion, B=$20 billion, F=$14.7 billion, and R=4/11 in 1971, a sufficient number of nineteen year old volunteers would have been attracted by a tax reduction of 16.8% and a surtax of 6.8% to meet the requirements of the armed forces in 1971.

The Gates Commission estimates that a 2,500,000 man,all-volunteer army in 1971 would require a net addition to the budget of $2.7 billion.6 The estimates of the surtax and the tax reduction assume that the same inducement to enlist when applied through the tax system would attract enough volunteers for military requirements. However, $2.7 billion would overstate the inducement needed under a volunteer draft.

There are estimates of the cost of an all-volunteer Army substantially lower than those made by the Gates Commission.7 The Gates Commission's estimate was made during the Vietnam war. Recruiting for the post-Vietnam army will be probably less expensive because of the absence of an unpopular war. According to the Gates Commission the yearly cost of an all-volunteer army will eventually decline to $2.1 billion.8

Only a fraction of the salary increases recommended by the Gates Commission was intended for first term enlistees. The incentive to enlist caused by the tax reduction and the surtax is directed only at first term enlistees.

FIGURE 1
VOLUNTEERS AS A FUNCTION OF THE MILITARY SALARY



Tax reductions distribute the inducement to enlist in a different way than salary increases. Figure 1 represents the hypothetical supply schedule for first term enlistees. An increase in military salaries from W_0 to W_1 would raise the number of volunteers from M_0 to M_1. If only the salaries of the M_1-M_0 soldiers who will not volunteer at W_0 but will volunteer at W_1 were raised there would be a savings of $(W_1-W_0)M_0$. Since everyone is a first term enlistee it is difficult if not impossible to pay different salaries for the same job.

But under a progressive income tax the higher the anticipated civilian income after military service has been completed, the greater the incentive to enlist caused by the surtax and the tax reduction. Differentiating D_{mc} in (3) for Y_c^t and r

$$(5) \qquad \partial^2 D_{mc}/\partial Y_v^t \partial r = (1+R^t)(1+i)^{-t} \partial T_c(Y_c^t)/\partial Y_c^t > 0 \quad \text{for } t=n+1,\ldots,H$$

Therefore, the tax reduction tends to offer the M_0M_1 reluctant volunteers a greater incentive to enlist than the M_0 hard-core volunteers who need no additional inducement.

On the other hand there are estimates of the cost of an all-volunteer army substantially higher than $2.7 billion.9

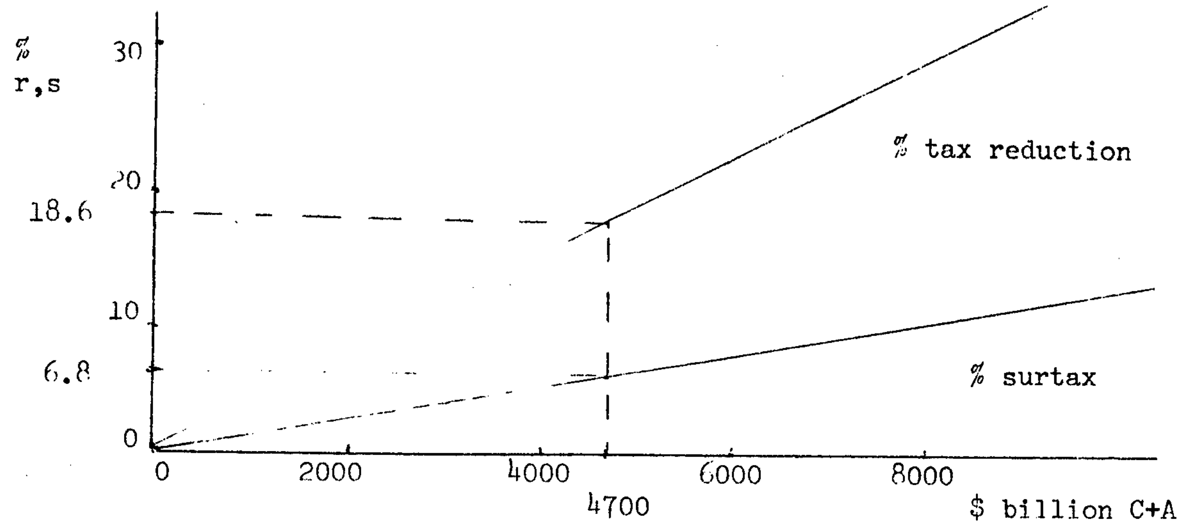
The salary increases recommended by the Gates Commission are available to anyone who enlists regardless of age. The tax reduction and surtax are limited to nineteen year olds who do not choose the draft option.

The Gates Commission assumes a decrease in required accessions from 440,000 enlisted men and 12,672 officers to 332,000 enlisted men and 9,500 officers due to a fall in the turnover rate. There probably would be only a slight decline in the turnover rate under the volunteer draft because the tax reduction is available to both veterans and career soldiers.

The estimate that A=$2 billion is based on the assumption that there is no difference between the income of a veteran and the income the veteran would have received if he had not served in the military.10 According to the Gates Commission the total military compensation is 62.5% to 67.8% of the total civilian compensation for the typical first term enlistee. To the extent that recent increases in military salaries have improved the ratio of military compensation to civilian compensation, $2 billion overstates the value of A.

Figure 2 describes the sensitivity of the surtax and the tax exemption to changes in the values of C and A.

FIGURE 2
r AND s AS FUNCTIONS OF C AND A



The values for B and F are based on the assumption that 20% of the $250,000 the typical volunteer would have earned had he remained a civilian would have been paid in income taxes and 15% of the $245,000 he would have earned as a soldier and then a veteran would have been paid in income taxes if there had been no surtax or tax reduction.

But $20 billion and $14.7 billion understate the values of B and F for the following reasons.

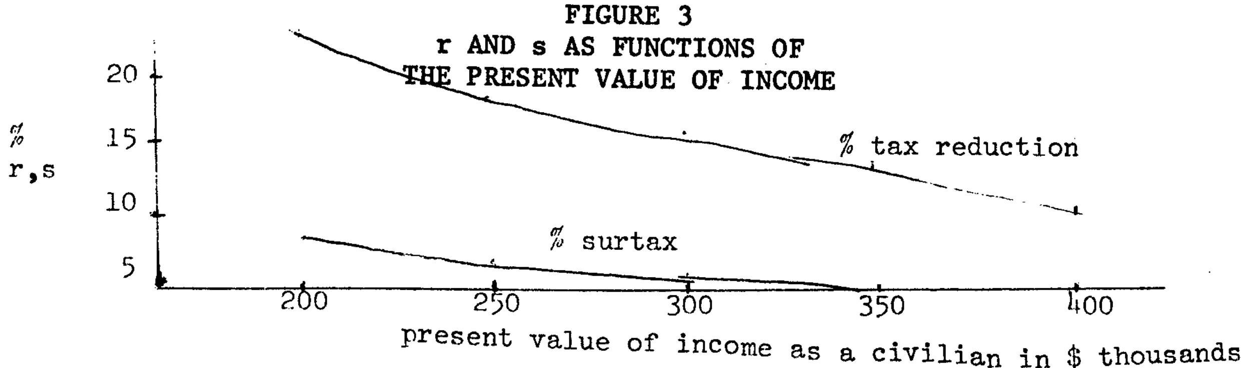
$250,000 is the lowest estimate of the present value of lifetime earnings.11 It is a projection of lifetime earnings from a cross section of incomes in 1960 and as such makes no allowance for increases in the average standard of living over the next forty years.

The 15% average tax assumes that each volunteer remains in the army his entire life and receives part of his salary in untaxable subsistance allowances, quarters allowances, and nonmonetary compensation. But many volunteers will serve two years in order to acquire the lifetime reduction in their income tax and avoid the surtax, afterwards becoming a civilian and paying higher income taxes.

The 20% average tax assumes, somewhat optimistically, that the level of taxation will not continue to increase as it has over the past forty years. But under a progressive income tax, as personal incomes increase, the percentage paid in income taxes increases.

Figure 3 describes the sensitivity of the estimates of the surtax and the tax reduction to the estimate of the present value of the lifetime income of a typical volunteer, everything else remaining the same.

FIGURE 3
r AND s AS FUNCTIONS OF
THE PRESENT VALUE OF INCOME



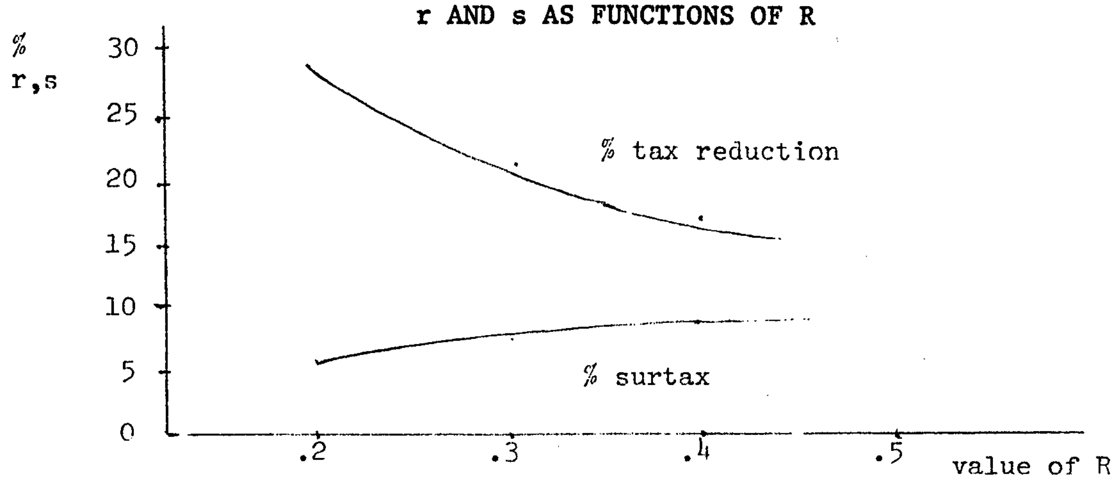
The ratio of 4/11 is based on the assumption that the 1.1 million nineteen year olds eligible for military service in 1971 who do not volunteer will pay the same average taxes each year as the remaining 400,000 nineteen year olds who enlist.

But soldiers pay less taxes than civilians. Secondly the civilians who do not volunteer will tend to earn more income and pay higher taxes than those who do volunteer.

Figure 4 describes the sensitivity of the surtax and the tax reduction to changes in the value of R, everything else remaining the same.

FIGURE 4

r AND s AS FUNCTIONS OF R



In summary the simulation of the volunteer draft for 1971 indicates that a 6.8% surcharge and a 16.8% reduction in taxes would have produced enough volunteers to satisfy military requirements. Discussion of these estimates indicate that they are robust and probably overestimates. But a 7% surtax is only one percent higher than the surtax imposed by President Johnson to control inflation. The volunteer draft would appear to have been feasible in 1971.

iii. Costless Benefits

The feasibility of the volunteer draft is important because changing from the present system to the volunteer draft offers substantial benefits to many AT NO COST TO ANYONE ELSE.

The nineteen year old who enlists under the volunteer draft has a higher after-tax income over his lifetime than under the present system.

The nineteen year old who pays the surtax has received security from the draft. The benefit of this insurance must be greater than the cost or else he would not have chosen taxation. Besides, as long as the armed forces will accept him in the future, he can reconsider and enlist at the cost of having paid the surtax and not received the reduction during the intervening years.

The nineteen year old who chooses the draft faces exactly the same chance of being conscripted as under the present system. But should he volunteer in the future after completing the obligation imposed on him by the draft, his after-tax income will be higher under the volunteer draft than under the present system because of the veterans' tax reduction.

The nineteen year old who is physically or mentally ineligible for service and everyone too old to participate in this program will have the same income under the volunteer draft as under the present system. They can not benefit from the tax reductions offered nineteen year olds who volunteer, but they are not subject to the draft or the surtax imposed on nineteen year olds eligible for service who do not want to enlist.

iv. Inexpensive to Administer

Reducing the income taxes of volunteers and raising the income tax of civilians who elect taxation by fixed percentages makes this an inexpensive program to administer.

For example, assume this program had been adopted in 1970. Income tax forms for 1972 would need one additional table of surcharges and reductions similar to the one in Table 1.

TABLE 1
1970 Tax Surcharge
and Tax Reduction Schedules

Age	TABLE A - Percentage Decrease in Income Tax for Soldiers and Veterans.*	TABLE B - Percentage Increase in Income Tax for Civilians Who Selected Higher Taxes
19	8	5
20	17	7
21 or higher	0	0

*If you volunteered at an age older than nineteen compare the tax reduction next to your age and the tax reduction next to the age of those who were nineteen when you volunteered. Your exemption is the smaller of the two.

From Table 1 a nineteen or twenty year old who enlisted in 1972 would receive an 8% reduction in his taxes. This would be financed out of a 5% increase in the taxes of the nineteen year olds who elected taxation in 1971 on registering with the draft.

A twenty year old who enlisted in 1971 would receive a 17% tax reduction financed by a 7% increase in the income tax of twenty year olds who chose taxation in 1970 and did not volunteer in 1971.

The Selective Service System determined that a 8% tax reduction would attract the required number of volunteers in 1972. The Internal Revenue Service found that the 5% surtax would produce enough revenue to compensate for the 8% decrease in taxes.

The 17% tax reduction had been calculated in 1971 and remains unchanged. In 1972 the Internal Revenue System, however, recomputes the surtax associated with the 17% reduction in taxes in order to be certain that the revenues lost due to the tax decrease will equal the revenues gained from the surcharge.

The cost of performing these calculations and adding this table to the tax forms must be weighed against the financial and moral benefit of eliminating draft boards. Under this program no one needs to sit in judgement on the conscience, family needs or occupational importance of applicants for deferments. Anyone can have a deferment as long as he is willing to pay the appropriate price.

v. Ability to Pay

This price automatically takes into account ability to pay. Under the progressive income tax as income declines both the percentage of income and the amount of income paid in taxes decreases. Since the surtax is a fixed percentage of the income tax, as income declines the cost of remaining a civilian both as a percentage and an amount of income falls.[12]

Assume that the tax reductions and surcharges in Table 1 are in effect in 1972. Table 2 illustrates how the price of remaining a civilian reflects ability to pay by contrasting the income taxes of three different twenty year olds who chose taxation.

TABLE 2

THE PRICE OF REMAINING A CIVILIAN

Name	Income	Income Tax	Surtax
Richard Rich	$50,000	$23,155	$1,620
Morris Median	10,000	2,245	157
Peter Poor	2,000	318	22

Richard Rich pays 3.2% of his income or $1,620; Morris Median pays 1.6% of his income or $157; and Peter Poor pays only 1.1% or $22 of his income in order to remain a civilian.

If the surtax and the income tax schedules do not change greatly from one year to the next, the price of remaining a civilian also depends on the ability to pay over time. The price is lowest during the years the civilian's income is least and highest when his income is at its peak.

For example, Carl Civilian in 1972 is a student. His income and the price of remaining a civilian corresponds to the situation of Peter Poor in Table 2. After he graduates from college his situation corresponds to Morris Median. In middle age his peak income corresponds to the situation of Richard Rich. When Carl's ability to pay is least, the price of remaining a civilian is smallest, but when his income peaks, the price of remaining a civilian is highest.

vi. Advantages to the Armed Forces

The surtax and the tax reduction combine to make military service more attractive the higher the income anticipated after the two year tour of duty has been completed.

Equation (5) already demonstrated this feature of the volunteer draft for any progressive tax system. In the example in the last section, if Richard Rich were a veteran instead of a civilian, his tax would have been reduced by 17% instead of increase by 7% for a savings of 11% of his income or $5,500 in 1972. But if Peter Poor were a veteran instead of a civilian his savings would have come to only 2.6% of his income or $53. Rich would consider spending two years in the army at a salary substantially below his civilian salary in exchange for the savings of receiving the veterans' reduction instead of paying the civilian surtax. Poor would be attracted instead by the fact that the military salary was higher than his salary as a civilian.

Because of this characteristic, the volunteer draft would tend to produce the same type of citizens' army that is supposedly the hallmark of the present system. Some who anticipate incomes above those provided by the armed forces will volunteer because of the tax reduction and the surtax. Others will volunteer because their anticipated salary as civilians is less than their salary as soldiers.

The critical difference for the military between the present system and the volunteer draft lies in the morale of the armed forces. Those with very negative attitudes toward military service are often compelled to serve two years under the present system. Their negative attitudes affect the performance of the army. Under this program those with very negative attitudes will choose taxation. For those who do volunteer, the carrot of a tax exemption once two years has been satisfactorily completed and the stick of the surtax if they receive a dishonorable discharge should further minimize disciplinary problems.

The taxes paid by those who do not under any circumstance want to serve in the armed forces helps improve the quality of the military in another way. Above average skill, initiative, and creativity are usually rewarded with higher than average incomes. Therefore, the surtax and tax exemption, at no cost to the military, provides additional encouragement to potential officers, medical doctors, lawyers, etc. to enlist in the armed forces in order to avoid the draft and the surtax and receive the tax reduction.

This last point can be demonstrated by returning to the example of Carl Civilian in section v. Adopting a volunteer army in 1970 would have the same effect as offering Carl increases in his after-tax income that range from $337 to $5,500 per year for the rest of his life, if he volunteered for two years of military service after he completed his college education. But the army does not pay for these increases in after-tax income because it does not finance the tax reductions or lose revenue if Carl does not pay the surtax.

The volunteer draft avoids a major objection lodged against changing the present system. The turnover rate in an all-volunteer army is very low in comparison with a draftee army. This lower turnover rate produces savings in training expenses, but at the cost of decreasing the influx of civilians into the armed forces and the number of civilians with military experience outside the armed forces.

Some authorities who are concerned with the overall strength of the armed forces are afraid that a small percentage of veterans would mean uninformed decisions about defense expenditures by voters. Since these veterans are the mainstay of the reserves, they argue that there would be little back up for the professional soldier.

Other critics focus on the civilian control of the military. Isolation of the soldier from the rest of the citizenry could lead him to become suspicious of the competence and direction of civilian decisions. This alienation could cause the military to intervene directly in politics to further what it viewed as the best interests of the country.

Under the volunteer draft there will be a turnover in the volunteers who want only to avoid the surtax and receive the tax reduction. After these volunteers have served two years, they would leave the army. As veterans they contribute information to the democratic decision-making process about defense and help support the army reserve. As soldiers they force the career soldier to adapt to an annual infusion of large amounts of civilians.

FOOTNOTES

1. The Report of the President's Commission on an All-Volunteer Armed Force, 1970, p. vii.
2. The number of years required for completion of the military obligation or the length of time veterans receive tax reductions are arbitrary.
3. This feature would enable the army to encourage draftees to reenlist in order to receive the tax reductions that their peers who selected service were receiving.
4. If he received a larger percentage reduction than his peers, his peers would be penalized for enlisting when they were ninetten. If he received a larger percentage than nineteen year olds at the time he enlisted, there would be a tendency for nineteen year olds to postpone service during periods of danger when the tax reduction was very high, receiving the same tax reduction during the period of less danger in which they choose to volunteer.
5. This does not mean that psychological values such as patriotism or distaste for the military are not considered. For example, someone who is patriotic could volunteer despite the fact that the present value of his lifetime income as a civilian was more than the present value of his income as a soldier. But if the disparity in incomes became too large, he would not volunteer despite his preference for military service. In this sense his decision to volunteer depends on the difference between the present values of his income as a civilian and his income as a soldier.
6. The Report...,pp. 7,8.
7. W.y. Oi, "The Economic Cost of the Draft," American Economic Review, May,1967, pp. 39-62.
8. The Report...,p.8.
9. For example, A.C. Fisher estimates that a volunteer army would cost from $5.7 to $6.9 billion.
A.C. Fisher, "The Cost of the Draft and the Cost of Ending the Draft," American Economic Review, June, 1969, pp. 239-254.
10. ibid., p. 241.
11. L.C. Thurow, "The Optimum Lifetime Distribution of Consumption Expenditures," American Economic Review, June, 1969, pp. 324-330.
12. If the effective tax rates did not reflect ability to pay because of the tax loop holes, then the surtax could be applied to the income tax as it would have been had there been no deductions and no exemptions.

MEASURES OF EFFECTIVENESS FOR ARMY COMMUNICATIONS SYSTEMS

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INTRODUCTION

During the past five years, a number of new concepts for large tactical communications networks have been proposed such as MALLARD, revised AACOMS and RADA. These propose wholesale equipment changes throughout the field army; they would introduce the general use of digital and secure voice techniques and would require expenditures estimated as high as a billion or more dollars over the next ten years. Needless to say, there has been a great deal of concern among the individuals responsible for funding terms of increased force effectiveness. As a result of this concern, there have been a number of attempts to apply operations research approaches to determine cost-effectiveness indicies for these improvements. Most of these efforts have defined effectiveness in terms of communications system performance (service provided). A few have attempted to measure effectiveness in terms of force effectiveness in combat.

In the past, efforts have been made to develop combat effectiveness measures for large communications systems but these have depended so much on subjective judgment that they have been unable to gain an acceptable degree of credibility. The difficulties involved in developing such measures are in themselves worthy of a paper; for this reason, this paper will deal only with the development of performance measures of effectiveness. The general tone of this paper is philosophic rather than scientific; it concentrates on the selection and organization of criteria rather than on analysis techniques. It is concerned principally with the evaluation of large trunking systems. In the discussion following, the general application of measures of effectiveness (MOE's) to system evaluation is discussed, the effectiveness measures used in two past Army study projects are reviewed, and a more integrated organization of effectiveness information is suggested and critiqued.

THE NEED FOR MOE's

As with all cost-effectiveness problems, the first questions which the communications system analyst must ask himself are, "What does the decision maker want to know?; What does he need to know?; And what is the study result to be used for"? The problem posed may be one or a combination of the following:

a) Optimizing a system design, by deciding what features to include and how much capability to provide in various system elements.

b) Comparing proposed system B with system A.

c) Determining how much communications to buy, or whether to buy a particular "improvement."

d) Deciding how to best use a new system or system element.

Plainly, the approach to the study and selection of measures of effectiveness is greatly dependent on which of these applications is designated as the purpose of the study. If the object of the study is merely to optimize the system by finding the most suitable elements, or levels of element capability etc., it is frequently possible to sub-optimize with regard to some particular performance characteristics without need for comprehensive effectiveness comparisons on a system-wide scale. It may then be necessary only to identify the basic measures of effectiveness applicable to the problem and provide a logical demonstration that the MOE's being ignored are insensitive to the system variations being explored.

When two systems are compared (Item b above), the first approach attempted is generally that of equalizing the capabilities of both systems by assembling and configuring them to provide equivalent service features and then looking to cost and resource consumption as discriminants. When it can be used, this approach provides a happy solution since it avoids the need to make either performance or combat effectiveness comparisons. It is more likely, however, that despite the best efforts of the analyst to design equal capabilities into the two systems, some differences in system characteristics will nevertheless appear which must be evaluated in terms of effectiveness.

If the decision maker's problem is to determine what degree of communications capability is justifiable, he faces the most difficult problem of all since he must then consider the impact of more or less capability on the combat effectiveness of the force. If the analyst can supply information only in terms of performance and capability he should at least present this information in a way that will minimize the difficulty of visualizing the effect of performance on military operations. One way to do this is to choose MOE's which accurately represent the interests of the real user of the system.

REVIEW OF PAST EFFORTS

It is instructive to review the MOE's and presentation techniques employed in past evaluations in order to become familiar with the difficulties encountered. This review also establishes a basis of comparison with the approach recommended in this paper. The MALLARD system study evaluations and an early TACSATCOM cost-effectiveness study have been chosen for this purpose because the writer is familiar with them and because both were concerned with large (field army scale) trunking systems. Both efforts resulted in study reports.

The MALLARD cost-effectiveness effort, originally conceived as a massive comparison of several contractor-proposed system approaches, in reality became a piece-meal comparison of designs for system elements. A set of MOE's for the evaluation was established by the MALLARD project in advance of the evaluation; this set was applied across the board to systems, sub-systems and sub-system elements. Results of the evaluation were presented as a written discussion and also as weighted - sum scores subjectively assigned by the members of the cost-effectiveness working group. Scores were developed both on "pure weight" and "ranked weight" bases and were presented as individual numbers for each MOE and also as a grand-aggregate total for each sub-system.

The measures of effectiveness prescribed for use in the MALLARD evaluation are listed below. It will be noted that only communications system characteristics and service features were used as measures.

MALLARD Effectiveness Measures

Satisfaction of User Requirements (See below)
Availability
Survivability
Security
Flexibility
Mobility
Economy of manpower
Ease of operation and maintenance
Conservation of frequency spectrum
Economy in electrical power
Ease of phase-in

MALLARD User Requirements

Security
Grade of service
Call set-up time
Interconnection time
Speed of service
Quality of service
Out-of-service time
Survivability
Special service features
Mobility
Flexibility
Phase-in compatibility
Frequency conservation
Power requirement
Manpower conservation
Range
Simplicity of operation and maintenance

The second case history to be reviewed is a cost-effectiveness study performed a year and a half ago comparing satellite and conventional communications. Again effectiveness was considered only in terms of system characteristics and service features. To provide an effectiveness comparison, MOE's were weighted and the competing systems were subjectively scored by a committee. However, in this case, a final, overall effectiveness index number was generated through the use of a relatively complex formula. This formula, the basic MOE's, and a break down of the "factors" contributing to each MOE are as follows:

Measures of Effectiveness
Used in Cost-Effectiveness
Evaluation of Satellite
vs
Conventional Communications

Effectiveness = S x F

S = Suitability = r + s + s + s + f + e

reliability	simplicity
security	flexibility
speed	economy

$$F = \text{Feasibility} = \frac{4}{\frac{1}{r} + \frac{1}{p} + \frac{1}{s} + \frac{1}{a}}$$

resistance to enemy action	spectrum availability
probability of communication	system availability during critical phase

Even a cursory examination of the preceding lists indicates that system evaluators were having trouble with selection and organization of measures. There can be little question that most of the items listed as measures are germain to an evaluation; the difficulty is that factors and sub-factors, requirements, service features, equipment characteristics and cost or resource items are all treated as MOE's with no clear delination of inter-relationships.

To provide a basis for a more detailed critique of these groupings, it is desirable to establish a set of criteria for the selection and grouping of MOE's. These are developed in the discussion following:

Criteria for Selection of MOE's

A cost-effectiveness analysis starts with the concept that the reader will use the results of the study to decide one of the types of issues listed previously, i.e.: Which system is best?; What is the best choice of configuration and equipment features?; How much capability should be bought?; Where can it best be used? In the decision maker's mind, (assuming he accepts the unavailability of combat effectiveness data), basic kinds of data needed are:

a) What degree of service does each system provide?
b) What resource penalties must be paid for the system considering such diverse elements as dollars, frequency spectrum, manpower, and operational handicaps.

This leads to the initial argument that each variable listed as an evaluation consideration should be classified either as a "cost" (resource demand) item or as an effectiveness measure - that is, each variable should be a measure of some aspect of penalty paid or service rendered.

The second important requirement is the need for a proper definition of the "user," - the individuals or groups served by the system. It is necessary to distinguish between those who use the system (subscribers) and those who are involved in its installation, operation and maintenance (Signal Corps personnel). The latter should really be considered as part of the system. This enables the distinction to be made between features which serve the user, and are therefore service or effectiveness features, and features which affect the difficulty of operating the system and are therefore, "cost or resource considerations." In this sense, Simplicity and Ease of Maintenance, are not user service features; they are factors affecting cost.

A third principle is that of maintaining independence (no overlap) in the basic measures themselves. No matter whether the reader is making a conscious, recorded weighting and scoring of systems or an across-the-board subjective judgment, he needs non-overlapping measures if he is to keep his thinking straight. It is plain that if two measures contain an area common to both, that area, to some degree, gets counted twice and so distorts the total picture. If, for example, Flexibility and Availability are both listed as ultimate measures, double credit is given to whatever effect flexibility has on system availability. There is no doubt that the intelligent reader can detect such overlaps between criteria, but it is doubtful that he can keep very many such relationships in mind without getting somewhat confused.

Also, any decision process becomes easier when the number of basic considerations is minimized. Hence it is important to employ as few basic measures of effectiveness as possible. This is done by consolidating lesser factors into bigger ones in a way that leaves the relationships between major factors and sub-factors clear to the reader. Another way of reducing the number of MOE's is that of equating the capabilities of competing systems as suggested previously in the introduction.

Finally, it is obvious that the set of MOE's selected should be quantitative in nature and taken together, should cover all of the performance aspects of importance in the evaluation.

A list of these selection criteria is as follows:

Criteria for Selection of MOE's

Relevant to the real user	Definable and unambiguous
Independent	Complete in coverage
Few in number	Quantitative

It is now possible to examine the MOE lists of the MALLARD and Satellite

System Studies with reference to the above criteria for selection. It is plain that the MALLARD selection of MOE's violates these rules in several ways.

To begin with, the second and third items, availability and survivability, can be combined, since true availability, seen from the user's point of view, is the availability of the system under stress.

Security (a user service feature) is usually a requirement which must be fully met by the systems under comparison. It should appear on the list of MOE's only if there is some required aspect of security not satisfied by one of the systems.

Flexibility and mobility are two particularly bad choices. They are difficult to define, and they are not service features of direct interest to the user. This is not to say that they are unimportant; the difficulty is that they are not primary MOE's. Instead, they should be handled as system characteristics affecting availability, survivability, cost and resource consumption.

The last five items on the MALLARD list are characteristics affecting cost and resource consumption and do not belong on a list of effectiveness measures at all.

Satisfaction of User Requirements, the first item on the MALLARD list, can introduce many or few effectiveness measures to be considered, depending on whether the systems being evaluated fully meet the stated requirements. For the MALLARD evaluation, many of these requirements were stated only as objectives; this made it necessary for many of these to be taken into account as effectiveness considerations.

In the list employed for the evaluation of satellite vs conventional communications, basic measures are relatively few. Sub-factors (system characteristics) were grouped under the measure they affect but the choice of basic measures still suffers from overlap, poor definition, and the listing of resource demands as effectiveness measures. A weighting and scoring system was used for presenting the opinions of the evaluation team and a formula of dubious logic was employed to consolidate these ratings. If the decision maker were disposed to investigate the basis for the final aggregate ratings presented, it is difficult to see how he could find satisfaction in this precise formulation of vague elements.

In summary, judged by the proposed criteria, it must be said that both the MALLARD evaluation and the satellite communication study have employed too many overlapping and poorly defined MOE's, have confused effectiveness and resource measures and have compounded the confusion by the use of weighting and scoring techniques.

A RECOMMENDED ORGANIZATION OF MOE'S

In the discussion to follow, an attempt will be made to define and organize a set of MOE's and resource demand catagories stressing:

a) A definition of the user as the subscriber.
b) The definition of MOE's solely as measures of the service given the subscriber.
c) Maintenance of clear distinctions between requirements, MOE's, equipment characteristics and resource demands.

An illustrative list of MOE's and resource demands will be presented and then reviewed to see if they satisfy the criteria just employed to critique the MALLARD and SATCOM lists. This proposed breakdown is as follows:

Measures of Effectiveness

Connectivity	Speed of Communications
Time to Establish Communications	Miscellaneous Special Service Features
Availability	

Resource Demands

Investment costs	Operational handicaps
O&M costs	Frequency spectrum
Manpower	Prime power

Measures of Effectiveness

The first four effectiveness measures listed are intended to satisfy the basic concerns of the user about his communications namely:

Who can I communicate with?
How soon can I have service?
How reliable will it be?
How long will it take to get my message transmitted and correctly received?

Suggested definitions of these measures follow:

Connectivity is defined as a statement listing the users serviced by the system and any constraint on service peculiar to certain users. Connectivity appears as a basic MOE when there are some subscribers who desire service but cannot be given it because of some inherent lack of capability in the system.

Connectivity would, for example, be a consideration in comparing a satellite system providing communications with distance mobile users with a conventional system unable to connect with these users.

Time to establish Communications meaasures how long it takes to establish various levels of communications capability when a force is deployed into a new theater or when a large component of the force moves to new positions. Equipment characteristics such as set-up and tear-down time, battlefield mobility, and land, sea and air transportability must be taken into account in evaluating this aspect of performance. "Time to establish" can be expressed by plots of the build-up of capability vs time for a newly deployed force with capability expressed in terms of number of operable subscriber-to-subscriber linkages or gross traffic handling capability.

Availability is a measure of "reliability of service" after the communications system has been moved in and placed in operation. It is affected by factors such as equipment reliabilities, repair times, system redundancy, degradation during movement, and vulnerability to enemy action. Availability could be measured in terms of the percentage of the installed subscriber linkages usually operable or as the percentage of installed traffic handling capability actually available to users. It will be noted that these measures are similar to those suggested for "Time to Establish." This is to be expected since, by definition, "Time to Establish" is concerned with the degree of communications availability during the build-up phase, while "Availability" is concerned with the level of communications capability maintained after build-up. The go, no-go nature of "availability of service" should be noted; as it is used here, the term implies that the individual subscriber is either connected into the system or he is not. It is possible that some analyses problems may require other definitions of a service outage, - for example, a rule that service has been lost if communications delays rise above some reasonable level.

Speed of Communications is defined for the telephone subscriber as the time interval between his initial call attempt and the time his call is acknowledged at its destination plus whatever time is lost in repeating the message because of poor quality of service. Teletype delays can be described as the time interval between submission of the original written message and the time it can be taken off the printer at its destination. In some circumstances, it may be appropriate to include delays in delivering the printed copy or to exclude time losses in message preparation at the originating terminal. It will be noted that these are comprehensive definitions of delay, including the combined effects of speed, grade and quality of service. Speed of service is the delay caused by system processing. Grade of service, however, requires a definition of user behavior before it can be translated into delay - e.g. if it is assumed that the subscriber whose call is blocked makes a given number of sequential attempts until he succeeds in placing his call, grade of service can be expressed as delay. Quality of service (if really bad) can also be converted to delay. With very poor quality of service, a voice or teletype message can be repeated as a whole or in fragments until satisfactory reception is achieved. These repetitions constitute delay.

Special User Features is a catchall catagory listing any performance feature having an effect on service that is not taken account of by one of the four major MOE's. For example, if a particular communications security feature is an option to be evaluated, or if one of two systems being compared provides a security feature the other does not have, these features would be listed as MOEs. Items which may fall into this catagory are:

Security features	Call transfer capability
Conference capability	Broadcast capability
Call capability	Mobile subscriber access capability
Voice recognition	

In a comparative analysis it is not likely that many of these specific "required" features would need to be considered, since they usually would be provided by all the systems being compared.

Resource Demands

The above list of resource demands has been included only because it helps to clarify the distinction between effectiveness and resource items. Most of the elements listed are familiar and need no explanation. An exception may be the catagory "Operational handicaps." This includes difficulties imposed on military operations by the nature of the communications system - e.g., an increased likelihood that the enemy may detect command posts because of the visibility of communications antennas.

Manpower is normally an element of cost, but it is listed here as a separate item because the Army usually attaches a special significance to an increased requirement for manpower in addition to its cost implication.

CRITIQUE OF PROPOSED MEASURES

With this proposed breakdown of MOE's defined, it is now of interest to pass judgment on it in accordance with the criteria suggested in the preceding section; namely that MOE's should be few in number, relevant to the real user, independent, well defined, and complete in coverage.

First, are the proposed MOE's few in number? If one assumes that few differences in special service features need be considered during a comparative analysis, the measures listed are unquestionably few. If differences in special features do appear, some may be eliminated as MOE's by evaluating them in terms of their effects on the more basic measures of Time to Establish, Availability and Speed. This would also present them in terms more meaningful to the reader.

Are the MOE's independent? Are they accurately defined? Because independence is in large part a matter of definition, these two questions will be considered jointly. First, it is desirable to review what is meant by the term independence. Here we seek independence in the sense that we do not want two MOE's measuring the same thing. An examination of the four major measures proposed shows that Connectivity and Speed describe completely unrelated aspects of service but Time to Establish and Availability are really expressions of Connectivity under different circumstances. This calls for rather careful definition of terms. Time to Establish must be viewed as the speed with which a given level of connectivity can be established. It therefore has a unique meaning despite its dependence on the use of connectivity as a measure. Availability expresses the probability that users will remain connected during operation under stress.

In a fundamental sense, therefore, each of the four major MOE's is measuring a different quality of the system, i.e. - capability to serve various types of subscribers, time to establish that capability, the probability that the capability will be retained, and call speed offered.

Finally, with regard to the criterion of "Completeness" does the set of measures proposed cover all of the aspects of performance important to the decision maker? The coverage of this set of primary MOE's can be illustrated by grouping all of the factors considered by the MALLARD and satellite communications studies under the primary MOE's that take account of them. A resource demand grouping is also shown. This does not provide a very useful list of subfactors because so many of them are vague and redundant. However, it does indicate that the proposed breakdown of MOE's is capable of representing all of the effectiveness items considered by the MALLARD and satellite communications system studies.

Equipment and System
Characteristics Coverage

Connectivity	
Range Flexibility	Survivability Probability of Communication Spectrum availability
Time to Establish	
Mobility Flexibility Survivability	Simplicity Resistance to enemy action
Availability	
Availability Survivability Flexibility Mobility	Out of service time Ease of operation and maintenance Reliability Simplicity

Speed

- Call set-up time
- Speed of service
- Grade of service
- Quality of service
- Interconnection time

Special Service Features

- Security

Resource Demands

- Flexibility
- Simplicity
- Economy of manpower
- Frequency spectrum conservation
- Ease of operation and maintenance
- Ease of phase-in
- Electrical power requirements
- Simplicity of operation and maintenance

A concluding argument for the use of the proposed set of MOE's is that a focus on user service features and reduction in number of ultimate measures provide a clearer picture for the decision maker and a better sense of direction for the analyst, helping both to put things in better perspective and reduce the amount of time spent on unimportant details.

PROBLEMS IN APPRAISING A TACTICAL COMMAND AND CONTROL SYSTEM

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I. INTRODUCTION

Application of combat power requires the orchestration of units and weapons to focus their impact at some designated time and place. No less than to the units and weapons, a share of the combat power generated by an army in the field must be imputed to the system which accomplishes this orchestration. A new staff arrangement, a new set of procedures, a new manning policy, each might itself be as cogent a contributor to combat effectiveness as a new weapon. The software of tactical decision, perhaps assisted by some specialized hardware, constitutes a combat subsystem in its own right. Such a subsystem is the Integrated Battlefield Control System (IBCS), now in its concept phase under the proponency of the USA Combat Developments Command. (See CSC, 1; U.S. Army, 7; Stewart, 6.)

As must any subsystem, each increment of a command and control system included in the force mix must justify its cost. Escalation in price and effectiveness of units and weaponry magnifies the opportunity costs of inefficient orchestration. Hence increasing the efficiency of command and control presents a significant potential for enhancing the cost effectiveness of a land combat system. IBCS is on the drawing board and others will follow (Stewart, 6), so the task of evaluating tactical command and control systems will confront analysts for the foreseeable future. This paper addresses the conceptual problems of evaluating a system such as IBCS.

Broadly stated, the problem will be to determine the economic feasibility of IBCS. This problem can in turn be decomposed into constituent questions: whether the system should be deployed at all and, if so, to what extent. This is not to say that in the real world the problem will be couched in these terms. Cost effectiveness is at best only one element in the complex and subjective calculus of defense decision making, and no analyst has yet designed a criterion statement to embrace the myriad internal and external, stated and implicit, objectives of the various executive agencies which have legitimate interests in the outcome.

Even in the narrow sense of determining IBCS's economic feasibility, the question of if and how much to deploy are part of a larger, simultaneous problem. Viewing the army in the field as a combat system composed of subsystems, only one of which is, potentially, IBCS, there is the problem of determining the optimum mix of such subsystems to provide the force for any particular level of combat capability. A second problem is to determine what level of capability should be provided. Obviously, the solutions are interdependent. Solving for the optimum mixes of subsystems to provide different capability levels will establish the cost of each level -- the expansion path as it were for the combat system. The cost of each capability level, the threat, and the political and economic environment are relevant variables in determining the optimum capability level which, ipso facto, specifies if and how much of each subsystem, including IBCS, is deployed.

This formulation of the problems suggests a research strategy directed toward estimating a combat capability function, a military production function if you will, for the army in the field. If the inputs to this production function are units of component subsystems, its specification will permit identification of an optimal expansion path for the force. As will be shown below, estimation can proceed by determining constant-capability (hyper) surfaces in (hyper) space defined by expenditures on IBCS and on operational subsystems.

II. COMBAT CAPABILITY

Given some structuring of the conflict situation, it would seem that a relationship does exist between the inputs of a combat system and the results it can be expected to attain. A functional relationship in this sense can not predict the outcome of a contest, obviously, since action and reaction of the opposing force is exogenous. What the capability function will do, in conjunction with a loss function, is define the pay-off matrix for the conflict. The arguments of the capability function are usefully conceived of as mission accomplishment, opposition faced, environment (physical, cognitive, and effective), risk level, and the subsystems of the field force. For analytical purposes it is also useful to treat the capability function as a military production function to which the field force subsystems are inputs and of which combat capability is the output.

Which brings us to the classic problem of the military analyst -- the measurement of output, a problem peculiarly intractable in the case of general purpose forces (even more so with land combat systems) because of the paucity of plausible indices. By contrast, the missions assigned an aerial combat system are often translatable into measurable outputs without such distortions as would preclude their usefulness (Gilster, 2:1, for example). Unhappily, missions appropriate to a land combat force simply do not lend themselves to this treatment.

And yet the institutionalized mission statement is the professional artifact most closely associated with our output variable. Perhaps "type" missions can be formulated and quantitative variations within each type regressed against input variations. This might be useful if one were careful to search for economies or diseconomies of scale. In the first place, these effects may be the major reflection of the command and control system being used, and secondly they lie at the heart of those realities the soldier calls the Principles of War. For example combat capability indexed by the number of kilometers of defended front which can just be breached to a certain depth would probably show such economies of scale. The larger the zone of action, the greater the potential for concentrating an overwhelmingly superior force in a subzone while economizing in the remainder. For activities within a subzone Lancaster's equations may provide an appropriate model.

But the formulation of "type" missions implies a qualitative differences between types. If an index is to measure all combat capability it must somehow weight these qualitative differences. It would be entirely feasible to weight mission types probabilistically, with weights derived empirically from historical circumstances approximating those of the scenario. All implications of such weighting are not intuitively obvious, but the high-risk bias of an expected value solution are apparent. On the other hand mission categories could be formulated so as to be progressively inclusive. Each mission would include at least the totality of the mission immediately (and hence of all others) preceding it in the progression. Marginal accomplishment of each mission in the progression then would provide in a limited sense at least a monotonic index of capability. Some elaboration of the index could be achieved by introducing quantitative variations within each mission category. Note however, that in each case the next subsuming category would have to include the quantitatively largest version of the immediately preceding category. The following example is illustrative:

Index	Mission
Mission Category A, quantitative level 1	Reduce 10 kilometers of defended front, (followed by detailed specification).
Mission Category A, quantitative level 2	Reduce 20 kilometers of defended front, etc.
Mission Category A, quantitative level 3	Reduce 30 kilometers of defended front, etc.
Mission Category B, quantitative level 1	Conduct a deliberate crossing of a major river (200 meter average width) and reduce 30 kilometers of defended front, etc.
Mission Category B, quantitative level 2	Conduct a deliberate crossing of a major river (300 meters average width) and reduce 30 kilometers of defended front, etc.

This scheme does provide a monotonicly increasing index from A1 through B2. Each step subsumes the previous capability. Note, however, that this progressive inclusion format excludes consideration of a mission such as "Conduct a deliberate crossing of a major river (300 meter average width) and reduce 20 kilometers of defended front, etc." without providing a plausible rationale for systematic exclusion. The problem of determining which of the inumerable possible combinations and permutations represent relevant increments of capability is not solved.

It is apparent that progressively inclusive ordering of missions does not eliminate the central dilemma -- the inability to objectively rank qualitative differences in mission with respect to the combat capability represented. Since progression from one mission category to the next is marked by the incorporation of a new mission type, categories farthest on in the progression will be the most complex. Quantitative variations within a category can take the form of increments to any one of the mission types subsumed in that category as a result of the inclusion requirement as well as to the mission type which differentiates that category from its predecessor. Thus even the definition of quantitative levels within a category implies discretionary elimination of alternative mixes. The consequences of using such an index would be to change the problem from one of weighting between mission types to one of weighting between alternative sequences of progressively inclusive missions. It might be worth considering that the latter formulation is more amenable to judgmental treatment. The relevance to a given scenario of a particular progression of missions is much more readily assessable than is that of a specific type mission. In this respect such a capability index may facilitate the rational meshing of objective measurement and subjective judgement to some extent approximating a cardinal measure of capability useful for determining the optimum capability level to be deployed. On the other hand, only ordinal capability is needed for optimizing the subsystem mix, so the elusiveness of rigorous cardinality may not be debilitating.

The subsystems into which the field force can be resolved are the inputs which produce the output capability. Since IBCS is the subject of inquiry, we may treat it as a unique functional subsystem and partition the remainder of the force into operational subsystems, the salient characteristic of which is ability to apply force. The analytical usefulness of operational subsystems accrues from their penultimate position in the catena from resources to combat capability; their logical proximity to combat capability makes their causal relevance directly perceivable to the professional observer. Moreover, it is entirely feasible to measure operational subsystems quantitatively. The unit of measure could be the largest unit within which organization is essentially independent of other subsystems and should approximate some existing configuration in order to provide continuity of perception with respect to its associated operational capabilities. Further, it would probably be useful to define operational subsystems by their combat roles. For instance, a subsystem might be defined by its application of force by fire alone and might have as its unit of measure an archtypical artillery battalion. A subsystem which applies force by a combination of fire, maneuver, and close combat might have as its unit of measure an archtypical tank and mechanized infantry battalion task force. Other operational subsystems are possible, but it seems that as a first approximation these two could reasonably represent that face of a combat system presented to the opposition while providing a format within which the input mix can be varied.

The IBCS subsystem provides a cluster of functional capabilities under the rubric of command and control. It is external to the units of the operational subsystems and their respective logistical slices, but is linked to them all by information flows of intelligence, internal status, and orders. According to current concepts, IBCS will provide routine and on demand information display. It will provide for order preparation and dissemination and perform feasibility checks on alternative courses of action. Intelligence will be served by data storage, retrieval, collation, and interpretation. Associated with the intelligence and order preparation functions, the capability to allocate available fire power among acquired target may eventually be included. Finally, IBCS will have some capability to interface with the systems of other services. (U.S. Army, 7)

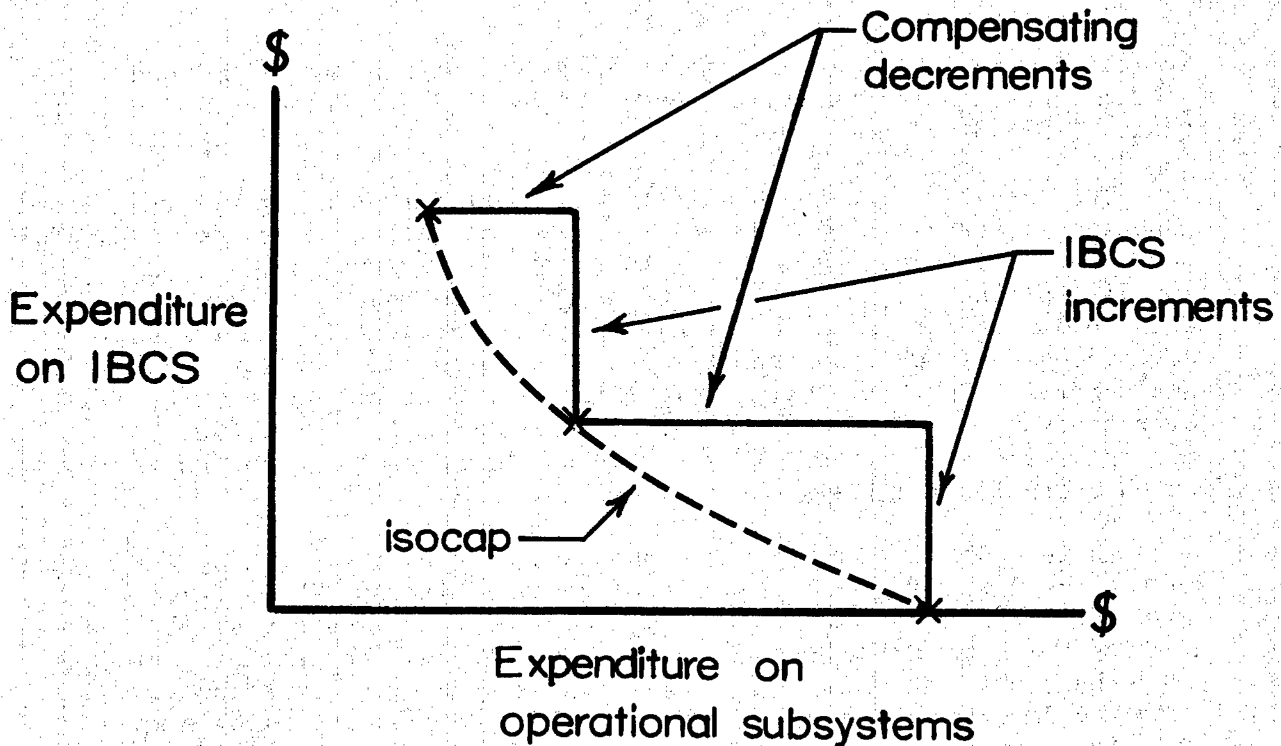
Quantitative measure of IBCS would probably be based on specific description of each functional capability. Relevant descriptors might include time, capacity/definitiveness, and compatibility with human cognition. Descriptors would have to be sufficiently inclusive to permit assessment of operational utility by professional judgment, yet not so numerous as to generate an unwieldly total when applied to each functional capability. If each quantity, or "density", of this subsystem is specified by description of each of its capabilities, the ordinal relationship of different densities can be described by their relative costs. Hence one can infer that as a practical matter this argument of the capability function is only grossly divisible. Any attempt at minute gradation would increase the pertinence of alternative allocations of the resources represented by any given density between the various functional capabilties of the subsystems. For heuristic purposes, the analyst might initially consider only a few, significantly different, densities, leaving for subsequent refinement the suboptimization between functional capabilities.

There are probably only a few useful things one can say about the capability function _a priori_. Malcolm Hoag of RAND (3: 3 - 23) has invited attention to the possibility of increasing returns to military production functions, which possibility would seem to extend to the operational subsystems described above. On the other hand, the Lancaster equations which Hoag invokes are based on assumptions most plausible in local encounters. Their generalization to larger magnitudes is tenuous. The lamentable, but apparently inevitable, slice of the field army that is associated with each combat unit is not represented in the Lancaster model and may more than offset the increasing returns to scale it predicts. On the other hand, if there is any validity in the conventional wisdom of tactics, the persistence of emphasis on concentration through generations of practitioners of the martial arts would suggest that, at least in the past, increasing returns have existed somewhere in the process. To the extent that these do exist, the combat capability function would appear to be homogeneous to a degree greater than one, with respect to its operational subsystems. In execution, however, realization of increasing returns requires concentration of combat power. On a battlefield where target acquisition systems are linked to nuclear firepower by real time command and control systems, concentration, and hence increasing returns, may be a relic of the past. Note, however, that whatever one may deduce concerning returns to operational subsystems, there are no obvious inferences concerning the effects of IBCS.

III. ESTIMATING THE CAPABILITY FUNCTION

Resolving the analytical problem into the complementary questions of determining the optimum subsystems mix and capability level suggests a research strategy directed toward identifying the optimal expansion path for the field force. To this end one attempts to identify constant-capability (hyper)surfaces (hereinafter referred to as isocaps) in (hyper)space defined by expenditures on IBCS and on operational subsystems. The estimating strategy is most readily illustrated initially in two dimensions. In Figure 1, one intercept of the isocap is established by specifying a level of capability and calculating the cost of the conventional operational subsystems associated with it. A second point on the isocap is identified by reference to that intercept: its ordinate is established by specifying some density of deployment of the IBCS subsystem, probably in terms of functional capabilities, and calculating the costs therefor, whereupon the absicissa is established by applying professional military judgement to determine the decrement in operational subsystems which would just compensate for the increment in the IBCS subsystem. By specifying alternative IBCS deployment densities and calculating the cost of each corresponding compensating decrement, sufficient points are located to define the isocap. Repeating this procedure, starting each time from a new intercept, provides isocaps for different capability levels. The locus of minimum cost points on all isocaps is the expansion path for increasing budgets and force capability.

Figure 1



Estimation usually proceeds from an historical data base, through manipulation by an analyst, to some desired generalization. It is proposed that in estimating the combat capability function the historical data base be filtered through the cognition of individual military members. Each individual's synthesis of that portion of the extant data base to which he has been directly or indirectly exposed is the basis of so called "professional judgment." Most historical experience with the military capability function is never reduced to writing; instead it lodges, inchoate, in the minds of the participants. Thus drawing upon professional judgment is an attempt to take advantage of an empirical reservoir untappable in any other way. A less exotic but perhaps more practical reason for inviting professional participation is to enhance the acceptability of the results.

It is perhaps a truism that in an inductive process the resultant generalization depends as much upon the process by which the specifics are successively summarized as upon their substance. This is especially pertinent when the efforts of many processors are required. The estimation of a capability function is no exception. Committee determination of a summary estimate would be suspect for a number of reasons. The decision process in a committee is very likely to be integrative instead of optimizing. Although the verbage may portray an attempt to satisfy some stated criterion, the real interaction is more apt to be dedicated to lowering internal conflict. Hence committee conclusions may be only incidentally based on the apparent data and actually be most strongly influenced by substantively irrelevant factors such as the power relationships between participants, their personalities, and their forensic skills. Delphi techniques can ameliorate these deleterious effects considerably, depending on the degree of anonymity accorded participants and the skills of the moderators (See Jantsch, 4:137 - 140; Quade, 5:324-344).

The results of analysis will be most useful if the capability function is estimated with an index of obvious relevance to any plausible scenario. The procedure would be to start with a scenario, a structured conflict situation, and a specified mission, and then to query professional respondents as to the number of standard operational subsystem units necessary for its accomplishment, assuming a conventional command and control subsystem. Using Delphi techniques to reduce the variance of responses, a specific amount of each subsystem is established as necessary and sufficient. This consensus then becomes the datum from which operational units are traded off for IBCS.

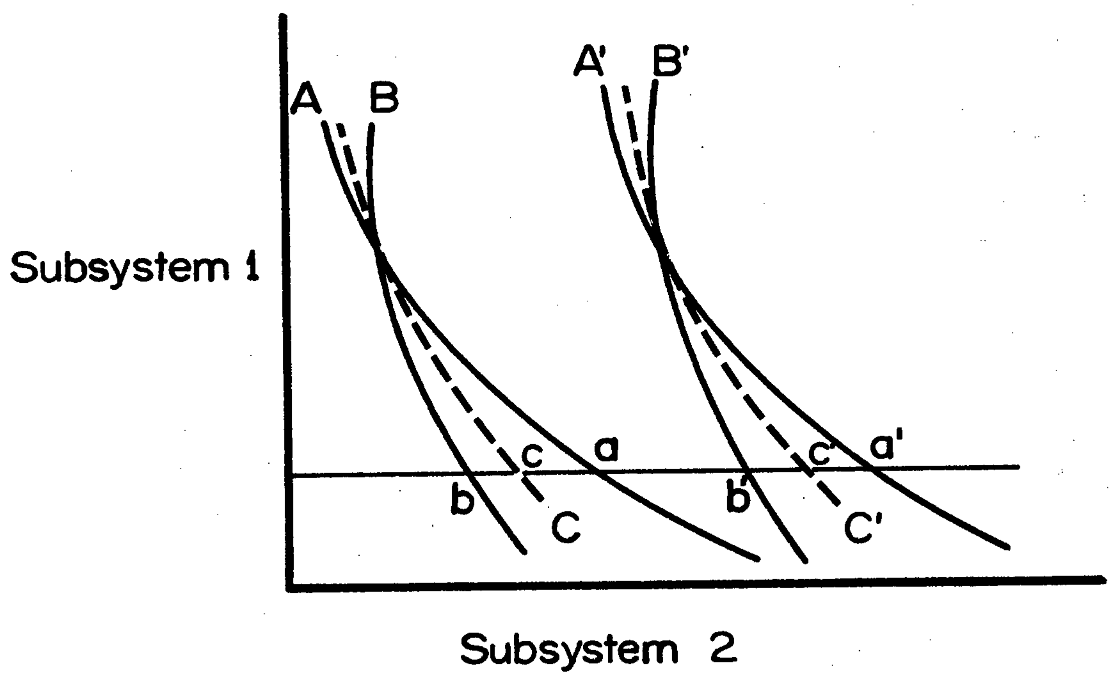
In the unlikely event that a consensus can not be reached, estimation must proceed without specification of an explicit capability index. Instead, recourse is made to the implicit index inherent in simply postulating some input mix, perhaps a mix suggested by the initial estimates or perhaps one approximating the mix represented by an existing organization with its doctrinally "normal" support. For example, one might simply specify ten maneuver units defined as composite tank-mechanized infantry battlions) and ten fire units (defined as medium artillery battalions in direct support or reinforcing roles), leaving it to each respondent to impute to this mix whatever capability he deems appropriate without having to articulate it in terms suitable for interpersonal comparison. From this datum, each respondent would then estimate the number of units of each type he would be willing to exchange for a specified IBCS density, retaining whatever level of capability he subjectively imputed to the datum mix. Establishing tradeoffs on the basis of imputed capability is tantamount to indexing combat capability with inputs under a conventional command and control system. It has the advantages of obviating direct interpersonal comparison of capability and of facilitating the estimation of isocaps. On the other hand, while the results of an analysis which relies on imputed capability will be fully useful for decisions on internal force structure, the absence of articulated mission relevance will detract from their usefulness for determination of total force level.

Estimation of the capability function is facilitated by a minimal assumption of transitivity. If operational capability is transitive for quantitative changes in the subsystem variables, isocaps (constant capability surfaces) in subsystem space will be non-intersecting. This would imply that the function is monotonic in the sense that with more imputs one can accomplish at least that which could be accomplished with less since redundant forces need not be used and are assumed not to represent a liability. On the other hand, qualitative parametric changes could yield families of isocaps, members of which intersect with isocaps of different families.

If at least two operational subsystems are considered, each respondent will estimate isocaps in three dimensions -- the two operational subsystems and IBCS -- therby permitting internal checks for consistency. For instance one might start with the ten and ten conventional mix mentioned above as one point on the isocap. If for convenience in explication the values of the variables, maneuver units (M), fire units (F), and command and control level (C), are represented as a vector, this datum point is (10, 10, 0). From this point the respondent states the increment of F required to just offset a unit decrement in M, with C held constant. Repetition provides estimates of successive vectors down to (M_{min}, F_{max},)). A reverse process from the same datum provides estimates up to (M_{max}, F_{min}, 0). At this point the first check for consistency can be introduced by estimating the compensating changes in M for successive increments and decrements to F (starting from the same datum) and resolving inconsistencies with the previous estimate. Having established a consistent trace in the C = 0 plane, one then specifies some minimal IBCS density, represented by C = 1, and describes to the respondent the functional capability provided thereby. Starting at one member of the family (M, F, 0), the respondent is asked to state the decrement in say M he will accept to increment C from 0 to 1. From this initial member, the entire new family of vectors (M, F, 1) can be estimated. Once again consistency can be checked by making the initial estimate in the (M,F,1) family with a compensating decrement in F instead of M. The trace in the C = 1 plane developed from this point can be compared to the previously estimated trace and inconsistencies resolved. This procedure is repeated for incremented IBCS densities until the isocap is sufficiently defined for the purpose of the analysis. In general, so long as the isocap is defined in more than two dimensions, any point on it can be estimated from more than one direction, thereby providing a consistency check on the individual respondent. So long as the respondent can resolve any initially inconsistent estimates, the assumption of transitivity of his estimate of the capability function is justified.

To be useful, estimates of individual respondents must be aggregated, but combat capability can not be shown to possess objective cardinality, so aggregation must take place in one of the input dimensions. Respondents provide sets of non-intersecting isocaps, corresponding members of which arise from common indexed or imputed capability and may intersect since interpersonal transitivity is not assumed. In Figure 2, for instance, the two-dimensional isocaps are the estimates of respondents A and B. A' represents the same level of capability as does B', which level exceeds that represented in common by A and B. It will always be true, in any subsystem dimension, that $a' > a$ and $b' > b$. If this is the case, it is obvious that in a system of aggregate isocaps, C, in which $c = \frac{a+b}{2}$, c' will always be larger than c and the system of aggregated isocaps will be non-intersecting. This results generalizes to n subsystems. Transitivity has not been assumed for the aggregated capability function; however, having generated non-intersecting isocaps, we need only the weak assumption of positive marginal capability of subsystem inputs to infer that the estimated aggregate combat capability function will in fact be transitive.

Figure 2

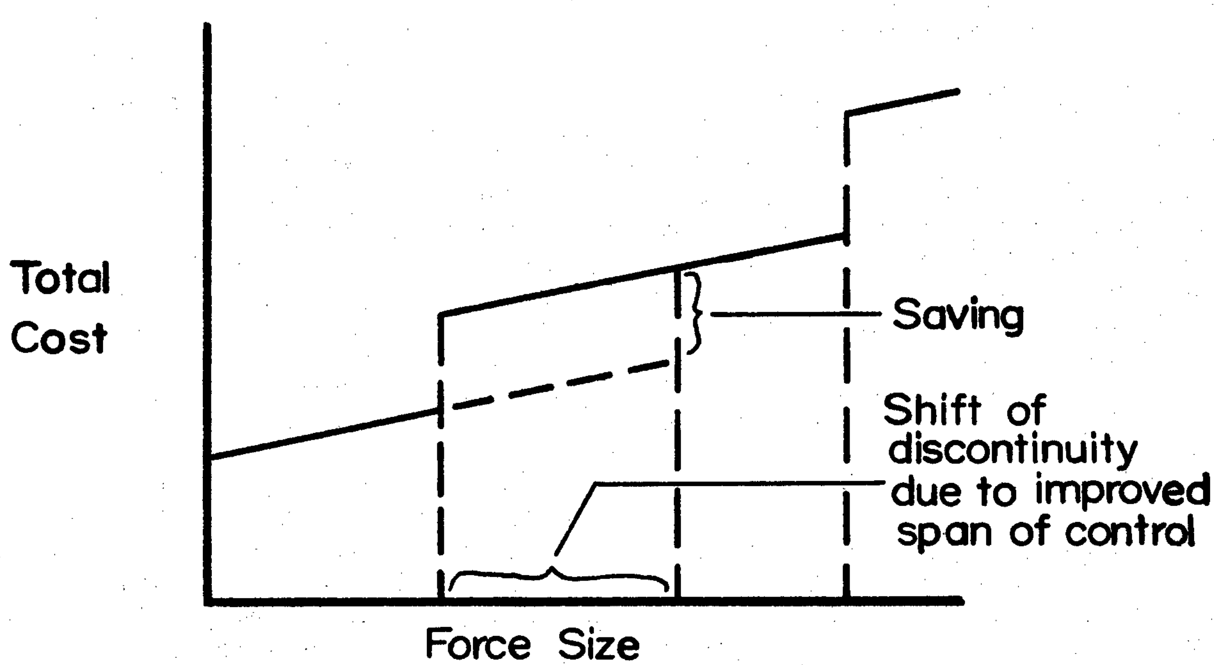


IV - COSTS

Since the problem to be analyzed is the economic feasibility of IBCS, cost calculations are central. Dollar valuation provides a reasonable approximation of opportunity costs both within and without the defense establishment and so is appropriate for measurement of resources utilized by each alternative. Political costs are best left for subsequent inclusion in some larger calculus in which the results of economic analysis are themselves an argument.

A total cost curve can be developed by stating force size in terms of number of units of its operational subsystems and appealing to current doctrine to determine the total field force structure. Extant cost data can then support the estimation of total cost of each size force. Consideration of current doctrine for organization suggests that a cost curve so obtained will probably show significant discontinuities at points where major command and support arrangements must be changed for span-of-control and efficient work load considerations. In the conduct of the analysis this characteristic of the cost curve should be determined early on so that the capability (and force) levels from which the estimation of the operational capability function proceeds may be chosen to fall between discontinuities. Since the estimating algorithm requires trading off between subsystems at cost, the marginal cost of each is crucial. Marginal cost may be different on different sides of a discontinuity and be patently meaningless in crossing the discontinuity.

Figure 3

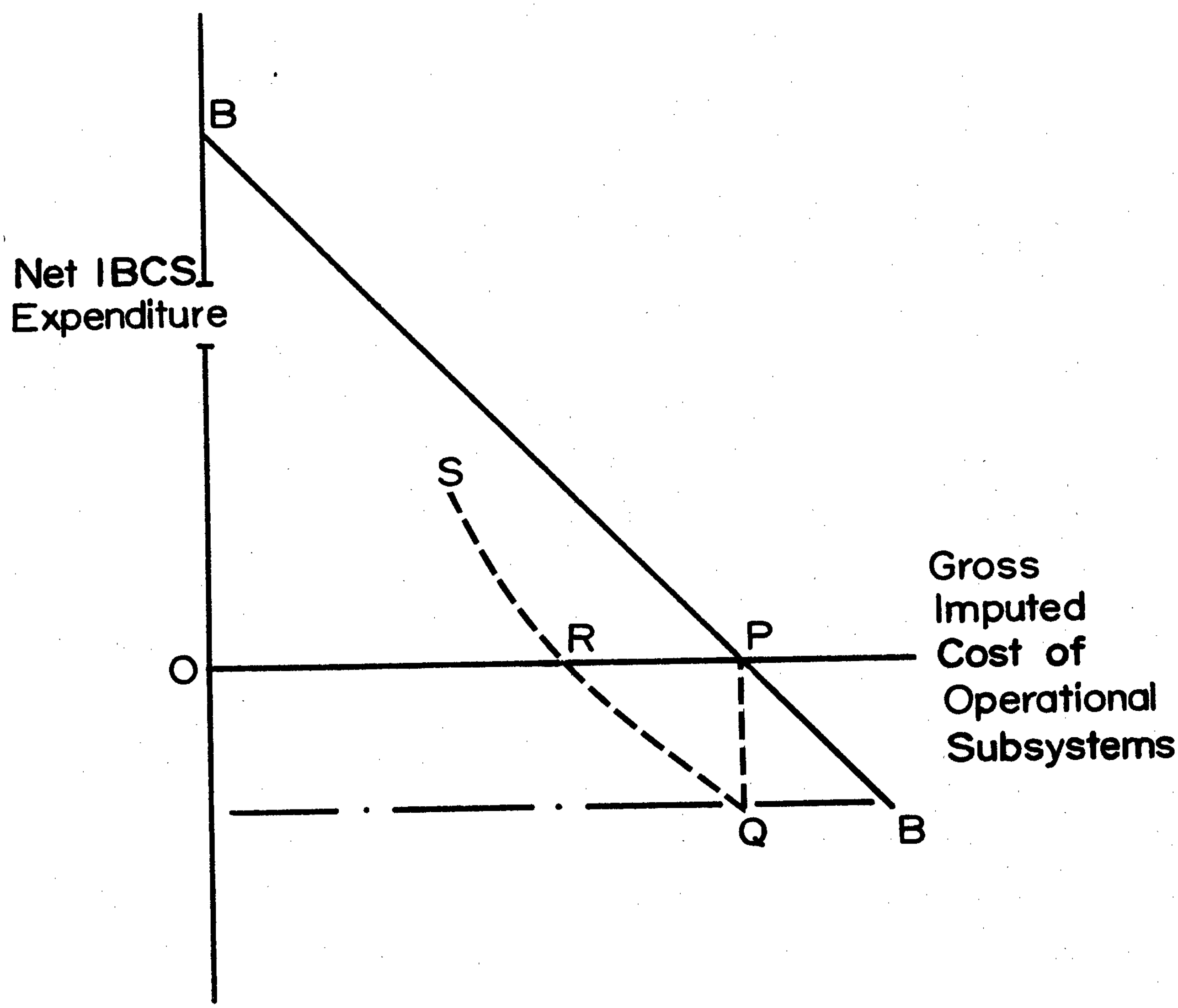


Introducing IBCS will of course change the total cost function. It is by no means obvious that the effect will be to raise the curve, especially at low capability levels. A more radical effect than raising or lowering, however, may be the shifting of discontinuities due to changes in span of control and efficiency of the logistical infrastructure. Figure 3 illustrates how significant cost changes might occur for a given force level if the introduction of IBCS were to shift a discontinuity past it to a higher level.

Costing the IBCS subsystem itself can introduce some conceptual problems. If one considers IBCS as a subsystem distinct from the existing conventional command and control subsystem, it would be necessary to trade off between these on the basis of functional capability. This is not appealing since it is difficult to think of them as distinct inputs providing functional capability as an output. Instead, it appears to be more fruitful to consider the IBCS subsystem, itself deployable at different densities, as replacing the entire existing command and control system while retaining some of its elements. The analysis would then be conducted in terms of the incremental cost of introducing IBCS, with total cost accounted for by subsuming the cost of a conventional command and control structure in the costs of the operational subsystems. Note that at low IBCS densities its net cost may be negative. If the estimated marginal rate of substitution of operational subsystems for IBCS is high, it will be just those low densities which will be of interest for force structure decisions.

Figure 4 relates this costing concept to the estimation algorithm. The vertical axis measures net expenditure on IBCS. The horizontal axis measures gross costs imputed to operational subsystems. In the first quadrant the budget line, B - B, is conventional; in the fourth quadrant the constraint is still met by the sum of ordinate and abscissa but the former is negative. Point P represents a conventional field force of a given size attainable with budget B-B. If net savings are possible, estimation of the capability function would proceed first by increasing gross expenditure on IBCS till the maximum net saving is achieved, keeping functional capability constant. This point is Q, whose ordinate also determines the terminus of the budget line. Since Q has the same functional command and control capability and the same operational subsystem mix, it will have the same operational capability as P, the only difference being the substitution of IBCS for conventional command and control at lower cost. From Q the isocap is estimated in the manner already described. Had net savings at low densities not been considered, the estimating algorithm would have produced an isocap P-R-S, overlooking the Q-R segment which might well be the most relevant for the purposes of executive decision.

Figure 4



V. INSTITUTIONAL SPIN-OFFS

Obviously, deployment of IBCS would have institutional repercussions which should be predicted and assessed. The most obvious effects, however, may cause the fewest problems. Elimination of intermediate headquarters and redundant weapons systems can be easily accomplished. Adaptation of mobilization plans to integrate National Guard and U.S. Army Reserve units into an IBCS-oriented field army is only slightly more difficult. But spin offs which will necessitate changes in the way people think or which invoke future uncertainties may be less tractable to institutional adaptation.

In the area of tactical doctrine, for example, the conventional wisdom as taught in the Army school system presumes the need to achieve superior combat power at some time and place deemed more important than other possible times and places. Superiority of combat power is most frequently conceived of in terms of preponderance of mass (maneuver and fire) and only rarely in terms of surprise. The addition of nuclear weapons to the equation has cut in two directions: it facilitates the massing of fires and makes risky the massing of units. The doctrinal answer to this dilemma has been to emphasize security through mobility. If we now add IBCS to the calculus and consider the decrease in reaction time it will effect, the security provided by mobility may be insignificant. Considering further the pervasive capability of STANO systems feeding into IBCS, (U.S. Senate, 8) it is difficult to see how contemporary concepts of concentration of combat power can remain relevant. In such an environment, tactics which exceed the rate of fire capabilities of opposing delivery systems may dominate. It is also conceivable that the decisive contest will take place in EW and ground combat will only serve to ratify the outcome. Perhaps general spatial stalemates characterized by granular tactics and attriting strategies can be expected. The problem is whether old dogs can be taught new tricks and whether the tricks and their teachers will be set upon the new dogs coming up. Assessing IBCS against a changing and uncertain milieu raises additional questions. Should the missions considered in an analysis include use of force in domestic crises? If some significant level of disaffection became endemic amongst Army personnel, would the incorporation of IBCS make military organizations more or less susceptible to dysfunctional consequences? Could one or a few technological breakthroughs obviate the system? If the IBCS-oriented combat system became suboptimal for any reason, would it be possible to revert to a conventional posture? Is the system "brittle" in the sense that a small margin of inferiority would have catastrophic results?

VI. SUMMARY

In this paper we have discussed some of the conceptual problems associated with evaluating a tactical command and control system, specifically IBCS. The problem is defined in terms of economic feasibility and decomposed into constituent questions of determining the mix of IBCS and other subsystems within the field force and of determining the total amount of the optimum mix to deploy. Indices of combat capability and the capability functions are discussed. An estimating algorithm is developed to provide an interface between professional judgment and objective analysis in order that the functional relationship between subsystems and combat capability of the field force can be specified. The aggregate capability function is shown to be transitive. A preliminary cost estimation may recommend entry points for the estimation process between discontinuities in the total cost function. Costing the IBCS subsystem at net expenditures seems promising but the induced institutional effects of IBCS are problematical.

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SESSION VI B - DISCUSSION

I like the use of your isocaps and what have you, but I think of course, and I'm talking in the presence of Dr. Uhlaner who is a lot more familiar with this than I am; as I recall, those things can be compared to utility curves. I question the substitutability or the lower half of your plane that you talked about. My experience is rather small but any time I've been involved with a system, and the largest one I've been involved with is the Q28, we always had to maintain a manual back-up. You talk about eliminating headquarters. I can't foresee total reliance on any system at the expense of man, or absence of manual back-up. So I think you probably have to restructure those isocaps and flatten them out in the bottom there to make your presentation more meaningful.

NOTE: The comment included in this section is not necessarily complete. It was necessary to delete some remarks as they were unitelligible on the recording.

SPECIAL SESSION ON THE MODERN VOLUNTEER ARMY

Major Peter Dawkins
OSAMVAR, Office of the Chief of Staff

I'm a little uneasy about being at an Operations Research Symposium, I've got to admit. Colonel Montague, whom I think a lot of, you know, and who is genuinely sorry that he can't be here today - being Deputy Dog, that's kind of one of the things you just can never plan for, is probably more appropriately prepared for this kind of thing than I.

I'm one of those other guys in the sense that my schooling, while I began sort of with an engineering background, has taken me adrift since then and my graduate schooling began with emphasis in philosophy, although I'm a political scientist by trade, and more recently in working in the Public Affairs School at Princeton, I've gotten into some sociology and psychology. I have a nodding acquaintance with those things and you all know what use a nodding acquaintance in those sort of things is.

Fortunately, for me, today the purpose that Lieutenant Colonel Butler and I have is not to present a technical paper on the modern volunteer Army, although, Jack will get into much more the sort of things that I think you naturally are involved in and are interested in than I. But rather, our main purpose is just to explain to you briefly what it is we're up to in this office of the special systems for the volunteer Army. What's the Army up to in its effort towards acquiring a volunteer status, and I say that advisedly with the hopes that we may be able to interest some of you - at least allow you to see ways that you can apply your tools to the kinds of problems that we have, because we have a lot of problems that we don't feel totally compentent certainly to deal with at this stage.

I find it mildly ironic that our session is to be followed by a session on the measures of effectiveness, since one of our biggest difficulties is in measuring, in cataloging, in evaluating the steps that we're taking. I offer, as an example, our advertising test that I think probably all of you are aware of - a somewhat controversial operation to which we've devoted about ten and a half million dollars, largely into buying paid TV time. People are saying "what's happening to our tax dollar - are you using that ten and a half million dollars effectively?" And they want to know. By effectively, I think they mean how many new volunteers have you gotten for that number of dollars? But figure it out per volunteer cost. There are some problems - we have some indicators, we have the list fact, the little number at the end of the ads and we're getting about fifteen hundred calls a day. Some of them are finks.

We've got some magazine coupons which are being very interesting. We are getting about twenty thousand a month - people writing and returning the little magazine coupon. Well we don't know what that is going to mean. Certainly it indicates that there is some increase in the amount of interest--people wanting to inquire. We certainly aren't showing any enormous increases in numbers of volunteers at this stage. But of course we have other things too.

We have veterans against the war being active, we've had the drama of the Calley trial, and certainly if there's anything that's been inimical to our purposes it's been that whole business of the Calley episode. In addition to these sort of problems, of course, we're doing other things as well.

We've introduced new enlistment opportunities. We're trying to alter the character of military life itself. So we've got a real problem in evaluating and finding out our effectiveness. So maybe some of you out there can give us a hand in this important area.

I've gotten a little bit ahead of myself and I'd like to back-track and really do what I was tasked to do today and that was to offer a few comments on the approach we are taking - just what is it that we are really up to?

Now this magnificant screen here in vista-vision--You're going to have to wait for a minute to get to enjoy, and I'll keep you in suspense as to what that's all about because my father once said, "you should never follow a dog act," and I feel I would be in real trouble if I did. No, this is a multi-media presentation and I'll explain that in a minute. But about the approach itself, I think all of us, or it's certainly common to have kind of a visceral reaction against the suggestion of a volunteer force, naturally feel threatened by the idea of a military that is somehow isolated from the people that it's pledged to defend. And you think about things like militarism and platorianism, you may think about the problems that the French Army went through with General Solon, when his little group decided that they saw better the purposes of France. You may conjure up images of Dr. Strangelove or Seven Days in May. There are lots of things that come to people's minds when the phrase "Volunteer Army" is mentioned. Some of the apprehensions are, I think, phantom apprehensions and I don't want to go into those, but you know there is a concern that there will be an Army of the poor and the black, but we don't know exactly what a volunteer Army is going to look like or would look like until we do it.

The best projections that we have indicate that the racial and economical balance, while it would change somewhat, wouldn't be violently different than that of a hybrid conscript volunteer Army like we have now. And of course it's important I think in all of this to remember that our blueprint is based upon a foundation of retaining the selective service machinery, so that in the event of large scale National crisis, the Army would be expandible by already registered people to be brought in through a renewal of the conscripting authority. So I think that certain apprehensions are appropriate.

I think each of us as citizens has the opportunity to think about whether we would desire to have a volunteer military, and as thinking people, we can't avoid the judgment of whether we think it is practical. In that regard, I think it's important to keep in mind that it's the Congress that is going to decide the future of the draft, not the Army. That's sort of the way it's suppose to be in the democracy and we have the obligation to establish the standard of who's going to get into the Army. It's the Congress' job to decide how it is to be there to be gotten, which reminds me of an aside, General Forsythe got a call the other--a lot of people want to help us in this project of ours. He got a call from a warden in Mississippi. He said, "General, you've got a problem with volunteers?" "I think I can help you out." So there are lots of ways to get at a volunteer Army. Our approach is really, I think, very simple and it involves three parts. Let me just try to note those very briefly.

First of all, we're paying attention to the disincentive of people joining the military. Those things which either drive people out of the military or which cause them simply to never consider out-of-hand. You can pick off a couple of things that are quite obviously in this catagory. Pay--you're never going to get rich in the Army, but having people on welfare doesn't strike a lot of people as being a kind of vocation they'd like to voluntarily become a part of.

The irritant--the Army is an institution. It has a lot of institutionalisms about it. For example, we've done away with reveille. Nobody could remember why we had reveille so they thought it wasn't a bad idea to do away with it. There is a story, by the way, about why we use to have it, but I don't have time to tell it. Anyway, we are trying to do away with a lot of these institutionalisms that aren't really productive but do tend to be irritant, particularly to young people today.

And finally, to try, in this area of disincentive, to develop an atmosphere of trust where you really treat the soldiers as mature citizens until such time that he proves that that trust isn't appropriate. We've tried to do away with sign-in, sign-out, no bed check, and allow them to have beer in the barracks. The big beer-in-the-barracks threat--just an idea of saying, "we're going to trust you all as being mature people until you prove you can't do it". By the way, we've had no incidents in the Army of problems as a result of putting beer in the barracks.

The second general catagory of our approach is what I'd say the positive incentive of addressing ourselves to those things which cause people to want to follow a certain kind of life - to want to become a part of an institution. In that area, we're primarily focusing on job satisfaction and achievement, what we in the Army call professionalism. It's a very homely sort of approach. It's to try to make people feel that they are an important part of a difficult job being done well. What does this involve? It involves things like making sure you have enough training funds so you can buy gasoline for the tanks so you don't have to have people walking through the fields going rumble, rumble, rumble, I'm a tank, I'm a tank. Now that doesn't really make a guy feel like he's part of something that matters. We've had problems getting enough money for training funds. We're trying to get people away from having to sweep floors and cut grass so much - hire people to do these sorts of things, so our soldiers can go out and train as teams and develop that kind of sense of practice-teamwork-that's so important to really feeling any kind of achievement.

Also, we're just beginning to have a hard look at the whole business of leadership techniques - how people relate to one another, how the superior relates to the subordinate and what aspects of that need to be pampered in connection with the mood of young people today. So there's that whole range of things having to do with the positive incentive to be a part of the institution.

The third part is trying to do a better job of explaining to people what the real opportunities are within the Army. Now, this involves the advertising campaign; it involves trying to get a better recruiting force and cover, more broadly, the whole of the potential population and the new enlistment offices some of you may have seen.

Now, it's within those three general areas that I think that most of the activities we've been part of and undertaken can be thought to fall. Jack Butler is going to go on after I've concluded here and explain in slightly more precise terms of how we arrived at this approach and what lies behind parts of it. A big part of this is our experimental efforts at our VOLAR post, Volunteer Army Test Post, and rather than to try to go through that, we have this vista-vision here. Lieutenant Donahue has come down with his multi-media presentation that is designed to be given to groups like this and lots of other groups, to give them a feel for what it is that we're involved in. Now this is a little bit rough-they finished it last night. I haven't seen it in this form. I saw it in an earlier form and it was fascinating to me. but it says in a lot shorter time than I could what these things are. So I think without further explanation, I'll turn it over to Lieutenant Donahue.

SPECIAL SESSION ON THE MODERN VOLUNTEER ARMY

Lieutenant Colonel Jack R. Butler
OSAMVAR, Office of the Chief of Staff

Gentlemen -

Major Dawkins has provided you with the framework within which we are working toward our goal of zero inductions by 1 July 1973. (Chart 1)

The basic philosophy upon which the Modern Volunteer Army Program evolved was arrived at after extensive study. As we saw it, there were three feasible approaches. (Chart 2)

The first approach of placing primary emphasis on pay was the central thrust of the Gates Commission Report. When that report was first published, we took a hard look at their approach and had a number of misgivings about the conclusions.

--They used an elasticity of supply of 1.25 assuming that the supply of eligible manpower can be accurately approximated by a linear mathematical function.

Chart three portrays a manpower supply function. The linear relationship represents the Gates Commission's estimates. Presumably a 20% increase in pay would yield a 25% increase in enlistments. Although we don't know the exact shape of the function, we do know it is not linear but curvelinear--somewhat like a lazy S. All we are saying is that manpower supply can't be predicted easily. The function accelerates rapidly at some point and then levels off. For example, if you need one hundred steeple jacks, you might pick up fifty at $500 a month but the next twenty-five might cost you $750 a month, the last twenty-five may raise the ante to $1000 a month. The key here is that you can't pay them differentially -- all would be paid $1000 a month.

In addition, their calculations concentrated on the Army's enlisted manpower deficits assuming that if the Army's manpower demands can be met, the other services will be able to staff their forces with qualified personnel. There is a major limitation inherent in this approach.

--Although focused on the Army's requirements, there is the implicit assumption that all branches within the Army have equal drawing power for volunteers. Not so. For example, combat arms draw only about 4% of all volunteers. When they used an overall aggregate Army supply elasticity assuming perfect substitution among branches, they underestimated actual requirements.

--Also, in the area of projecting the capability to attract volunteers, the commission based their projections for FY 70-80 on the pre-Viet Nam FY 63-65 experience. This was highly questionable since it suggests that enlistment behavior post-Viet Nam will be the same as it was Pre-Viet Nam. We all know that attitudes toward military service have undergone a marked change since 1965. It would be more reasonable to project accessions from an average of equal periods pre and post-Viet Nam assuming enlistment attitudes would not be as favorable post-Viet Nam as they were pre-Viet Nam, yet not as unfavorable as they were during Viet Nam.

--We now know that our misgivings were sound. For example, Gates projected FY 72 Army accession requirements to be 148,000. In fact, we will need 244,00. They underestimated by 40%. They estimated true volunteers would total 97,000 as opposed to the 60-70,000 true volunteer range the Army projects, based on recent behavioral data obtained through an analysis of enlistees and their draft lottery sequence number. (Chart 4)

To approximate the number of true volunteers, we divided the lottery sequence numbers into three subsets: 1-120 (those likely to be inducted); 121-240 (those less vulnerable to induction); and, 241-366 (those with a remote chance of induction).

The last subset (241-366) is distinctive because it contains those who are almost assured that they will not be drafted. Therefore, enlistees from this subset are classified as true volunteers. The other two subsets contain a combination of true volunteers and draft-motivated enlistees.

To separate the true volunteers from the draft-motivated enlistments, surveys were taken and studies made, and we found that if we multiplied the number of persons enlisting with sequence number 241 and higher by 2.9, the total number of true volunteers could be closely approximated. This obviously assumes that the number of true volunteers in the subset 241-366 is nearly equally represented in the other two subsets.

This chart is a hypothetical example of the process. Note the three subsets with volunteers in each subset broken out by two-year groups 1950 and 1951 or 20 and 21 year olds. We take the 500 volunteers in subset 241-366 and multiply by 2.9 and find that of the 3000 enlistees (1500 + 1000 + 500), 1450 are true volunteers.

Volunteers from year group 1952 and later, that is 19 year olds or younger, pose a problem since they do not have a lottery sequence number. We found that if the rate of true volunteers for 1951 were calculated, and this rate applied to the 52 and later group, we could again closely approximate the number of true volunteers. Note on the chart that we have taken the 250 volunteers from subset 241-366 for year group 1951, multiplied it by 2.9 and divided by the total number of enlistments for year group 1951 (750 + 500 + 250 = 1500). This gave us a true volunteer rate of .49 for year group 1951. We then took the 200 volunteers from year group 1952 and multiplied by the true volunteer rate of .49 to get a total of 98 true volunteers from year group 1952.

To obtain the total number of true volunteers, we simply sum the numbers of true volunteers from the three distinct year groups (1450 + 98 = 1548). Therefore, out of a total of 3200 enlistments, 1548 were true volunteers.

Although the Army supports comparability with civilian wages, pay alone will not be sufficient. Above a reasonable level of pay, other factors become more important. This brings us to the second possible approach. (Chart 2)

We could launch a massive program incorporating "in one-fell swoop" all of the untried actions surfaced in studies and recommended from the field, obviously, this approach is terribly expensive with no guarantee of success. It is, however, the kind of approach we will probably have to take if induction authority is not extended for two years as the administration and DOD propose.

The third possible approach is the one we are embarked upon. It is essentially a "cut and try", "fly before you buy" approach. We began with an analysis of the problem and concentrated our efforts and money where the problem was most acute. Let's look at the magnitude of the problem as we see it. (Chart 5)

In FY 72 we need 244,000 new accessions or about 20,000 each month. From past experience, we can predict that under current benefits and incentives, we can expect these 20,000 to come from three sources:

--10,000 will be draftees.

-- 5,000 will be draft-motivated enlistments.

Those who elect to enlist in lieu of the draft because they want to choose their time of entry or military occupation.

-- 5,000 will be true volunteers.

So you can see that elimination of the draft eliminates three fourths of our accessions. Or to put it another way, we must quadruple enlistments to satisfy requirements with true volunteers. But this is not the whole story. Only about 300 volunteer each month for the combat arms out of a total requirement for 6500. Although the additional emphasis we are now placing on combat arms enlistments is beginning to pay off, you can see that enlistments in the infantry, armor and field artillery must be increased dramatically if we are to have a volunteer force. Today most of these positions are filled by draftees.

Recognizing the magnitude of the problem and the need for a cost-effective approach to its solution, the Army developed a comprehensive MVA Program. (Chart 6)

The goal is to create a professionally challenging and personally rewarding Army and, in the process, progressively reduce reliance on the draft to zero by 1 July 1973.

It is designed to significantly increase enlistments particularly in the combat arms skills by increasing professionalism and improving service attractiveness, by reducing irritants and menial tasks, by expanding the recruiting effort, and by improving the image of the Army.

Although all facets of the program are important, the heart of the effort is centered on a series of experiments. (Chart 7)

These experiments are designed to accomplish three things:

--First, determine the effect of certain incentives to volunteer.

--Second, measure the potential of new recruiting incentives, especially paid radio and television.

--Third, test combinations of professionalism, life style and society-related actions to determine the most effective mix.

A modest field experimental effort began early in 1971 at four locations in Conus and in Europe. (Chart 8)

Known as project VOLAR it targets on the Army's principal problem, attracting and retaining personnel of the quality and in the numbers needed for the combat arms. It involves a test of "resource supported" actions to determine those that are most productive in producing reenlistments and junior officer retention in the combat arms.

As I said before, it is a "fly before you buy" experiment. It involves a field test and evaluation of measures which will lead to recommendations for acceptance or rejection.

It also involves flexibility. Post Commanders are being given wide latitude in adopting measures which will produce results. VOLAR permits rapid "cut and try" of new ideas as they are presented.

Included in the FY 72 MVA funding is $75.0 M for expansion of VOLAR to 16 locations with an average expenditure of $5.0 M per post.

Actions to be tested at VOLAR installations are designed to improve leadership, increase job proficiency and job satisfaction, and produce better trained, more responsive and capable units, improve living conditions for the soldier and his family, and provide programs to deal with societal problems of the 70's such as drug abuse, race relations and improved Army image.

Evaluation of the test actions will include <u>cost analyses</u> with estimates of incremental capital and operational costs and benefits; <u>military performance measures</u>; and <u>attitudinal surveys</u> relating to changes in attitude toward career intentions and the Army. VOLAR Post Commanders will continue to have wide latitude in adopting measures to improve performance and retention, and maximum flexibility in dropping non-productive measures and beginning new measures.

If we are to realize the full potential of the steps we are taking, the public must be informed -- both the young men and women whom we seek to interest in the Army, and the many groups in American society whose understanding and support is so important to our success.

Consequently, we have intensified our recruiting and advertising efforts to stimulate the flow of new volunteers. As you all know, a nationwide 13-week paid radio/TV advertising test was begun on 1 March. This is another part of our experimental effort. We are watching this with great interest and will evaluate the test carefully to determine its effect on the number of young men who enlist or contact recruiters as a result of this advertising. As of yesterday we were receiving about 1500 calls a day through our listfax service.

If our FY 71 test works -- that is, greatly increase volunteer enlistments -- then in FY 72, we plan a further expansion of our recruiting and advertising effort, and have requested additional money for this purpose. Also we will about double our current recruiting force and add 500 new stations.

To augment our regular recruiting activity, a program of unit recruiting has been initiated in which major units, such as the 82D Airborne Division, actively assist the U. S. Army Recruiting Command within their local areas. So far this appears to be a promising innovation.

A moment ago I spoke of evaluation. We are not so naive as to believe we will come up with really hard data from our VOLAR posts in FY 71. We will surface some indicators and by end FY 72 we ought to have firm evidence on those productive actions which we will expand Army wide in FY 73.

In general our evaluation plan involves data collection and evaluation in several areas. (Chart 9)

<u>Attitude/opinion data</u> will be used to evaluate selected actions as a source of satisfaction, dissatisfaction or of no consequence to experimental groups, to assess further areas where improvement is necessary and to give direction to future MVA programs.

<u>Cost Data</u> will be used to perform a cost/effectiveness analyses of specific actions taken during the VOLAR experiment to identify the relationships of the cost of a given action to its effects. Cost data will include detailed incremental capital and operational costs for the actions implemented. Consideration will also be given to differences in training time, manpower and other resources required to meet suitable levels of military performance.

<u>Statistical data</u> will provide corollary information using Article 15's, AWOL rates, other delinquency actions, etc. These will help measure the progress of Project VOLAR by showing trends and indices.

Performance data will also be used such as comparative inspection reports, skill and knowledge testing, unit testing, and commanders evaluations to determine the effects of VOLAR actions on performance.

Enlistment/reenlistment and retention data will be gathered on the individual's intention and ultimate behavior with regard to remaining in the military service to determine the attraction and retention potential of specific VOLAR actions.

Recruiting/advertising actions will be evaluated as to their cost effectiveness by means of the ultimate indice-increased enlistments in both quantity and quality.

The Human Relations Research Organization and Research Analysis Corporation are providing direct support to each of our FY 71 VOLAR installations and in conjunction with each Commander are responsible for design and evaluation of the installations test. HumRRO is responsible for the overall evaluation. Other agencies in-house and contracted outside the Army will evaluate our recruiting efforts -- particularly paid radio and television.

As for FY 72, our evaluation plan is not yet complete but will probably involve a much expanded Human Relations Research Organization and Research Analysis Corporation support.

Let me close by saying that none of our measures are magic and we have made some mistakes. We have failed to communicate properly our intent to create a better more professionally competent Army. A modern, not a mod, permissive Army. We know that we don't have a clean experimental design and that the results of our efforts will be confounded by numerous uncontrolled external variables. I can only say in defense of our approach that the urgency of time precluded a natural birth. Our organization came into being by caesarean and grew to maturity before our musculature was well developed. This, not withstanding, we have survived the trauma and have made great progress during the short period we have existed.

Major Dawkins and I will be happy to answer any questions.

SUBJECT: Measures of Effectiveness for Direct Fire Infantry Weapons
AUTHOR: Mr. Ronald L. Simmons
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In recent years the Army has spent much time and many dollars in studies which have attempted to assess, quantitatively, the relative worth of infantry direct fire weapons. For both small arms and antitank weapons the scope of the assessments has encompassed essentially every computable quantity - from values as simple as the weight of the combat load to the complexity of all the possible printout from computer simulations. Each of these weapon types has been the subject of extensive studies and simulations - the Small Arms Weapons Study (SAWS), the Tank, Antitank Weapons Study (TATAWS) and the Antitank Weapons Systems Requirements Study (ATMIX). From such studies one obtains measures of effectiveness which aggregate the influence of all the input data and the rules of the game - Blue wins and Red losses, Exchange ratios, etc. As input to these simulations a variety of data has been necessary - measures of accuracy, weight, rate of fire, lethality, vulnerability, etc. Undoubtedly, the resemblance between the simpler quantities which one either would compute or had already computed independent of the simulations is more than coincidental. A significant portion of any easonable analysis of the results of the simulations is a determination of the sensitivity of overall results to changes in the input data.

With these introductory comments, it is now rather obvious that I am going to stress the significance of obtaining valid input data and the validity of conclusions which can be drawn from simple, easily computed measures of effectiveness. Indeed, I would like to suggest that the value and necessity of large-scale simulations has been oversold to the Army and that the possibility of obtaining valid conclusions without such expense has been given short shrift.

An excellent example of this is drawn from the Army's assessment of rifles. The pieces of information which are available for consideration in themselves or as inputs to more grandiose assessments are derived from small-scale experiments. Such relationships as aiming error and the rate of aimed fire as functions of rifle parameters are established in limited firing experiments. Lethality measurements are made separately in the laboratory. Systems weights are immediately available. By using these simply derived data, which are necessary inputs to simulations, very useful comparisons can be made. Hit probabilities, kill probabilities, relative number of casualties per combat load or per unit time can be determined as a function of range to the target for various fire roles. Further, by establishing the functional relationships between the weapon systems parameters and these measures of performance, one is able to generalize results so that additional weapon concepts or modifications to already known weapons can be assessed in the framework of easily understood relationships.

For rifles, such data were assembled and, in my own biased view, provided the most easily understood basis for comparison of competitive weapons. The extent of the data assembled indicates the magnitude of the task of building an adequate simulation. For example, rifles are used in a variety of different fire roles including the sniper role, a quickfire role, a typical day defense role, day assault role, a night assault role, etc. Experimental data tell us that the accuracy in each of these roles is different and that in the sniper role the primary parameters influencing hit probability are associated with the sights and the ballistic dispersion. In the quickfire role, configuration is the controlling parameter; in the day defense role other parameters have been determined to be controlling; in the assault roles errors are so great for all weapons that it has been pretty well concluded that such experiments are not appropriate frameworks for evaluating relative hit probabilities. All of these roles have to be represented in an adequate simulation so building the simulation gets to be quite complicated.

For antitank weapons comparable measures of performance are derived from experiment and analysis. With the arrival of antitank missiles on the scene, the primary measure of effectiveness is single shot kill probabilities - a measure which reflects accuracy, lethality, and reliability. For the missile systems the resultant numbers are so high that other measures of effectiveness are automatically less significant. And this is so even though the times of flight of the missiles are quite large compared to times of flight of the projectiles from the earlier infantry antitank systems, such as the 90mm recoilless rifle, M67 and the 106mm recoilless rifle, M40. However, it is rather obvious that anytime an infantryman takes on a tank, the influence of the times involved is very important. For such assessments we have found that one-on-one duels provide significant comparisons of weapon systems incorporating all of these elements of performance and again indicate that high single shot kill probabilities are dominant. Incorporating all of the times necessary to observe impacts, reload, adjust, etc., relegates systems with low-single shot kill probabilities to secondary status.

All of the tank and antitank weapons have been assessed in a great number of computer simulations. As input to these simulations, it has been necessary to provide all of the bits of data which permit the evaluation of each weapon's role in the larger scenario. Accuracies, time, vulnerabilities, lethalities, etc., have all been required. And again, a primary concern with the ooutput is that is be understandable in terms of its sensitivity to the input data. I conclude, therefore, that an understanding of the elements which make up the input to the simulations essentially provides the solution. For reasonably comparable or competitive weapons, I'm sure this is the case. For weapons which are complementary, this is, to a very large extent, also the case. Thus, I'm suggesting that the more complex assessment of weapons systems by computer simulation is really appropriate only when significant different weapon types are competing for the available manpower or dollars.

SESSION VIII A. - DISCUSSION
Measures of Effectiveness for Direct Fire Infantry Weapons

Question # 1: Dr. Schmidt

Answer:

Mr. Simmons: I would like to comment that I agree with your comment relative to the use of combat data and I recognize that it is impossible to get. In lieu of it, however, what we have done is generate the same kind of data which we have generated for things like the anti-tank systems and for the tank gun. That is, we have in fact tried to develop experiments which determine which parameters are significant in the specific fire roles. Now, one of the things that we have attempted to do here is make sure that the experimental data that we do derive are those generated by soldiers in situations which are reasonably appropriate situations. For example, the Day Defense Experiments at Fort Benning and the Quick-Fire Experiments at Fort Benning. We have never advertised these to be essentially the values appropriate to combat. However, in the larger experiments, for example the CDEC Field Experiments which were carried out as a part of the SAWS Exercise, we did have an opportunity to compare the results based on our predictions from the simple models developed in the Fort Benning experiments with the conclusions obtained as a result of the CDEC experiment. The correlation was essentially exact.

Question # 2: Professor Bonder

Answer:

Mr. Simmons: If I understand you correctly, I absolutely disagree. I don't see how you can, correct me if I'm wrong now, you're saying we can analyze the single shot kill probability, the firing times, the input, and make assessments of better systems. I don't agree at all. I can think of systems where the response times are different and the single shot kill probability slightly different with the importance of response time as highly related to the terrain. You can think of the extreme case where one system has, you know, two systems, one the response time of 10 seconds and one of 12, where you never get a 12 second interval to fire the round at all due to the terrain line of sight. I think that's put in context there. I can think of systems that are longer ranged so you place them at longer ranges but it affects your acquisition time and therefore, you may not do as well. I think you oversimplify the problem, by saying you can look at the input and figure out what the best system is. I think you lose the synergistic effects between the anti-tank systems and the tank systems. I think in some of the situations where we know when somebody fires on another system he tends to expose himself and therefore the anti-tank systems may be good.

Professor Bonder: Obviously, I stated that I over-stated, and I did it deliberately. There are in fact, many situations where direct comparisons can be made, however, because items are essentially comparable items, not really replacing anything in significant terms but providing a better measure of performance in specific catagories. One of the things that concerns me is that each of the developing arsenals and their contractors are eager to provide complex evaluations in as large a scale as the money will permit to address that question which I think need not be addressed and I can give you specific examples that are not appropriate here at the moment. Certainly I agree with you on the matter of the significantly diverse things but even on the input data, given that you have a reasonable set of input data and you have someone who is willing to say that o.k, I think these are appropriate tactical situations or reasonable tactical situations. You have to worry about weighting these things because the conclusions are going to be different for each set. As a matter a fact for rifles, I can give you two experiments, one of which will show weapon A better than weapon B and another one that will show the opposite.

Dr. Grubbs: May I just add, Professor Bonder, that there are some obvious improvements I think. We have lighter weight, high-velocity trajectory bullets for rifles and the lethality has been looked at quite extensively so there's some obvious improvements, such as trying to decrease round-to-round dispersion.

NOTE: The comment included in this section is not necessarily complete. It was necessary to delete some remarks as they were unitelligible on the recording.

MEASURES OF EFFECTIVENESS FOR INDIRECT FIRE WITH NON-NUCLEAR ARTILLERY WEAPONS

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A commonly used measure of effectiveness for an artillery weapon is the lethal area (A_L). The lethal area (also called mean area of effectiveness) is determined for a given weapon/target combination and a specified set of terminal conditions as follows:

1) $$A_L = \int\int_{-\infty}^{\infty} P_K(u, v)\, du\, dv$$

where the target elements are assumed to be uniformly distributed and $P_K(u, v)$ is the probability of "killing" (causing at least a certain damage level) a target element located at the point (u, v).

Equation 1) can be used for either personnel or materiel type targets. However, what is more commonly used for "hard" materiel targets such as a tank is the vulnerable area (A_V).

$$A_V = \int\int_{A} P_K(u, v)\, du\, dv$$

where A is the area of the target as seen by the projectile and $P_K(u, v)$ is the probability of "killing" the target given the projectile lands at point (u, v).

The lethal or vulnerable area can be an adequate measure of weapon effectiveness for comparing projectiles of the same caliber and ballistics. However, the overall ability to damage a target depends also upon how accurately the warhead can be delivered. Therefore a more complete measure of the effectiveness of a weapon system would be the average fraction of casualties for a given expenditure of munitions. Let us denote this by $\bar{f}(n)$. If $\bar{f}(n)$ is used as our measure of effectiveness dissimilar weapon systems can be compared directly on the ability to damage a given target. Effects numbers of this type are currently being computed and published by the Joint Munitions Effectiveness Manual for Surface to Surface Weapons (JMEM/SS).

The JMEM/SS is sponsored by the Joint Technical Coordinating Group for Munition Effectiveness (JTCG/ME). This is a joint effort of the Army, Navy, Marines, and Air Force and as such reflects effectiveness data approved by all of the services. These effects data are computed and then published in tabular form. An example of a page from one of the pamphlets is shown in Figure I. The title and exact firing condition is not included so as to keep it unclassified.

Because the average fraction of casualties is in most cases an adequate measure of weapon effectiveness, let us look at some methodsof obtaining it. For simplicity, let's consider only the case of a point detonating fuze. That is, only the dimensions of range and deflection are considered. Let us use the following notation:

$\bar{f}(n)$	- average fraction of damage for an expenditure of n rounds on one occasion
(u, v)	- location of a target element
(x, y)	- terminal point of a round
$P_d(u, v, x, y)$	- probability of damage to the target element (u, v) given a round lands at (x, y)
$g(\mu, \nu)$	- aiming error distribution (also called bias error or center-of-impact error)
$f(x, y)$	- round-to-round error distribution
$h(u, v)$	- distribution of target elements
(a_i, b_i)	- aiming point of the ith round
A	- area of the target
R	- reliability of an individual round

The average fraction of casualties will then be given as

$$3) \quad \bar{f}(n) = \iint_{-\infty}^{\infty} h(u, v)\left[\iint_{\infty}^{\infty} \left\{1 - \prod_{i=1}^{n} \left[1 - R \iint_{-\infty}^{\infty} P_d(u, v, x, y) \cdot f(x - \mu - a_i, y - \nu - b_i)\right] dx\, dy\right\} g(\mu, \nu)\, d\mu\, d\nu\right] du\, dv$$

The usual distribution assumptions for area targets are

$h(u, v)$ - uniform over A

$g(\mu, \nu)$ - non-correlated bivariate Normal

$f(x, y)$ - non-correlated bivariate Normal

The assumption on the damage function, P_d (u, v, x, y), is not so easy. Since the choice of this function will greatly affect the degree to which Equation 3 can be simplified, let us discuss some possible damage functions.

The JMEM/SS uses an actual damage function matrix in their methodology. A typical damage pattern is shown in Figure (II). In general, by employing the actual damage pattern a more accurate answer can be obtained.

Most other $\bar{f}(n)$ effectiveness models assume the existence of an analytic function which depends upon the type of munition being considered. It is advantageous to pick a damage function which will simplify when it is combined with the round-to-round error distribution.

Two of the most commonly used damage functions are the "cookie-cutter" and the exponential square fall off.

Although the "cookie-cutter" damage function assumes a constant probability of kill with a given area it can be quite good for artillery delivered sub-munition type rounds, or for a single target such as a tank. The cookie-cutter is given as follows:

4) $$P_d(u, v, x, y) = P \quad \text{if } \sqrt{(u-x)^2 + (v-y)^2} \leq RE$$

$$= 0 \text{ otherwise}$$

where P is the probability of kill within the radius of effects (RE)

The exponential square fall off is given by

5) $$P_d(u, v, x, y) = c \exp\left\{ -\left[\frac{(u-x)^2}{2\sigma_{kx}^2} + \frac{(v-y)^2}{2\sigma_{ky}^2} \right] \right\}$$

where c, σ_{kx}, σ_{ky} are parameters to be fit from the actual damage pattern in a manner such that

$$A_L = 2\pi c \, \sigma_{kx} \, \sigma_{ky}$$

For the three-dimensional cases such as for a proximity fuzed projectile, Equation 3) must be extended to include the height dimension. The JMEM/SS is handling this problem by first averaging the actual damage matrices over the burst height so as to get an "average" damage function matrix, and then proceeding as in the two-dimensional case.

Equation 3) can also be solved by using standard Monte Carlo techniques. This method can work very well, especially in the case where the third dimension of height becomes important. However, in most cases, the computational times needed makes this method impractical except for a small number of cases.

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FIGURE I -- EXAMPLE OF PAGE FROM JMEM/SS PAMPHLET

Target Radius (meters)	Expected Fraction of Casualties — Number of Volleys (Rounds) 1(6)			3(18)			6(36)			9(54)			12(72)			18(108)			24(144)			30(180)		
	Standing	Prone	Foxhole	Standing	Prone	Foxhole	Standing	Prone	Foxhole	Standing	Prone	Foxhole	Standing	Prone	Foxhole	Standing	Prone	Foxhole	Standing	Prone	Foxhole	Standing	Prone	Foxhole
Range: 1,000 meters; Charge 1; Angle of Fall 8°																								
50	.10	.03	–	.24	.10	–	.38	.17	–	.46	.24	–	.52	.29	–	.59	.37	.01	.63	.42	.01	.66	.47	.01
100	.05	.02	–	.13	.05	–	.22	.10	–	.27	.13	–	.31	.16	–	.36	.21	–	.40	.24	–	.42	.27	.01
150	.03	.01	–	.07	.03	–	.12	.05	–	.15	.07	–	.17	.08	–	.20	.11	–	.22	.13	–	.24	.14	–
200	.02	.01	–	.04	.02	–	.07	.03	–	.09	.04	–	.10	.05	–	.12	.06	–	.13	.07	–	.14	.08	–
250	.01	–	–	.03	.01	–	.04	.02	–	.06	.03	–	.06	.03	–	.08	.04	–	.09	.05	–	.09	.05	–
Range: 3,000 meters; Charge 4; Angle of Fall 15°																								
50	.08	.03	–	.21	.08	–	.36	.15	–	.46	.21	–	.53	.27	–	.63	.36	.01	.69	.43	.01	.73	.49	.01
100	.05	.02	–	.13	.05	–	.23	.10	–	.30	.14	–	.36	.17	–	.43	.23	–	.48	.28	–	.52	.32	.01
150	.03	.01	–	.07	.03	–	.13	.05	–	.17	.07	–	.20	.09	–	.25	.13	–	.28	.16	–	.31	.18	–
200	.02	.01	–	.04	.02	–	.08	.03	–	.10	.04	–	.12	.05	–	.15	.07	–	.17	.09	–	.18	.10	–
250	.01	–	–	.03	.01	–	.05	.02	–	.06	.03	–	.08	.03	–	.10	.04	–	.11	.06	–	.12	.07	–
Range: 5,000 meters; Charge 6; Angle of Fall 17°																								
50	.08	.03	–	.21	.08	–	.35	.15	–	.46	.21	–	.54	.27	–	.64	.36	.01	.70	.43	.01	.74	.49	.01
100	.05	.02	–	.13	.05	–	.23	.10	–	.31	.14	–	.36	.17	–	.44	.24	–	.50	.29	–	.54	.33	.01
150	.03	.01	–	.07	.03	–	.13	.05	–	.17	.07	–	.21	.10	–	.26	.13	–	.30	.16	–	.32	.18	–
200	.02	.01	–	.04	.02	–	.08	.03	–	.10	.04	–	.12	.06	–	.15	.08	–	.18	.09	–	.19	.11	–
250	.01	–	–	.03	.01	–	.05	.02	–	.07	.03	–	.08	.04	–	.10	.05	–	.11	.06	–	.12	.07	–
Range: 7,000 meters; Charge 7; Angle of Fall 22°																								
50	.08	.03	–	.21	.08	–	.36	.15	–	.46	.21	–	.54	.27	–	.64	.36	.01	.70	.43	.01	.74	.49	.01
100	.05	.02	–	.13	.05	–	.23	.10	–	.31	.14	–	.36	.17	–	.44	.23	–	.50	.28	–	.53	.33	.01
150	.03	.01	–	.08	.03	–	.13	.05	–	.17	.08	–	.21	.10	–	.26	.13	–	.29	.16	–	.32	.18	–
200	.02	.01	–	.04	.02	–	.08	.03	–	.10	.04	–	.12	.06	–	.15	.08	–	.17	.09	–	.19	.11	–
250	.01	–	–	.03	.01	–	.05	.02	–	.07	.03	–	.08	.04	–	.10	.05	–	.11	.06	–	.12	.07	–
Range: 9,000 meters; Charge 7; Angle of Fall 33°																								
50	.08	.03	–	.21	.08	–	.36	.15	–	.47	.22	–	.55	.27	–	.65	.37	.01	.72	.45	.01	.76	.51	.01
100	.05	.02	–	.14	.05	–	.24	.10	–	.32	.15	–	.38	.18	–	.47	.25	–	.53	.31	–	.57	.35	.01
150	.03	.01	–	.08	.03	–	.14	.06	–	.19	.08	–	.23	.10	–	.28	.14	–	.32	.18	–	.36	.20	–
200	.02	.01	–	.05	.02	–	.08	.03	–	.11	.05	–	.13	.06	–	.17	.08	–	.20	.10	–	.21	.12	–
250	.01	–	–	.03	.01	–	.05	.02	–	.07	.03	–	.09	.04	–	.11	.05	–	.13	.07	–	.14	.08	–
Range: 11,000 meters; Charge 7; Angle of Fall 51°																								
50	.09	.04	–	.24	.10	–	.40	.19	–	.52	.27	–	.60	.34	.01	.70	.45	.01	.77	.53	.01	.80	.60	.01
100	.06	.03	–	.17	.07	–	.29	.14	–	.38	.19	–	.44	.24	–	.54	.32	.01	.60	.39	.01	.64	.44	.01
150	.04	.01	–	.10	.04	–	.17	.08	–	.23	.11	–	.28	.14	–	.34	.19	–	.39	.23	–	.42	.27	.01
200	.02	.01	–	.06	.02	–	.10	.05	–	.14	.07	–	.17	.08	–	.20	.11	–	.24	.14	–	.26	.16	–
250	.01	.01	–	.04	.02	–	.07	.03	–	.09	.04	–	.11	.05	–	.13	.07	–	.15	.09	–	.17	.10	–

FIGURE II - TYPICAL DAMAGE MATRIX

										1	1	1	1	1	1	1	1	1	1	1										
							1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1							
						1	2	2	2	3	3	3	3	4	4	4	3	3	3	3	2	2	2	1						
					1	2	2	3	3	4	4	5	5	6	6	6	5	5	4	4	3	3	2	2	1					
					2	3	3	4	5	6	7	8	8	9	9	9	8	8	7	6	5	4	3	3	2					
				2	3	4	5	6	8	9	11	12	14	15	16	15	14	12	11	9	8	6	5	4	3	2				
			2	3	4	6	8	11	12	13	18	22	25	28	29	28	25	22	18	13	12	11	8	6	4	3	2			
		1	2	4	6	8	10	15	19	23	29	36	43	48	49	48	43	36	29	23	19	15	10	8	6	4	2	1		
		2	3	5	8	12	15	20	30	39	49	64	79	85	85	85	79	64	49	39	30	20	15	12	8	5	3	2		
1	2	3	5	7	12	19	23	34	50	64	85	11	13	15	16	15	13	11	85	64	50	34	23	19	12	7	5	3	2	1
3	4	6	8	12	19	27	40	56	78	11	15	19	26	31	33	31	26	19	15	11	78	56	40	27	19	12	8	6	4	3
4	8	13	16	22	31	45	59	87	12	17	26	37	51	62	66	62	51	37	26	17	12	87	59	45	31	22	16	13	8	4
3	7	12	19	32	54	76	11	16	20	32	44	66	*70*	*73*	*73*	*73*	*70*	66	44	32	20	16	11	76	54	32	19	12	7	3
1	4	8	14	24	43	81	15	28	46	69	80	*73*	*20*	*33*	*17*	*33*	*20*	*73*	80	69	46	28	15	81	43	24	14	8	4	1
	1	3	4	13	31	60	10	19	38	86	*78*	*34*	*46*	*73*	*20*	*73*	*46*	*34*	*78*	86	38	19	10	60	31	13	4	3	1	
				2	6	14	27	46	75	14	29	64	*76*	*40*	*66*	*40*	*76*	64	29	14	75	46	27	14	6	2				
						4	9	21	38	61	62	18	1	2	3	2	1	18	62	61	38	21	9	4						
2	3	4	6	9	14	14	12	8						1	1	1						8	12	14	14	9	6	4	3	2
5	5	5	5	4	1																				1	4	5	5	5	5
2	1																												1	2

Each figure represents a damage probability within a rectangular area. For the italized figures, place the decimal just before the two digits given; for the underlined figures, insert a zero to the left of the two digits and then place the decimal before the zero, for example, 16 = .016; for the unmarked number add two or three zeros , for example, 14 = .0014, 1 = .0001.

MEASURES OF EFFECTIVENESS FOR SURFACE TO AIR WEAPONS

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There are numerous measures or indexes of effectiveness that can be employed as criteria for an air defense system's efficiency. Some examples of measures which have at times been utilized are as follows:

- the single shot kill probability of a missile or gun system against typical threat targets

- the engagement kill probability of an air defense gun or missile system; the burst kill probability of a gun system

- the cumulative kill probability along the flight path of the target and prior to aircraft weapon release

- the engagement envelope (launch and intercept boundaries) of the SAM system against an aircraft or missile threat

- the mathematical expectation of the number of targets damaged or killed; the mathematical expectation of the number of rounds required to kill with a given level of assurance

- the probability of survival of raids of aircraft attempting to penetrate a single or mixed air defense

- the level of expenditure of ammunition and the cost of facilities to ensure a fixed kill level

- the determination of the kill level of an air defense system or family for fixed cost levels

- number of air defense systems (costs) required to provide minimum coverage over some type of area (field army) and a specific threat vehicle

- number of air defense systems (costs) to limit damage inflicted to field army to some predetermined value or to the point where adding more defense resources results in diminishing returns

- an effectiveness matrix or effectiveness function which relates threat, mission, environment, and tactics to availability, maintainability, and capability (lethality).

As we proceed through these examples we are generally progressing from the simple to the more complex. It should be noted that as we progress we also change our concept of "effectiveness". The first and early examples center on the idea of "lethality or kill effectiveness", i.e., this concept involves an index of the weapon's capability; while the last example is trying to characterize overall "system effectiveness".

My talk shall center around these two concepts. I have chosen several simple indices to illustrate both types of "effectiveness" and these are presented in Table 1.

Table 1

Simple Measures of Effectiveness for Air Defense Weapons

Kill Capability (Lethality) Measures

- Single Shot Kill Probability
- Engagement Kill Probability
- Lethal Ground Range/Characteristic Width Concept
- Burst Locator/Defended Area Concept
- Index for Randomly Dispersed Air Defenses

System Effectiveness Measures

- WSEIAC Effectiveness Equation
- Special Adaptations of WSEIAC Equation

I think it is safe to say that I cannot conceive of a measure of system effectiveness which excludes the weapon's kill capability. Therefore, I shall discuss this concept first.

The most elemental measure of a weapon's capability is denoted as the single shot kill probability. Single shot kill probability is defined

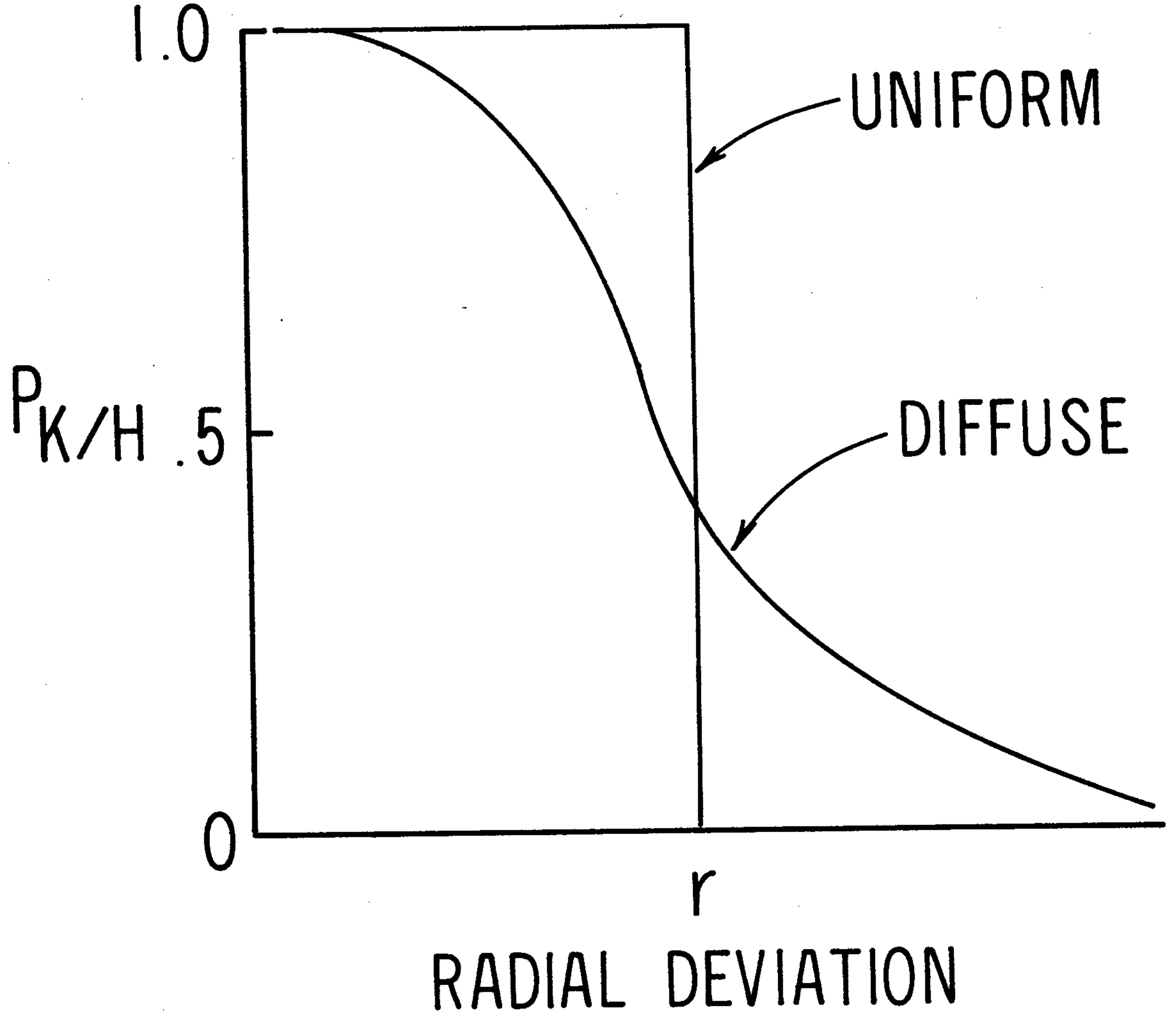
$$P_{KSS} = E\,[P_{K/H}\,(X, Y)] = \iint P_H\,(X, Y)\,P_{K/H}\,(X, Y)\,dxdy \qquad (1)$$

i.e., P_{KSS} is the expected value of the vulnerability function $P_{K/H}$ (X, Y) or more explicitly, the product of the probability distribution of kill given a hit at a point (X, Y) and P_H (X, Y) the hit probability distribution of points (X, Y).

Less rigorously stated, the single shot kill probability is often defined simply as:

$$P_{KSS} = P_H \cdot P_{K/H}.$$

VULNERABILITY FUNCTIONS



The vulnerability function, $P_{K/H}$, is directly related to the concepts of kill or damage criteria and vulnerable area. The various kill criteria are shown in Table 2.

Table 2
Categories of Kill

Fixed Wing Aircraft

KK - Immediate Disintegration From Catastrophic Damage

K - Loss of Control Within 10 Sec

A - Loss of Control Within 5 Min

B - Failure to Return to Base or Forced to Land

C - Mission Abort

E - Damage Preventing Target Availability for Next Scheduled Mission

Rotary-Wing Aircraft

- Forced to Land

- Attrition

Now, most aerial targets are constructed of vulnerable components that vary in both hardness and in many cases in their influence on the operation of the total system. In a single-engine-single pilot aircraft, for example, the vulnerable components include the pilot, engine, and fuel tank. In theory, if any of these are destroyed or damaged, the aircraft or one of its functions is destroyed — perhaps catastrophically. Such components are defined as singly vulnerable.

If the aircraft has built-in redundancy in its vulnerable components, such as a copilot, two engines, or several independent fuel tanks, the criticality of any of these is greatly reduced in terms of its vulnerability to a single impact. Such components are defined as multiply vulnerable.

The concept of vulnerable area has been found useful in measuring the hardness of complex targets to weapons that can damage a component if the equivalent of a single direct hit has been obtained. Mathematically, the vulnerable area of a component is defined as the integral of $P_{K/H}$ function taken over the area of the component, i.e.,

$$A_V = \iint_{A_C} P_{K/H}(X, Y)\, dxdy \qquad (2)$$

The total vulnerable area of the target is defined by

$$A_{V_T}(\alpha,\beta) = P_{K/H_1}A_1 + P_{K/H_2}A_2 + \ldots P_{K/H_j}A_j + \ldots P_{K/H_w}A_w \qquad (3)$$

where A_j's are the projected areas of the vulnerable components and the P_{K/H_j}'s are the kill probabilities given a hit on these components.

It is noted that the vulnerable area is specified to be a function a α and β, the azimuth and elevation angles from which the attacking projectile is approaching. Also, the P_{K/H_j}'s depend on the striking energy and consequently on the range.

This dependence on three independent variables presents a problem in describing the vulnerable area of a target in compact form. One compromise that is often resorted to is the following:

1. Average P_{K/H_μ}'s with respect to the impact angle are obtained.

2. The areas of the vulnerable components are projected onto the faces of a box surrounding the target (front, back, top, bottom, and side). Results are given for specific weapons as a function of striking velocity on each of these surfaces. Many modelers are now converting the areas of the "shoe-box" into equivalent ellipsoid areas, finally projecting the ellipsoid on a plane perpendicular to the relative velocity vector between the shell and target.

3. The vulnerable area on each surface is multiplied by the appropriate direction cosines and the products are added to account for direction.

A knowledge of the probability of hit distribution or hit probability is required in order to complete the computation of single shot kill probability, equation (1). In cases where we know the actual form of the distribution we can employ it exactly. For cases where we do not know the actual form or type of hit distribution we, in many instances, assume it to be Gaussian.

$$P_H(X, Y) = \frac{1}{2\pi\sigma^2} e^{-\frac{X^2 + Y^2}{2\sigma^2}} \qquad (4)$$

Where σ is the linear standard derivation in both dimensions, i.e., $\sigma_x = \sigma_y = \sigma$. Equation (1) can be integrated quite easily for a normal hit distribution when combined with simple vulnerability functions. Two such vulnerable functions are:

Uniform vulnerability function:

$$P_{K/H}(X, Y) = \begin{cases} 1 & X^2 + Y^2 \leq r^2 \\ 0 & X^2 + Y^2 > r^2 \end{cases} \qquad (5)$$

Diffuse target vulnerability function:

$$P_{K/H}(X, Y) = \exp\left[-X^2+Y^2/r^2\right] \qquad (6)$$

These functions are depicted in Figure 1. Using (4) and (5) in expression (1) results in:

$$P_{KSS} = 1 - \exp\left[-r^2/2\sigma^2\right] \qquad (7)$$

On the other hand, use of (6) in place of (5) yields:

$$P_{KSS} = \frac{r^2}{r^2 + 2\sigma^2} \qquad (8)$$

Equation (8) can be transformed to its more recognizable form, the Carlton-Von Neumann Formula:

$$P_{KSS} = \frac{A_V}{A_V = 2\pi\sigma^2} \quad \text{or} \quad \frac{A_P}{A_P + 2\pi\sigma^2}\left(\frac{A_V}{A_P}\right) \qquad (9)$$

where A_V is the vulnerable area of the target, A_P is the presented area of the target, and σ^2 is the variance of the firing error distribution.

In the derivation of this formula it is assumed that $\sigma^2 >> A_V$. Equation (9) may be used for either point detonating projectiles or proximity fuzed projectiles; except when used for the latter, lethal area A_L should be substituted for A_V. However for proximity rounds and missiles we generally use a single shot kill expression:

$$P_{KSS} = \int_A \int_Z P_A \, P_Z \, P_{K/H} \, dZdA \qquad (10)$$

dA - element of area in plane perpendicular either to the trajectories or the approach velocity vector

Z - coordinate along the trajectories or the approach velocity vector

P_A - distribution function of trajectories in plane normal to the trajectories or the approach velocity vector

P_Z - distribution of burst points along the trajectories

$P_{K/H}$ - same concept as defined before, conditional kill probability for a detonation at the given position

Firing errors can be categorized into three main types:

Type 1: Errors which vary so rapidly that no correlation exists between the hit positions of different rounds.

Type 2: Errors which vary so slowly that they may be regarded as constant while a target is under fire.

Type 3: Errors which vary so closely that a correlation exists between hit positions of different rounds but so rapidly that they cannot be regarded as constant while the target is under fire.

Type 1 errors are designated "ballistic dispersion" or "round-to-round errors", σ_D; while Types 2 and 3 are usually designated as components of the "systematic error" or "aiming error", σ_A.

In formula (9) the firing errors are considered independent and are combined statistically, i.e.,

$$\sigma^2 = \sum \sigma_{A_i}{}^2 + \sum \sigma_{D_i}{}^2$$

where σ_{A_2} are aiming error components and σ_{D_i} are dependent error components.

Now the engagement kill probability for firing N rounds is given by

$$P_{K_N} = 1 - \left[1 - P_{KSS}\right]^N , \qquad (11)$$

the probability that at least one round will hit and kill the target. The following approximation to Equation (10) is often used for small P_{KSS} and large N, i.e.,

$$\log(1 - P_{K_N}) = N \log(1 - P_{KSS}) \cong -N P_{KSS}$$

$$P_{K_N} = 1 - \exp[-N P_{KSS}] \qquad (12)$$

Equations (11) and (12) are used for guns and missiles where the firing of the individual rounds and the firing errors are independent or "near independent". These formulas are appropriate for point-detonating or contact-fuzed rounds which must hit the target in order to be effective.

For the case of rounds that are fired on a burst from a gun or rocket system such that the rounds can be considered to be a salvo (i.e., all the rounds of the burst have essentially the same point), formula (13) gives the probability that at least one round hits and kills the target.

$$P_{K_N} = \sum_{j=1}^{N} \binom{N}{J} \left(-1\right)^{j+1} \left[\frac{A_V}{2\pi\sigma_D^2 + A_V}\right]^{j-1} \left[\frac{A_V}{2\pi(\sigma_D^2 + j\sigma_A^2) + A_V}\right] \qquad (13)$$

Equation (13) assumes that the center of the aiming distribution is on the center of the target. This expression must be modified for the case where the mean of the aiming distribution is displaced from the center of the target. The modification factor B_j must be multiplied to each term of the series in (13).

$$B_j = \exp\left[\frac{-j\pi h^2}{2\pi(\sigma_D^2 + j\sigma_A^2) + A_V}\right]$$

Here h is the distance between the center of the target and the center of aim.

I have just outlined the principal closed form kill effectiveness measures utilized in air defense evaluations. There are some other methods, simulation methods, which simulate the end-game encounter, hit, and kill and therefore do not use closed form formulas.

The engagement kill probability concept can be extended to a measure of a fire unit's effectiveness called Lethal Ground Range or Characteristic Width. Characteristic Width (CW) is the sum of the values of engagement kill probability for all off-set distances for which a system has some effectiveness and correcting the sum for the grid scale factor:

$$CW/LGR = SF\sum P_K = \int_0^{R_{max}} P(R)\, dR \qquad (14)$$

Clearly the greater the CW, the more effective is the system. CW has the unit of meters. An estimate of the number of systems required to erect a fence for length L would be

$$N = \frac{L}{CW}$$

CW can also be divided by cost to obtain a measure in meters of defense line per dollar. Characteristic width permits comparison of air defense weapons of different probability of kills, off-set flight path capability, and cost. It may also be used to estimate the number of weapons required for different missions.

Another concept similar to characteristic width is "burst locator" or "defended area diagrams". CW can be used for both gun and missile systems; however "burst locator" concept is used principally with missile systems.

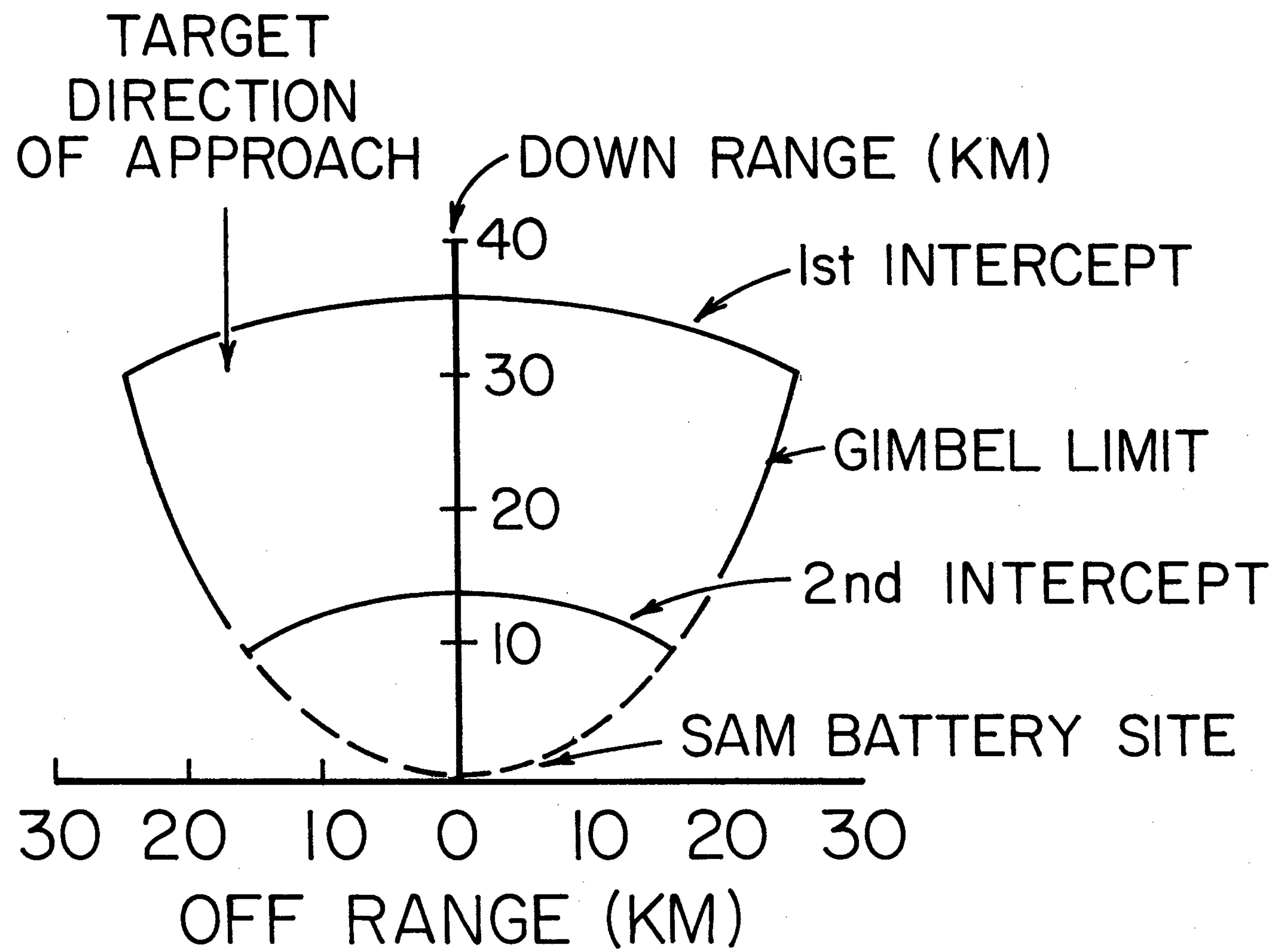
A burst locator graphically simulates a typical engagement for a SAM for an assumed attack configuration, including target speed, altitude, and arrival rate. The burst locator procedure involves determining the point where the targets are likely to be detected based on performance of the system acquisition radars. The average processing time, which represents a delay from detection to launch, then allows the calculation of estimated launch range. Length of delay is a function of target altitude, ECM level, system mode of operation. Once processing time is specified, sequential engagements of an attack can be simulated on a battery coordinated system. The procedure uses target position at first launch to start a matching of the appropriate missile fly-out trajectory with target travel after launch. This determines the range at first intercept. After another processing delay, the calculation proceeds in a similar manner to find the range at second intercept. Process continues until no intercepts are possible. The burst locator can be converted to a kill-kilometer diagram, which gives the expected target killed as a function of the off-set range that the targets pass the SAM battery. A typical burst locator and an associated kill-kilometer diagram are shown in Figures 2 and 3.

Burst Locator/Defended Area as the name implies is an area concept. The characteristic width can be extended to examination of the effectiveness of randomly deployed air defense systems in some area of deployment. Formula (15) gives the kill probability for the deployed fire units against a single aircraft attempting to

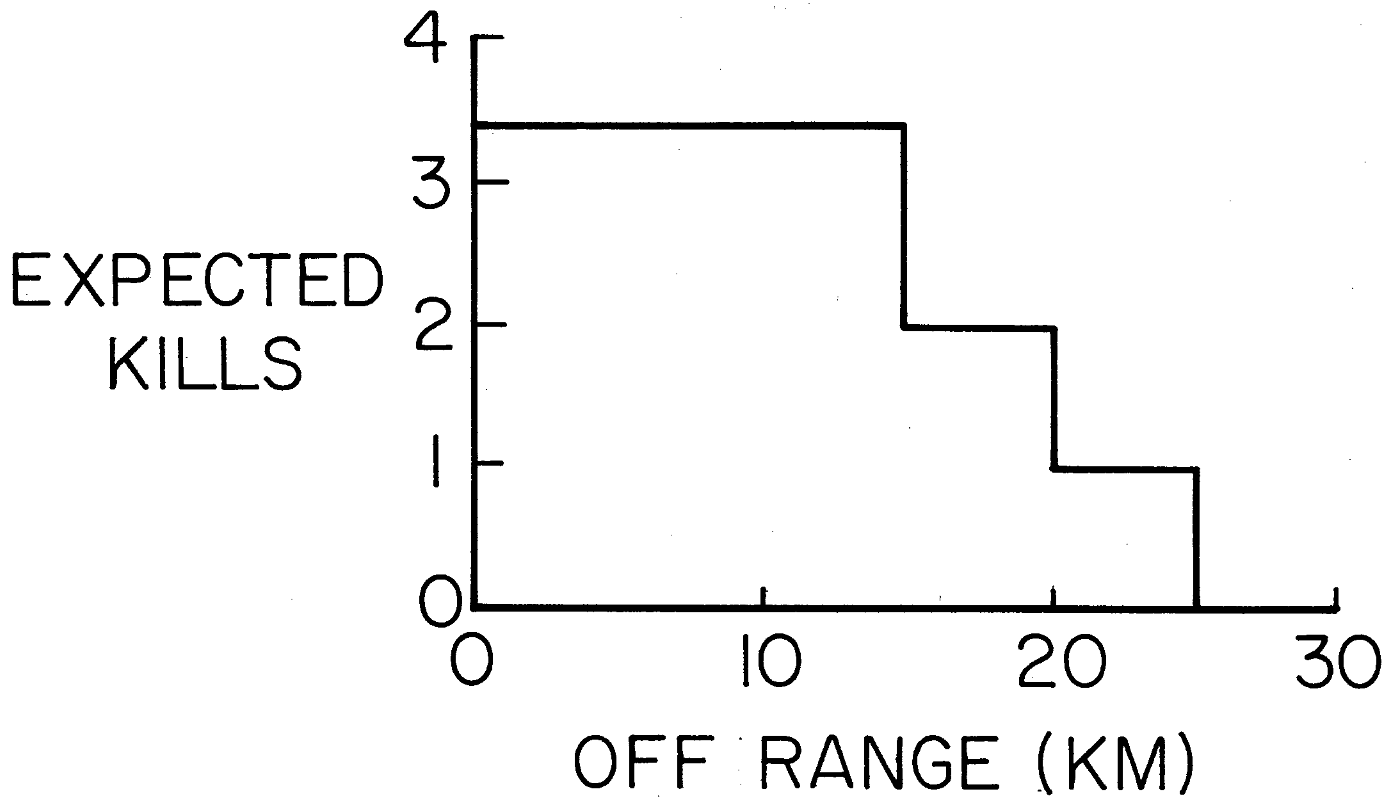
$$P_{K_{N_W}} = 1 - e^{-\frac{2RLP_K N}{A}} \qquad (15)$$

penetrate over the area of deployment. Here R is the maximum range of the air defense weapon; L is the length of penetration of the aircraft over

BURST LOCATOR / DEFENDED AREA



BURST LOCATOR KILL KILOMETER DIAGRAM



the deployment; P_K is the average kill probability of the weapon over all offsets; N is the number of air defense weapons; and A is the deployment size (area). We can define

$$RP_K = CW$$

and

$$\frac{N}{A} = \rho = \text{weapon density}$$

then (15) becomes

$$P_K = 1 - e^{-2\rho(CW)L}$$

This type of formula is also used in many aircraft attrition and aircraft survivability analyses.

I would like now to switch to a brief discussion of overall system effectiveness.

System effectiveness is a measure of the extent to which a system may be expected to achieve a set of specific minimum requirements. One analytic effectiveness model that has generally been accepted is the WSEIAC* model. The WSEIAC model is based on a breakdown of the effectiveness parameter into three major components -- availability, dependability, and capability. Availability is a measure of the system condition at the beginning of a mission; dependability is a measure of the system condition during the mission, given the system condition at the start of the mission; and capability is the ability of the system to perform its mission, given the system condition during the mission.

To apply the model, given a mission definition and system description, it is necessary to delineate possible mission outcomes and significant system states. The availability and dependability measures are then related to the possible system states, and the capability measure relates these possible system states to the possible mission outcomes.

For the very simplest of cases, in which a system must be in either a working or a failed state, the measures of availability, dependability, and capability represent the following fundamental questions:

- Is the system working at the start of the mission?

- If it is working at the start, will it continue working throughout the mission?

- If the system works throughout the mission, will it actually achieve mission success?

**WSEIAC - Weapon System Effectiveness Industry Advisory Committee*

As the systems considered become more complex - e.g., when there are more than two possible system states, and such factors as in-mission repair, degraded modes of operation, multi-mission requirements, enemy counter-measures are to be quantified elements in the model - these questions may be too difficult to answer in simple model construction, but this approach can still be used.

The general form of the WSEIAC system effectiveness is given by the next equation.

$$E_{FF} = A \times D \times C$$

where A, D, and C are factors pertaining to availability, maintainability and capability. Most of the Army missiles are being evaluated against effectiveness criteria of the following type. A typical equation is:

$$E_{FF} = A_o \times P_{DET} \times P_{KSS}$$

where

$$A_o = \frac{MTBF}{MTBF + MTTR}$$

$$P_{DET} = P_{cum} \; P_o \; P_{TR}$$

$$P_{KSS} = R_L \; R_F \; M_L$$

Here A_o - Operational Availability

P_{DET} - Probability of detection, evaluation and transfer

P_{KSS} - Single shot kill probability which is defined to include the reliability of system during launch, reliability of system during flight, and the missile lethality.

MTBF - Mean time between failure

MTTR - Mean time to repair

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The Concept of Opportunity

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Measures of effectiveness for tactical systems is a rather ambitious subject for a ten minute treatment. Rather than expose to you the full depth of my ignorance in this area, I choose to limit my remarks to a fundamental concept central to the effectiveness of any system -- tactical or otherwise.

To give this concept a name, we shall call it the Concept of Opportunity. System effectiveness is governed by two factors.

a. The opportunity generated by the system or presented to it by another system.

b. The system response to opportunity.

Our notions of MOE seem generally to encompass both of these factors, and so they should. But there is need for caution! Suppose we seek effectiveness comparisons within a set of candidate systems each of which, for purposes of this example, is assumed to be dependent on some superior system for its opportunity -- its stimulus. Here, opportunity is exogenous since it originates external to the systems being examined. In such instances, valid comparisons between candidate systems are guaranteed only in their respective responses to a common opportunity. To a more limited extent, valid comparisons may be possible if system response is normalized to a unit of opportunity.

The matrix is intended to illustrate the point being made.

	Opportunity (%)	Effective Response to Opportunity (%)
System A	50	90
System B	80	70

System B is preferred due to its greater net effectiveness (56% vs. 45%). But System A has the more effective response to opportunity (90% vs. 70%) and, from that viewpoint, may be the preferred candidate. Some questions which need to be answered are:

a. Was there some pathological cause for the greater opportunity having been presented to System B (80% vs. 50%)? If there was such a cause then it is likely that opportunity was not strictly exogenous and there was some system contribution to opportunity.

b. If the opportunity presented to System A were to be increased to 80% (the same as for System B) would the effective response of System A remain at 90%? If not, there exists some interaction between opportunity presented and the ability of the system to respond effectively to that opportunity. Response is then a function of opportunity. An example of this situation might be the following. The number of targets presented to a combat system is a measure of that system's opportunity to engage. But if those targets are not benign with respect to the system being examined, then their increase presages an increase in the risk that the candidate system will be attacked and its marginal effectiveness reduced before it can effectively respond to the opportunities presented.

Opportunity is dynamic. Perhaps it would be better to describe it as an immediate precursor to the effectiveness of any given subsystem of the whole.

Example: Let N - the number of elements in the opposing force which are potential targets. Then the process flow might be summarized as:

$$\frac{n}{N} \triangleq \text{fraction presented} = \text{opportunity to acquire}$$

$$\frac{a}{n} \triangleq \text{fraction acquired} = \text{opportunity to engage}$$

$$\frac{e}{n} \triangleq \text{fraction engaged} = \text{opportunity to hit}$$

$$\frac{h}{e} \triangleq \text{fraction hit} = \text{opportunity to kill}$$

and so on. As we can see here, the opportunity presented to Subsystem I is the cumulated system effectiveness through Subsystem I-1.

Latent effectiveness may also be illustrated with this example. Suppose we are interested in the potential effect on battle outcome from improvements in the accuracy and lethality of the firepower of a tactical system. Assuming we are able to resolve the decision to engage as a function of some threshold levels of accuracy and lethality, we can then force every engagement by the system to result in a kill by imposing on the simulation the constraint

$$P_{SSH} = P_{SSK} = 1$$

The differential battle outcome between this ideal weapon system and the realistic weapon system is a measure of the latent effectiveness of the system. That latent effectiveness further may be used to describe the potential opportunity which the system being evaluated could contribute to force effectiveness if that potential could be exploited.

As suggestions on where to begin the assessment of system effectiveness, I offer the following two principles:

First Principle: Thoroughly define the system being evaluated through all its major subsystems. Construct a diagram of the subsystem flow. Determine if opportunity is endogenous or exogenous to the system.

Second Principle: If the system generates its own opportunity and there are no interactions between subsystems (series - parallel flow without feedback), then maximizing opportunity is a necessary condition to maximizing system effectiveness.

SESSION VIII A. - DISCUSSION
Measures of Effectiveness for Tactical Systems

Question:

Based on the work that he has just presented here, would Dr. Blum care to comment on what we can obtain from the CDEC experiments, these are multi-million dollar experiments, that are in progress or in the planning stages. These experiments measure things like tactical outcomes in terms of exchange ratios and so forth.

Answer:

LTC Blum: I don't think your question is addressed to any opinion on my part as to the efforts of any of the measures of effectiveness being used, that being the loss exchange ratio. I don't think that is the question. I think I understand the question thoroughly. If I may rephrase it, I take the question as being, how can we use opportunity, the concept of opportunity, what influence does that have in my opinion on CDEC 43.X series of experiments. Now, for those of you who are not familiar with these attack helicopter experiments, there are two fundamental flaws that denigrate the effectiveness of the blue attack helicopters. One is that the first shot advantage lies with the ground forces. This is what we have witnessed before. And the second is that the engagement ranges are too short to effectively exploit the standoff capability of the TOW missile. There's the crux of the problem, I think. The concept of opportunity as used here for instance, might very well be, what opportunity was there within the tactics that we are using, the nap-of-the earth tactics, to acquire targets from the air at three thousand meters or four thousand meters? If the terrain over which you're operating is such that it is incompatible with the tactics of nap-of-the-earth flying, you can't expect the opportunity to acquire targets to yield a situation where you can acquire them to exploit the capability of the hardware. That's a kiss at the problem.

NOTE: The comment included in this section is not necessarily complete. It was necessary to delete some remarks as they were unitelligible on the recording.

Conflicting Measures of Performance in Inventory Systems

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This paper deals with performance measures applied to a repair parts catalog — the group of repair parts managed by an Army Inventory Control Point, for example. In managing such a catalog, one would like to use an optimizing model that would get the best possible performance for a given investment. There are, however, several measures from which to choose and it is discomfiting to find that optimizing on one measure can give poor performance in terms of another. Thus, selection of the performance measure is not a trivial matter and remains, in fact, a problem with DOD that has not yet been resolved in a wholly satisfactory manner.

The main difficulty arises from the fact that all measures of supply performance are surrogates for what one might designate as the "true" measure. If all items in the catalog were used on a single weapon system, and if the effect of each item's failure on the performance of the weapon system were completely known and quantifiable, and if agreement could be reached on the way in which the weapon system's performance should be measured, then selection of the "true" supply performance measure for the parts could be made without difficulty. However, none of these conditions applies. Moreover, in inventory systems as complex as the Army's, many of the stockage points exist largely to serve other stockage points one or more levels removed from the actual parts users. Thus, the effects of their shortages on weapon system performance are obscure indeed, no matter what performance measure is used. This is particularly true of the Army's Inventory Control Points, most of whose customers are themselves intermediate stockage points, quite far removed from the consumer.

The choice of a measure was perhaps the most discussed subject during the development of Department of Defense Instruction 4140.39, "Procurement Cycles and Safety Levels of Supply for Secondary Items." This DODI, which was published last July, represents a notable attempt to put all Services on a compatible footing in the competition for the repair parts dollar. It specifies the measure of performance that all Service Inventory Control Points must use in setting performance targets, it stipulates how these targets are to be used in the development of repair parts budgets and even gives the form of the inventory model to be used to assure that the service provided to customers is provided at minimum annual operating cost.

The performance measures most seriously considered by the group that developed the DODI were:

(a) Units Short - used by DSA and Marine Corps

(b) Requisitions Short - used by Navy

(c) Time Weighted Units Short - tentatively selected for use by Air Force

(d) Dollar Value of Time Weighted Units Short - used by Army

(e) Time Weighted Requisitions Short - selected for Service-wide use by DOD

The definitions of these measures can be given most simply by referring to the usual type of inventory diagrams:

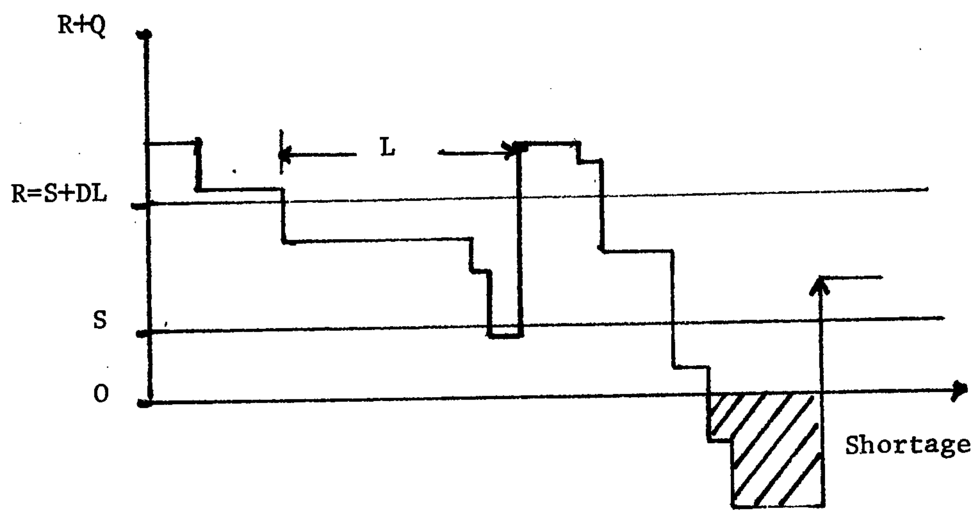


Fig. 1

This diagram depicts the on-hand stock position over time. A new order is placed when the Reorder Point R is reached for a Reorder Quantity + any deficit to R that exists when the order is placed. This quantity arrives a Procurement Lead Time later, L. Units Short is defined as the quantity on backorder when the replenishment shipment arrives; Requisition Short has the same meaning, expressed in terms of requisitions without regard to quantity. Note that these measures do not reflect when the shortages occur or for how long they persist.

We refer to the next diagram for definition of the time-weighted measures.

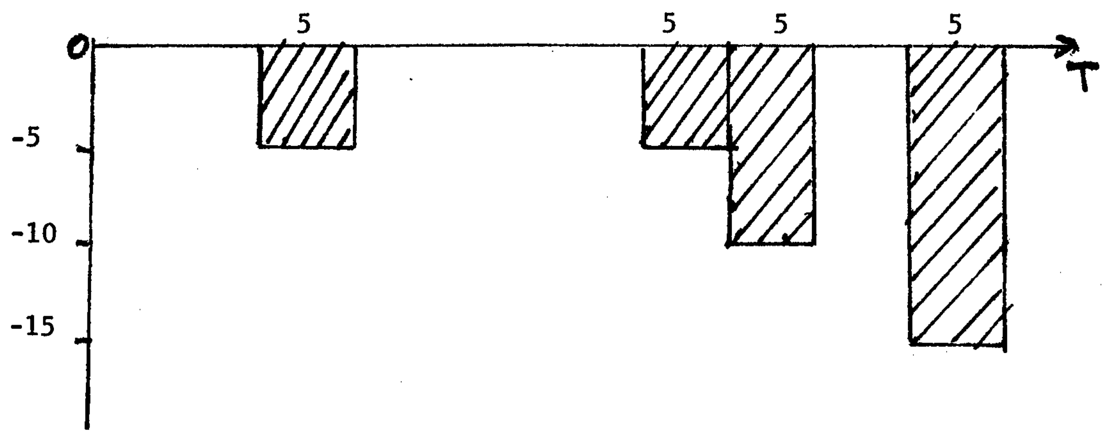


Fig. 2

The quantity (units) not filled from stock on hand are weighted by the time duration of shortage. For example if T is 1 year

32	weeks	x	0	units	on	backorder	=	0
5	"	x	5	"	"	"	=	25
5	"	x	5	"	"	"	=	25
5	"	x	10	"	"	"	=	50
5	"	x	15	"	"	"	=	75
								175

$$\text{Time Weighted Units Short} = \frac{\text{172 unit weeks}}{\text{52 weeks}} = 3.37$$

Note that this same result would have been obtained by counting the units short periodically, say, weekly, and dividing by the number of observations. Thus, this measure is often called Average Units or Backorder or Average Backorders.

The time dimension of this measure can also be used directly. By analogy to the well-known queueing equation ($L = \lambda T$)

$$B = Dw$$

when B = Average backorders

D = Demand rate

w = Average customer wait

This form of the measure is expected to be used by DOD in the budget negotiation cycle, as will be described later.

One other very commonly used measure not listed is <u>Availability.</u> This is defined as the fraction of time demand is filled from stock on hand. It would be $\frac{32 \text{ weeks}}{52 \text{ weeks}}$ = .61 in the above example. It is related to the Average Backorders measure in an interesting way,

$$\alpha = \frac{K_b}{K_b + I}$$

where K_b = cost per unit backordered per unit time

I = cost of holding a unit of inventory per unit time

This relationship holds when R and Q are selected so as to minimize total annual operating cost. If I and K_b are multiplied by the unit price of the item, the penalty cost for demands not satisfied without delay is not only time-weighted, but also dollar-weighted. This, as indicated earlier, is the performance measure in the MIT model that had been implemented in some of the Army Inventory Control Points, although its effect is noted only indirectly. In practice, one manipulates the performance measure by choosing a target Availability for a catalog of items or a portion thereof; then, since estimates of the value of I are available, the imputed value of K_B is calculated and the values of R and Q that minimize total annual operating cost can then be found directly.*

The inventory model in DODI 4140.39 is

$$TVC = \sum_{i}^{N} AD_i/Q_i \qquad \text{(Procurement Cost)}$$

$$+ \sum_{i=1}^{N} IC_i \, (R_i + Q_i/2 - D_i L_i) \qquad \text{(Holding Cost)}$$

$$+ \lambda \sum_{i=1}^{N} \gamma \frac{1}{Q_i} \int_{R_i}^{\infty} (x - R_i) \, [F(x+Q_i, L_i) - F(x, L_i)] \, dx$$

*See "Dynamics of Two Classes of Continuous Review Inventory Systems," by Galliher, Morse and Simond, Journal of the Operations Research Society of America, vol. 7, no. 3, May - June 1959, for description of the MIT model and of the α, K_b relationship.

where

TVC = total annual operating cost
N = number of items in the catalog
A = cost of a procurement action
D = demand rate (in units per year)
Q = procurement quantity (in units)
I = holding cost rate (expressed as fraction of inventory value)
C = unit cost of the item
R = reorder point (in units)
L = procurement lead time (in years)

The last term, except for the λ and γ, is the expression for Average Backorders. The DODI requires the γ to be

$$\gamma = E_i/S_i$$

where E_i = item essentiality

S_i = average requisition quantity

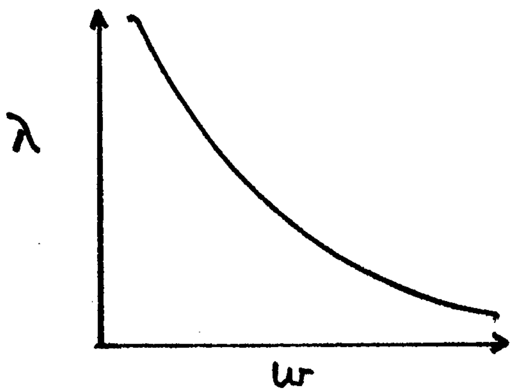
and thus, the DODI requires the performance measure to be time weighted requisitions short, essentiality-weighted, if such a measure is available.

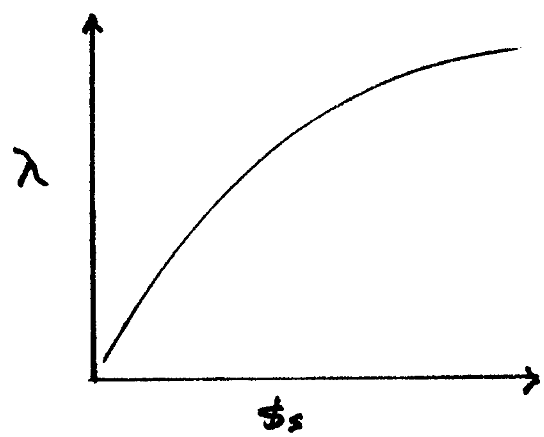
The λ is given a Lagrangian interpretation and constrains investment for the entire catalog. The DODI idea is to select a tentative target in terms of expected customer waiting time to get a requisition filled. Each Service then finds the R_i and Q_i for each item by means of the optimizing equation with different values of λ and finds how big the budget would have to be for each, finding, also, the average customer wait for each. Then, back to the budget table with these results and, after negotiation, presumably agreement on a budget is reached. The corresponding λ is then used as an operating constant in the actual R_i,Q_i calculations until the budget is changed again. The procedure is illustrated schematically in Fig. 3.

Now, the interesting thing is what happens to these R_i,Q_i when budgets are tight, particularly when an essentiality measure is lacking. The model loads up the inventory with items having a high demand frequency and low unit price. Their fill approaches 100%; low demand frequency, high unit price items, however, get very little inventory and their <u>Availability</u> may approach zero. If the Average Backorders measure is used, high quantity demand, low unit price items get the lion's share of the funds. In either case, the slower moving items that cost a lot are given little of the investment share. It is interesting to note that one can "cheat" a bit with this formulation by considering an item's essentiality to be equal to its unit price, or even the product of its unit price and its average requisition size and convert to the measure the Army uses. Then <u>Availability</u> can be used as the control knob, perhaps being set differently for different classes of items in the catalog. The alternative is to put Availability constraints, both upper and lower bounds, on different classes of items

1. DOD gives target Average Customer Wait to each Service.

2. Each Service computes for its catalog the value of λ needed to achieve the target Average Customer Wait. The budget requirement for the catalog associated with this value of λ is also calculated. This is done for several other values of λ so that the following types of curves can be drawn.





3. Services present their funds requirements and, after negotiation, a budget is agreed on.

4. The Service uses the value of λ associated with the agreed on budget in its calculations of R and Q for each item in determining how much to buy.

Fig. 3

in the catalog, to mitigate the harsh impartiality of the optimizing model.

The important message of this paper is that no inventory model can be used without intervention in some arbitrary way to manipulate the penalty cost function. Exactly how one chooses to do this is by no means an easy matter to decide and, at least in the Army's case, has not been completely decided yet. These difficulties could be overcome by a quantitative measure of relative item essentialities but a practical way of doing this has not yet been found.

SUBJECT: Human Engineering Measures of Effectiveness of System Performance

AUTHOR: Mr. Andrew J. Eckles, III
Human Engineering Laboratories

The Human Engineering Laboratories are the Army Materiel Command agency responsible for seeing that Army equipment is conceived and designed so that soldiers can use it efficiently, quickly and with the fewest possible errors.

Human factors engineers originally concerned themselves chiefly with displays and controls. Then human engineering became concerned with the effective integration of the entire man-machine system. Today, the emphasis in human engineering is on adequate consideration of the intelligent but variable human operator at every stage of the design and development cycle, from the initial conception to the assignment of the operational system to troops in the field.

Human engineering factors taken into account include controls, displays, aspects of the environment which can affect human performance (heat, cold, noise, motion, etc.), and anthropometrics (how body dimensions affect workspace, etc.).

The further objective of human engineering is the timely and effective integration of all human factors into the development cycle. The final measure of success is how well the combat soldier can operate the system in the battlefield environment.

Achieving that objective, however, requires well-defined measures of effectiveness. It is the often difficult, and sometimes embarrassing, development of these criteria of effectiveness which I will address today.

We have, for the past few years, deluded ourselves in the Combat Vehicle Systems program. We have persuaded ourselves that we have been taking the "systems approach" in our efforts to measure and, through appropriate Human Factors Engineering, improve the combat performance of tank systems. We have used all the good and popular words, and we have conducted field studies to obtain quantifiable data --data ostensibly of value to the op-search and gaming techniques of the analyst. But then, as we have looked more closely at measures of effectiveness for combat vehicle systems, we have had to go back and re-examine some of the basic assumptions upon which these measures were predicated. The results of this re-examination have been most embarrassing. Many of our measures--even our definitions--of effectiveness relate far more closely to the ease with which we can obtain quantifiable data than they do to combat effectiveness in the real world.

Our delusions began when we first attempted to define the tank system. We said, essentially, that we considered the tank system to include (Slide 1) the Man, the Machine, and the Environment. Our goal was then simply to obtain quantitative measures of the combat effectiveness of this system as a whole, and to obtain these measures in such detail that we could isolate the contributions of the various subsystems to overall performance. Examples of the various measures of effectiveness with which we were primarily concerned are (1) times to fire first round; (2) times to fire subsequent rounds; (3) factors which affected delivery accuracy, such as tracking performance, lay errors, ranging errors, etc.

Our goal was then to examine these data to assist in the design (or redesign) of the various crew stations to improve the system performance. We thought we had the problems solved, needing, of course, only the constant refinement of techniques, etc. After all, we had closed the loop. Not only had we put the "man" into the system as a major component, but also we had extended the system to include its operational environment--a truly soul-satisfying accomplishment.

We know now we were too easily satisfied. We had assumed, for example, that we could investigate "tank effectiveness" by examining the behavior of an individual tank. We thought that from valid measures of times to fire and delivery accuracies we could extrapolate measures of effectiveness of the tank's performance in combat. But even our basic definition of the tank system was in error. The tank system in combat is never an individual tank! Our doctrine and our combat experience tell us the individual tank is not a viable weapon system on the modern battlefield.

Even more importantly, we found we had been investigating only half of the individual tank even as a subsystem. It is true that the tank system includes the man, the machine, and the operational environment--but the total tank system also includes the enemy and his reactions.

Now everyone recognizes the fact that some aspects of the target influence fire effectiveness. We carefully investigate the effects of target size, target range, and to some limited degree, target movement. But these are only relatively minor aspects of target behavior insofar as they influence tank system performance in combat. Meanwhile, we have neglected the major proposition that in combat the enemy also wants to survive and behaves rationally to enhance his probability of surviving.

The target knows the characteristics of our weapons systems, or will after the first engagement. Then the enemy revises his tactics, utilizes all his resources and takes full advantage of the terrain to minimize the effectiveness of our weapons.

In this light, it is likely that many of the systems that appear to be so effective on the gunnery range will prove, to a very large degree, to be far less effective on the battlefield.

We had assumed that we could define, and study, the tank system independently of the way it was used on the battlefield. We thought we could learn something about fire effectiveness by studying hit probabilities and rates of fire independently of enemy reactions and target behavior. And yet, I think, if we look at all of the results of recent studies in the area of target detection and rates and accuracies of tank fire, we find that target behavior (including tactics, target presentation, etc.) has much more effect on our current measures of tank effectiveness (that is, times to fire, hit probabilities, etc.) than could any possible design modification which we could currently make in the tank system.

For example, it takes between 12 to 16 seconds with most tank systems to complete a reasonably accurate gun lay on a clearly visible target and pull the trigger. If we must track the target for 10 seconds after trigger pull and before impact, the target must be available for a total of 22 to 26 seconds after it is detected.

Now if the enemy tank is loafing along at five miles per hour, it is covering between 50 and 82 meters of varying terrain during the time when it must remain visible to the firer with no significant interruptions to the line of sight.

On the other hand, if the enemy realizes he is being fired at and travels 10 to 15 miles per hour (still a slow speed under fire), he could cover between 100 and 250 meters over terrain with all of its irregularities, cover and concealment; and he could do so with considerable impunity.

If our enemy knows or soon learns the basic capabilities of such a weapon and wants to survive, he knows he can move for 100 to 250 yards before seeking concealment. He need not even stop his advance, only be out of sight behind trees, terrain features or even artificial smoke.

Now let's look at some of the effects of the other major misleading assumption--that the tank system is the individual tank. It would appear that all of our design activities, testing and evaluation are directed toward the development of the most effective individual tank which can be placed on the battlefield. As a result, we find, for example, that we can improve the gunnery performance of this individual vehicle, when assessed in isolation, by including the commander as a necessary link in the fire delivery subsystem. (We do this by assigning continuously increasing proportions of the gunner's tasks to the tank commander.) Thus, essentially, during the period of a fire-fight we have effectively removed the commander from the vehicle and made him an assistant gunner. And yet we still say we must recognize the role of the individual tank commander in unit coordination in order to enhance platoon fire effectiveness.

In other words, we too often find that we design the commander's station to enhance the performance of the individual vehicle on the gunnery range, and ignore those factors of station design which could enhance the coordinated combat effort of the tank platoon (that is, the total tank system) for increased combat effectiveness.

Once we recognize target behavior is an important parameter of tank system effectiveness and that one of the commander's primary tasks is to command his tank and keep it coordinated with the other tanks in his formation, we are compelled to re-examine our current ranking of tank design factors as they affect the outcome of tank battles. Such re-examination might produce a priority of effort for total tank system improvement that would look, in decreasing order of importance, something like this (slide):

1. Command and control.

2. Tactical mobility.

3. Target acquisition capabilities.

4. Target presentation--as a function of size, time, movement, shape, etc., as affected by ability to use terrain.

5. Time to obtain a first hit.

   a. Rates of fire.

   b. Delivery accuracy.

6. Terminal effects of rounds.

7. Armor protection.

This ranking of relative importance of effectiveness measures for combat vehicles is almost exactly the inverse of the ranking normally accorded to these factors. It is, not coincidentally, also an inverse order to the ease with which we can devise quantifiable measures. This would mean, then, that we know a lot about those parameters that have little effect on the outcome of combat, and relatively very little about those far more important parameters which have a significant effect on combat.

As a direct outgrowth of this re-examination of effectiveness measurements and re-ordering of criteria, we at HEL have recently embarked on a series of operational field studies of artillery, armor and infantry performance. In these initial studies, we are using present-generation materiel not only to determine component contributions to system effectiveness (or ineffectiveness) but also to achieve valid total-system effectiveness data against which future system concepts can be compared.

Two such studies have already been completed in the area of battalion artillery operations (HELBAT I and HELBAT II). These studies, employing combat scenarios and the integrated systems approach, have clearly indicated where errors enter into a battalion artillery mission and how performance can be significantly improved through the introduction of new techniques and materiel.

In a similarly conceived armor study, HELAST I will employ full platoons or higher-level units of M60 series tanks and Sheridans in combat scenarios under fully operational conditions, including a reacting enemy force. The objective of HELAST I will be to obtain measures of overall system effectiveness, develop effectiveness criteria for future studies, and identify subsystems requiring additional design effort to increase the total effectiveness of the present systems.

In due course, this integrated systems approach will be applied to infantry weapon systems, and it should eventually be extended to all types of Army materiel.

SUMMARY

All too often, in the past, we have erred in developing our measures of effectiveness:

1. We have defined our terms for measurement more for the ease with which we can obtain quantifiable data than for their relationship to the real world of combat.

2. We have used erroneous assumptions, even to the point of inadequately defining the "system" with which we work.

3. We have assumed, almost entirely, that we could measure the effectiveness of weapons systems while ignoring fully one-half of the system--the enemy's behavior and his responses to the battlefield characteristics of our weapons.

At HEL we are building on our re-examination of these past errors by studying artillery, armor and infantry systems under the most realistic obtainable field conditions so we can provide designers of future systems with effectiveness criteria that will allow those systems to function effectively, not on the firing range or test course, but where it really counts--on the field of battle.

RECOMMENDATIONS

To obtain more valid measures of effectiveness of system performance, it will be necessary to take the following steps toward the development of more valid criteria:

1. Assess not only the more easily quantifiable measures of effectiveness but also the less quantifiable but perhaps more important measures of real-world effectiveness.

2. Define the system more realistically in terms of its combat mission and battlefield conditions.

3. Assess system performance in terms of those aspects of total system behavior which affect the outcome of battles.

4. Recognize that weapons systems are usually engaged on the battlefield, not singly, but in combination with other weapons systems. Thus, even in tank-oriented battles, most targets engaged by tanks are not other tanks (though tanks may be the most important targets engaged).

5. Consider the other half of our combat systems--enemy behavior in response to the characteristics of our weapons systems.

FOR VALID MEASURES OF TANK EFFECTIVENESS WE MUST:

1. ASSESS COMMAND AND CONTROL, ALONG WITH FACTORS SUCH AS DELIVERY ACCURACY, RATES OF FIRE.
2. DEFINE THE TANK SYSTEM AS IT MORE NEARLY EXISTS--THE "TANK PLATOON."
3. INCLUDE ASSESSMENT OF SUCH FACTORS AS USE OF TERRAIN AND TACTICS.
4. RECOGNIZE THAT THE MILIEU OF ARMORED COMBAT INCLUDES OTHER WEAPONS SYSTEMS AS WELL AS TANKS.
5. RECOGNIZE THAT MEASURES OF EFFECTIVENESS OF A WEAPONS SYSTEM MUST INCLUDE BEHAVIOR OF THE ENEMY TARGETS.

A Computer Model of a Semiautomatic Flight Operations Center (SAFOC) Using the General Purpose Simulation System

Mr. John Mikula, American Electronic Laboratories, Colmar, Pennsylvania
Dr. Erwin Biser, Mr. Arthur Coppola, and Mr. Herman Mencher
Avionics Laboratory, USAECOM, Fort Monmouth, New Jersey

Introduction

The purpose of this paper is to discuss the use of the General Purpose Simulation System (GPSS)/360 in modeling a Semiautomatic Flight Operations Center. SAFOC is being tested and evaluated at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, N. J., by the U.S. Army Electronics Command, Avionics Laboratory (AMSEL-VL-G), Fort Monmouth, N. J.

Construction and utilization of the GPSS/360 model is but one part of a series of tests designed to determine the effectiveness of SAFOC in performing its mission in a realistic environment. The series consists of Preliminary testing for familiarization with the equipment and training of controllers; Phase I testing to determine the best operational method and to find the system performance measures and effectiveness measures; and Phase II testing to fully evaluate SAFOC using realistic scenarios and to recommend changes to optimize SAFOC. GPSS/360 modeling contributes to system optimization within Phase II.

SAFOC Technical Objectives

The technical objectives of the SAFOC are:

1. To regulate Army air traffic under instrument flight rules.

2. To provide flight following capability under visual flight rules.

3. To improve information transfer among system elements and units being supported.

4. To provide computer facilities to automatically analyze air traffic data for display and decision-making by an operator.

5. To provide a means for making commanders aware of the current air traffic situation for overall tactical planning.

6. To perform specific functions required for air traffic regulation.

System Functions

The SAFOC system includes a data processing subsystem, radar processing subsystem, display subsystem, and a manual backup subsystem to provide the following capabilities:

a. Flight Data Processing
b. Flight Following
c. Flight Handoff
d. Identification Assistance
e. Emergency Assistance
f. Air/Ground Coordination
g. Ground/Ground Coordination

SAFOC provides the following methods of flight tracking: digital data link, radar beacon, radar skin return, and flight plan following.

SAFOC Test Configuration

Figure 1 shows the SAFOC test operations and information flow diagram. The scenario generator program generates scenarios and scripts based on realistic scenarios. The scripts are followed by pilots who simulate actual flights using target generators which are part of NAFEC's data link simulation.

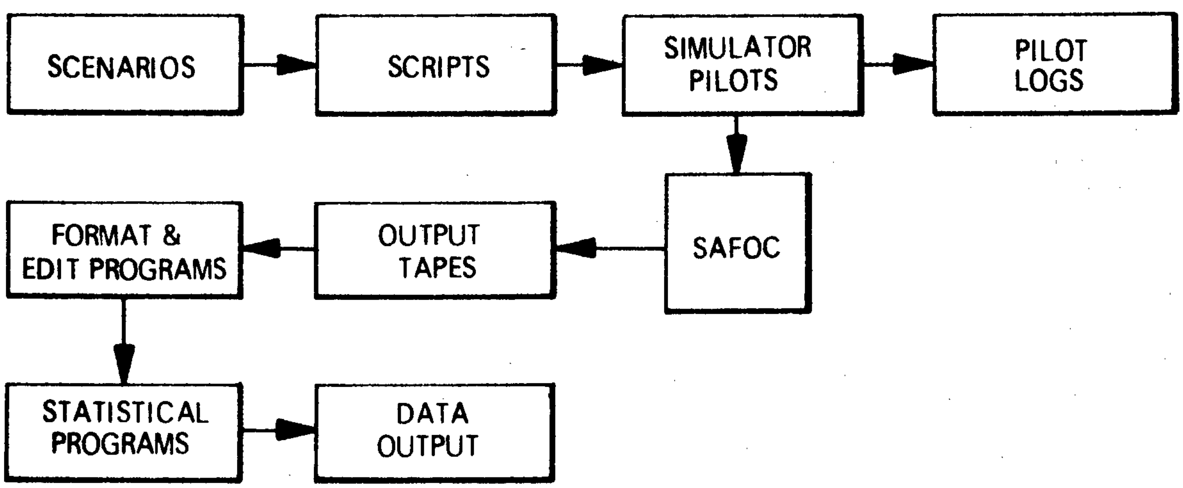


Figure 1. SAFOC Test Operations and Information Flow Diagram

Using a pre-determined operational-procedural mode, SAFOC controls the simulated flights and produces exhaustive time histories on magnetic tape. These histories include all actions performed by the equipment or by the controller. The raw output data tape and the target generator history tape are processed using a series of formatting and editing programs, after which statistical programs generate the desired data output.

Phase 1 Test Plan

The purpose of Phase 1 of the SAFOC system evaluation is to determine the best operational-procedural combination for SAFOC. The tests consist of a series of scenarios of three different traffic levels. Each of four controller teams operate the SAFOC according to four different operational-procedural combinations. The outputs, consisting of system effectiveness measures, are ranked to determine the best operational-procedural mode. Figure 2 illustrates this experimental design.

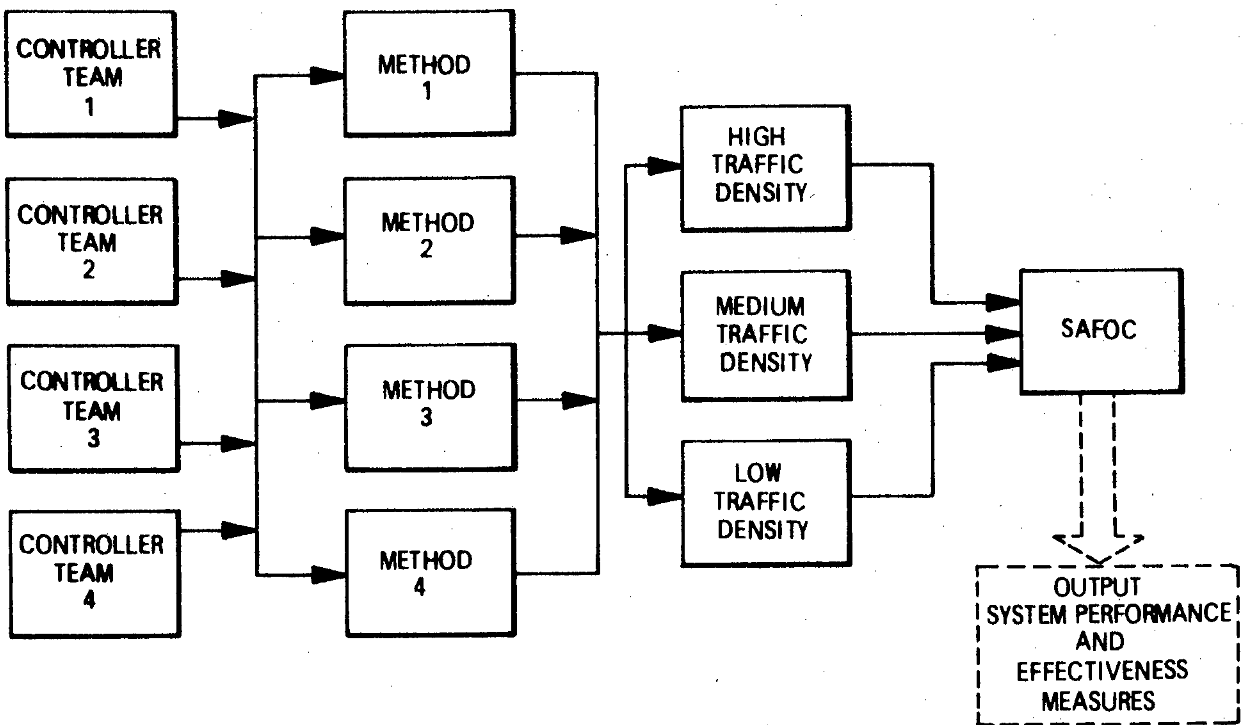


Figure 2. Phase I Experimental Design

System Performance Measures evaluate the individual items which, in total, influence the system effectiveness. The performance measures represent, for example, the actual contributors to total workload, and it is through improvements in the performance measures that the effectiveness measures can be improved.

1. Time to perform each service
2. Service rate
3. Waiting time for service
4. Event time history
5. False dismissal probability
6. Actual density history
7. Queue lengths
8. Typewriter errors
9. Near miss history
10. Communication time history
11. Number of impossible requests
12. Altitude change history
13. Closest approach history

System Effectiveness Measures are used to provide relative rankings of the operational-procedural modes and to evaluate relative controller team performance. The following measures are chosen because they represent the characteristics most important to the user:

Safety is the number of near misses per aircraft mile flown.

Controller workload is the total time for all flight servicing.

Communications workload is the total time spent in communications.

Delays are the actual departure time delay from the planned departure time. Delays are important in a tactical situation.

Throughput is defined as the actual number of flights entered during steady state divided by the number of entries planned in that time.

Capacity is the peak flight density safely handled by the system.

Uncontrolled time is the total time of flights within the SAFOC control area without being controlled by SAFOC.

Phase II Test Plan

The objective of Phase II testing of SAFOC is to evaluate the system as presently configured and to recommend techniques to optimize the system. Figure 3 shows the interrelationships of the tasks included in Phase II testing.

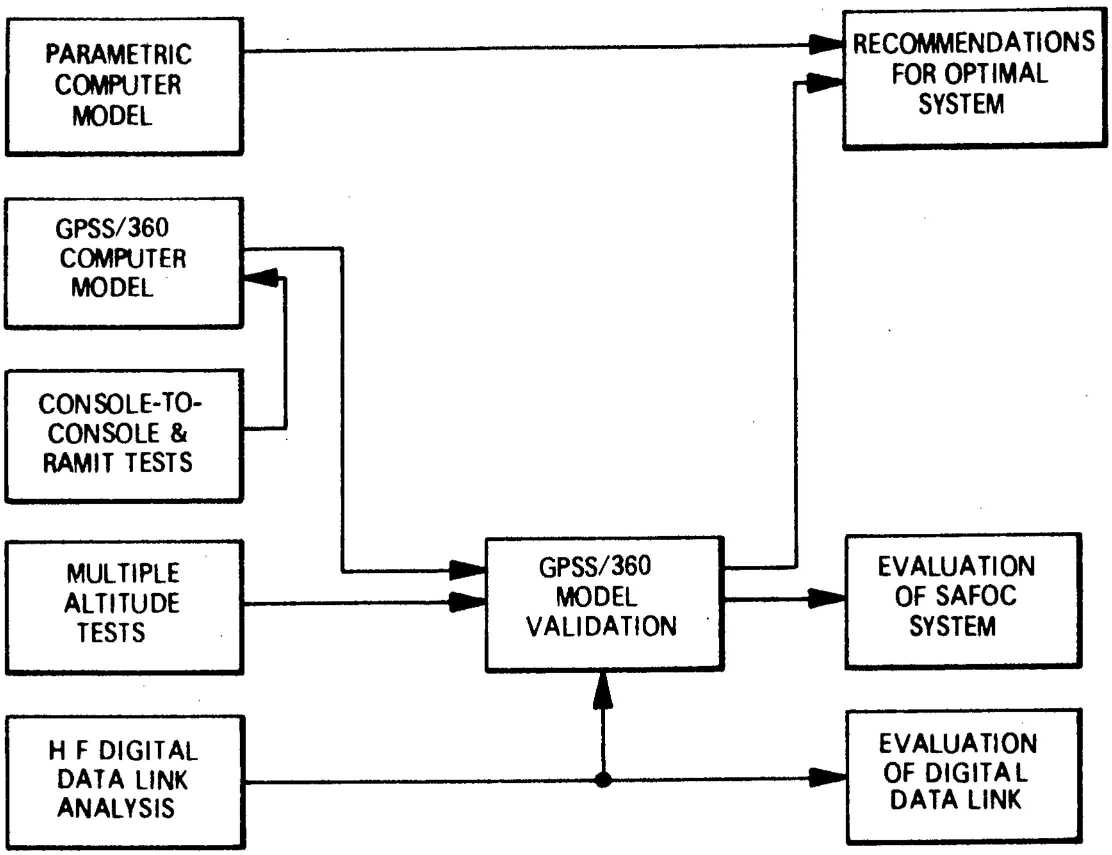


Figure 3. Phase II Task Interrelationship

a. SAFOC System Parametric Computer Model - involves a FORTRAN simulation of the computational algorithms used in the SAFOC operational program. By varying those parameters associated with smoothing and tracking, conflict prediction and resolution, alert processing, data link and beacon tracking, etc., the optimum set of parameters can be determined.

b. GPSS/360 Computer Model - involves simulating the flows of information and events within the SAFOC system. The interactions of the controllers, displays, and the SAFOC computer are examined. Phase I tests will provide the service time distributions used in constructing the model. A series of tests will then be run on the actual SAFOC and on the model and the results compared statistically to validate the model. The search for system optimality can proceed by implementing proposed changes into the model and noting the effect of these changes on system effectiveness. The output of this study consists of a set of recommendations for an optimal system.

c. Other Phase II tests include the automatic console-to-console handoff capability; the ability of the controllers to manually acquire and semiautomatically track a target from radar skin returns (RAMIT); the ability of SAFOC to handle traffic over a wide range of altitudes; and the effects of the HF digital data link errors on system performance.

SAFOC Statistical Computer Model

The objective of developing the statistical computer model is to provide a means of determining the optimum design of the system. The model is a tool for testing and evaluating proposed changes to the system before they are actually implemented. This section will discuss the steps followed in constructing the model, the utilization of the model, and the statistical validation of the model.

Construction of the Model

There are three main sources of information used in constructing the model:

1. Phase I Tests

a. Statistical distributions, consisting of data on service request rates, service times, communication times, and similar system workload data.

b. Operational procedures, as described in the Phase I Test Plan* and modified as a result of experience gained during testing.

2. SAFOC Documentation, including operational profiles describing the interactions of controller, display subsystem, and the computer. The Phase I operational procedures plus the SAFOC operational profiles constitute the actual flow of events in the man/machine system and are thus used to generate the event flow diagrams from which the model is developed.

3. Phase II Tests of specific SAFOC functions, including multiple altitude, console-to-console handoff, and RAMIT will provide data on the times required by the controller to perform these services.

Queue Structure of the Model

To understand the queue structure of the model, it is convenient to first define several terms used in the GPSS/360 language and to show their application to this model:

* "Phase I Test Plan for a Semiautomatic Flight Operations Center (Design of Experiments Program)", July 1, 1970, Contract No. DAAB07-69-C-0040.

1. Transactions - the dynamic units of traffic, representing flights in the SAFOC control area, or messages or service requests to be processed.

2. Facilities - entities which act upon the transactions and represent potential bottlenecks in the system. In this model, the controllers, communications channels, and typist are represented by facilities.

3. Queues - waiting lines for a facility.

4. Blocks - the logic structure of the system, instructing the transactions what to do next.

5. Seize - if a facility is not in use, a transaction can immediately "seize" (assume complete use of) a facility. If a facility is in use, the transaction enters a queue where it awaits its turn, based on a system of priorities.

6. Preempt - a transaction so instructed can immediately "preempt" (gain instant access to) the facility. If the facility is already "seized" by a previous transaction, processing of the previous transaction is suspended while the preempting transaction utilizes the facility.

Figure 4 shows the structure of queues for one of the SAFOC controllers. A similar structure exists for the other controller. Transactions waiting in each queue are assigned the specific priority for that queue. The Conflict 1 and Conflict 2 Alert Queues have the power of immediately preempting the facility.

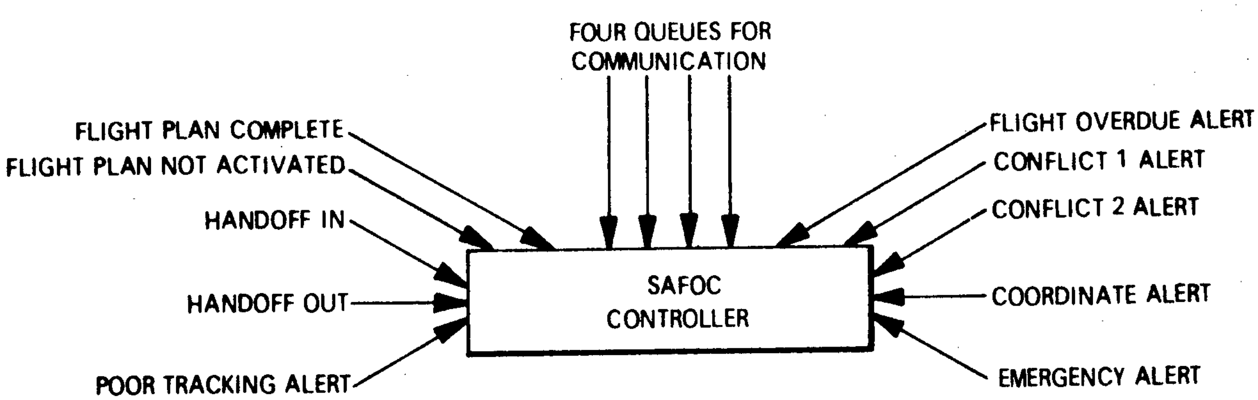


Figure 4. Queue Structure of SAFOC Computer Model

Fundamental Structure of Model

Figure 5 represents the fundamental flow diagram used in statistical computer modeling of the SAFOC system. This flow diagram is used repeatedly in the model and, with minor modifications, is made to represent the flow of events for any service request, communications request, or other response required of the controller.

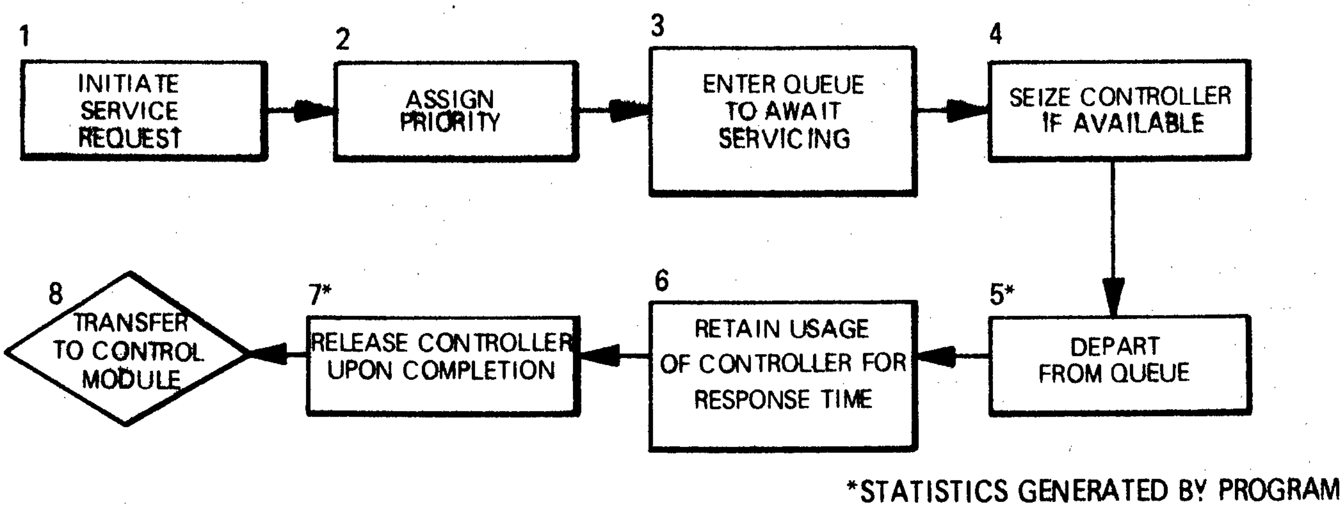


Figure 5. Fundamental Flow Diagram of Model

1. The first block in the flow diagram represents the initiation of a request for the services of the controller.

2. A pre-determined priority is assigned to each request.

3. If the controller is busy, the transaction (service request) enters a waiting queue until all higher-priority transactions have been processed.

4. When the controller is free, the transaction seizes the facility.

5. The transaction at the same time departs from the queue, whereupon queue statistics are generated automatically by the program.

6. The transaction (service request) retains usage of the facility (controller) for some response time selected from a response time distribution for that service.

7. Upon completion of the service, the facility is released by the transaction. The controller is now free to perform some other task.

8. The transaction is then returned to the control module to await the time for the next service request.

Statistical Inputs to Model Construction

The statistics and histograms generated in Phase I and in the Console-to-Console Handoff, RAMIT, and Multiple Altitude portions of Phase II are incorporated into the model to yield the response times for which the controller is seized for each service. Elapsed time histograms are constructed for each type of alert service request, alert or non-alert hook, typewriter message, and communication message.

Each cell of the histogram gives the number of times that the observed elapsed time falls within some range. Division by the total number of occurrences gives an estimate of the probability density function, from which the cumulative distribution function is constructed. This latter function is inserted into the GPSS/360 model using standard techniques described in IBM Manual GH20-0326-3, "GPSS/360 User's Manual." During the running of the model, a random number generator internal to the GPSS/360 program selects a value from the cumulative distribution function and assigns that value for a response time. This is repeated each time the controller responds to a service request.

GPSS/360 Entities Utilized by the Model

Facilities (7)

Assistant Controller
First Controller
Second Controller
Adjacent Sector (Ghost 1)
Commo. Channel, Controller 1
Commo. Channel, Controller 2
Adjacent Sector (Ghost 4)

Communications Queues (10)

Controllers to Pilot (2)
Each controller to each adjacent (ghost) sector (4)
Controller 1 to Controller 2 (1)
Each ghost sector to pilot (2)
Typist (1)

Alert Service Queues (20)

These are shown in Figure 4 for each controller.

Transaction Parameters

The following scenario parameters, assigned to each flight at the beginning of a run, contain all the scenario information input to the model:

Serial entry number
Altitude
Velocity
Series of control sectors
Entry times to four sectors
Estimated time of arrival (ETA)
Aircraft Emergency time
Tracking Mode
Conflict 2 schedule
Conflict 1 schedule

The following data collection parameters act to save certain values assigned to each flight during a run:

Out-of-altitude amount	SAFOC entry delay
Return to altitude time	Uncontrolled time
Velocity error	Actual time of arrival (ATA)
Accumulated time delay	ETA coordination time

The following bookkeeping parameters aid the program in keeping track of internal operations on each flight:

Control sector counters	Sector entry times
Sector type designators	Conflict resolution flag
Conflict counters	Delayed handoff flag
Elapsed times	Coordination flag

Program Structure of the Model

Figure 6 shows the structure of the SAFOC system computer model, which consists of four main modules:

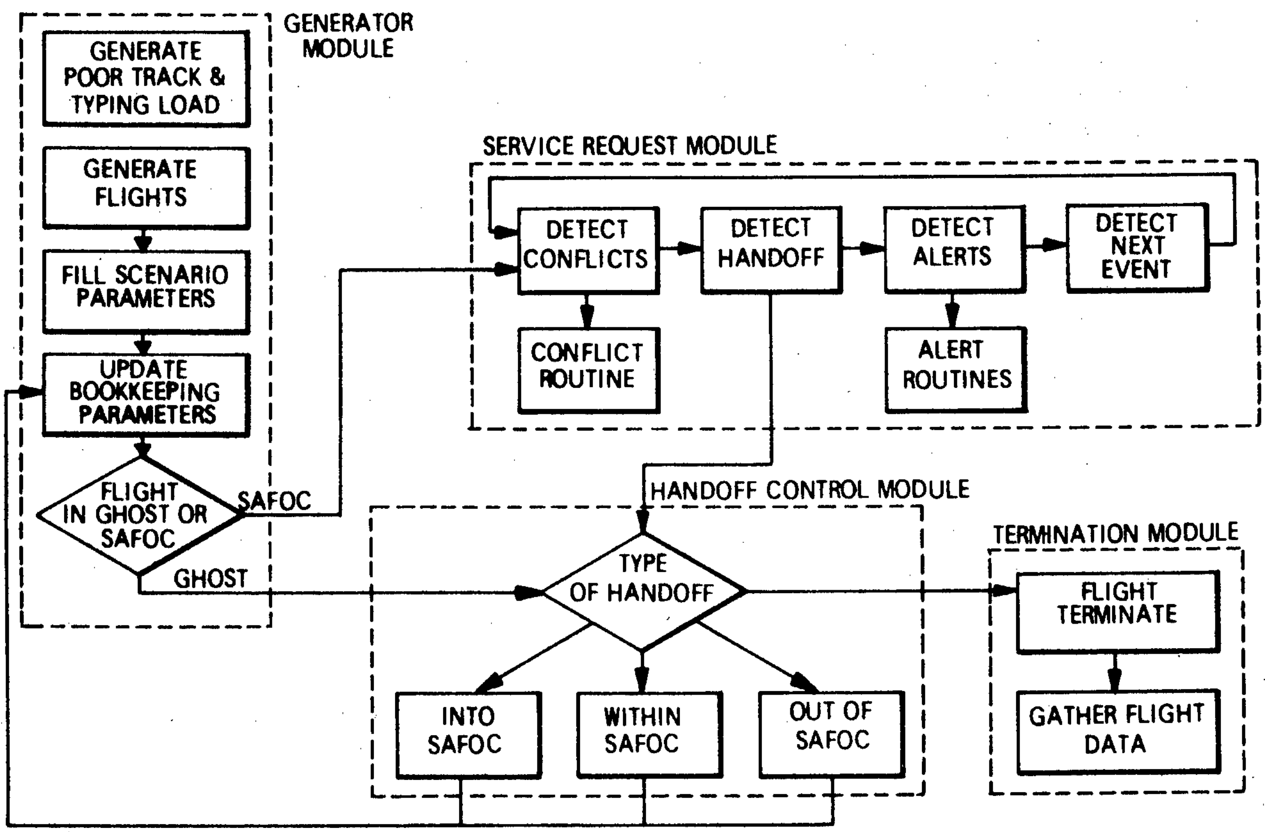


Figure 6. Structure of SAFOC Computer Model

1. Generator Module: generates and resolves poor tracking alerts, generates the flight plan entry workload for the typist, and generates all flights for the model. It also

inputs all scenario constants into the appropriate scenario parameters, and initializes or updates the bookkeeping parameters. It then steers the flight according to whether it is under Ghost or SAFOC control.

2. Service Request Module: for flights under SAFOC control, this module simulates the performance of all services, including RAMIT updating, conflict detection and resolution, handoff time detection, ETA updating, emergency alert servicing, and altitude change requests.

3. Handoff Control Module: upon detection of handoff time from the Generator Module or from the Service Request Module, this module performs the necessary kind of handoff, then steers the flight back to the Generator Module to update the bookkeeping parameters.

4. Termination Module: terminates flights which have reached their destination, decrements the flight density counter, and gathers data from these flights.

Model Output

The standard GPSS/360 statistical output consists of counts of the number of transactions passed through each block; the average utilization, number of entries, and average time/transaction for each facility; the maximum and average contents, number of entries, and average wait times for each queue; table contents (data for histograms); and save value contents (flight-generated data).

In addition to the standard output, special purpose output includes the following:

1. Tables of flight characteristics, including velocity error, entry delay, uncontrolled time, estimated time of arrival, and actual time of arrival (Figure 8a).

2. Actual density history (Figure 8b).

3. Altitude change history for all flights (Figure 8c).

4. Operator and communication queue statistics, including maximum and average contents and average waiting times (Figure 7a).

5. Operator and communications workload summary (Figure 7b).

6. Histograms of entry delay times and uncontrolled flight times (Figure 8d).

Model Validation

The objective of this task is to statistically verify that the computer model is an accurate simulation of the actual SAFOC system. This is a vital step if the model is to be used to study proposed changes in the actual system.

OPERATOR QUEUE STATISTICS

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	AVERAGE TIME/TRANS
CONFLICT2	1	.000	2	2	.000
CONFLICT1	1	.000	5	5	.000
POOR TRACK	1	.040	19	6	7.684
HANDOFF OUT	2	.103	11	1	33.727
COORDINATE	2	.113	6		68.000
FLT PLN NOT ACT	1	.000	1		1.000
HANDOFF IN	5	.408	37	18	39.783
CLEAR/COORD	9	2.026	29	10	251.586
FLT PLN COMPL	6	.779	11	1	255.181
COMMUNICATIONS QUEUE STATISTICS					
OPER-PILOT	5	.525	57	25	33.210
OPER-GHOST1	4	.261	22	6	42.818
OPER-GHOST4	2	.250	26	13	34.653
PILOT-GHOST1	1	.010	20	17	1.949
PILOT-GHOST4	2	.040	20	16	7.250

a) Queue Statistics

OPERATOR WORKLOAD SUMMARY

FACILITY	AVERAGE UTILIZATION	NUMBER ENTRIES	AVERAGE TIME/TRANS
OPER	.650	158	14.829
COMMUNICATIONS WORKLOAD SUMMARY			
COMM CHANN1	.160	42	13.738
COMM CHANN4	.198	46	15.565
OPER COMM	.458	105	15.714

b) Facility Statistics (Workload Summaries)

This and following figure show sample outputs from a trial run of the model using a 29-flight scenario. Only one SAFOC operator is used.

All times are in seconds. Total simulated run time is 3600 seconds.

Figure 7. Partial Listing of Model Output

FLIGHT NUMBER	VEL ERROR	ENTRY DELAY	UNCNTR TIME	ETA	ATA
1	-2	8	0	1800	1677
2	-4	22	0	3100	2957
3	0	0	0	2000	1837
4	-3	41	0	0	0
5	-3	28	0	3300	3174
6	1	0	54	3600	3415

a. Flight Data Table

DENSITY	TIME
1	360
2	540
3	540
4	780
5	940
6	1060
7	1060
8	1340
9	1340
10	1350
11	1400
12	1460
11	1677
10	1693
9	1837
10	1880
11	2000
12	2120
13	2400
14	2410
15	2420
16	2420
17	2420
18	2520
17	2595
18	2904

b. Flight Density History

FLIGHT NUMBER	BASE ALT.	CHANGE	TIME
7	3000	-1000	1548
5	3000	-1000	1597
5	3000	0	1853
11	2500	1000	2098
9	3000	-1000	2226
11	2500	0	2352

c. Altitude Change Table

```
4*      **  **                  **
 *      **  **                  **
3*      **  **  **      **      **      **
 *      **  **  **      **      **      **
2*      **  **  **  **  **  **  **      **
 *      **  **  **  **  **  **  **      **
1*  **  **  **  **  **  **  **  **      **  **          **
 *  **  **  **  **  **  **  **  **      **  **          **
0************************************************************
     0  20  40  60  80 100 120 140 160 180 200 220 240 260
            HISTOGRAM OF ENTRY DELAY TIMES (SECS)
```

d. Entry Delay Histogram

Figure 8. Partial Listing of Model Output

The mathematical model has the objective of searching for any statistically significant differences in results between SAFOC tests at NAFEC and computer model runs. The system effectiveness measures from the model and from the actual SAFOC will be compared.

The case to be considered is that of taking pairs of observations under like conditions, but with conditions varying from pair to pair. In this case, an observation using the NAFEC simulator and one using the computer model, both for a common scenario, constitute a pair. The varying experimental conditions are the different scenarios and the different controllers.

Denote a set of n paired random variables, corresponding to the results of n trials, as $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$. The difference between the members of the pair are then $d_i = x_i - y_i$. It is assumed that each of the x_i and y_i are independent, normally distributed random variables. Under this assumption, the difference d_i are independent normally distributed random variables with common population means μ_d and common standard deviations σ_d.

Testing for equality between results from SAFOC and from the model is equivalent to testing the hypothesis the $\mu_d = 0$ when σ_d is unknown. The usual test statistic t with n-1 degrees of freedom is

$$t = \frac{\bar{d}\sqrt{n}}{s_d}$$

where

$$\bar{d} = \frac{1}{n}\sum_{i=1}^{n} d_i \quad \text{and} \quad s_d = \sqrt{\frac{\sum_{i=1}^{n}(d_i - \bar{d})^2}{n_1}}$$

Each of the system effectiveness measures previously described will be tested in this manner. If the hypothesis of equality must be rejected for any measure, the model will be corrected until all measures are in agreement.

System Optimization

An optimal system will be sought by postulating design and procedural changes, implementing these changes into the GPSS/360 model, and examining the resultant influences on the system effectiveness measures.

Design changes to be examined include the alert processing parameters, automatic handoff, automatic flight plan entry and update, and other changes to increase or decrease the degree of automation of SAFOC. Procedural changes include changes to the alert priority schedule, variation of the altitude change procedure, modification of the handoff procedures, etc.

By approaching these changes in a way which systematically improves the effectiveness measures, a model of an optimal SAFOC configuration can be attained.

SUPPORT FORCE ANALYSIS AND PLANNING
A Programming Model

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INTRODUCTION

The need to integrate support requirements with combat requirements in theater force planning has gained much emphasis in recent years. Efficient and computerized procedures that generate or round out a total troop list from a specified combat force mix have now been realized. Two such procedures, Modular Force Planning System (Battalion Slice) and Force Analysis of Theater Administration and Logistic Support (FASTALS) represent the current state-of-the-art in theater support force planning methods. Both methods calculate the military workloads generated in a single theater of operations, and by using pre-determined allocation rules, establish the support force required to satisfy these workloads.

Although this requirements oriented approach is necessary, it is not sufficient for the force planner because support forces are often strongly dependent on priorities and economic considerations. Also, since planning must be implemented in order to be effective, it is necessary for the Army's planning process to receive DOD acceptance and subsequent approval of resources for Army forces. Hence, the force planner needs a means of developing quickly and systematically alternative forces that satisfy desired constraints. The concept developed here then is to take a theater force, established from military requirements, along with the allocation rules for the support units, enter resource or other constraints of the force planner, and generate constrained alternative forces.

This need of the planner is met in the mathematical programming approach described in this paper. The approach provides a tool that permits the Force Planner to perform economic trade-offs in the force structure at an early state of planning. It will point to those units and to those allocation rules in the force structure that contribute the most to the force costs. By allowing the planner to add tolerances to the allocation rules, to add resource constraints and specify priorities, the model greatly increases the flexibility of the current requirements oriented procedures. This model reflects the change in support planning taking place, i.e., the change from a 'requirements oriented' approach to 'what are the alternatives' coupled with 'what can we afford.'

AN OPTIMIZATION APPROACH: CSS FORCE MODEL

A standard technique for the kind of approach described above is a constrained optimization or a linear programming approach. In this approach, requirements are constraints which are inputs to the analysis, and such constraints can represent requirements and priorities of many kinds in addition to the strictly combat requirements. Alternative forces are developed as a result of changes in the constraints and/or objective function of a programming model. They represent the difference between a given force and its alternatives. Tradeoffs are the substitutions that occur among force elements during a force transformation. The needs of the Army Support Force planner therefore find a natural interpretation in the concepts and capabilities of a constrained optimization approach.

The outline of the presentation is shown in Fig. 1. We will report to you the most recent results of the research effort during the past year, the time since the last symposium meeting at Durham. After a brief description of the model, you will see some results of applying the model to a large European force. In one set of tests the number of combat units remained fixed and the allocation rules of the support units were varied. We studied the impact on the total force structure of these variations. Another way that one can reduce the strength in a force is to keep the allocation rules fixed and allow the combat units to change. This will be illustrated by some examples of alternative forces that have been generated allowing the original combat unit requirements to change and imposing the constraint of reducing the overall force strength.

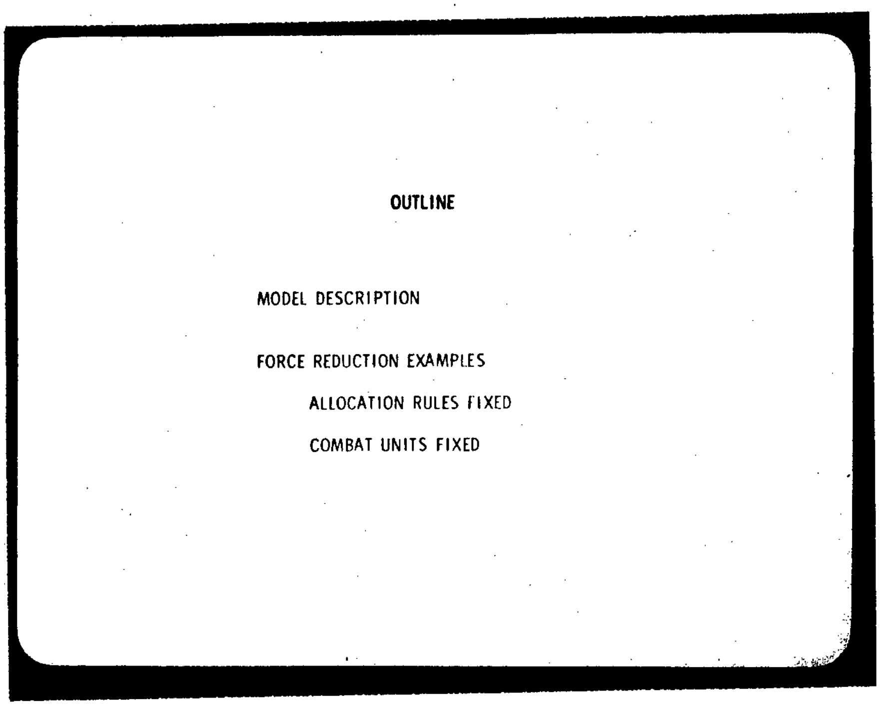

Fig. 1—Outline of Paper

THE MODEL: GENERAL DESCRIPTION

The basic concepts of the model are shown in Fig. 2. We first take a troop list that has been generated from military requirements. This list may include the combat units used in a war game and rounded out with the support units, using pre-determined allocation rules. The roundout procedure might be one of the recent developments in support planning such as the battalion slice method or the FASTALS model. These forces are then examined by a force planner and he may wish to constrain the force in various ways. In particular, he may wish to reduce the support strength, or he may wish simply to reduce the overall strength of the force. He may want the combat to support ratio increased. Also, he may want to enter certain priorities into the force structure. Priorities here could mean, for example, changing the balance or the ratio of mechanized troops to infantry troops or the ratio of armor to artillery. In any case he can enter these priorities into the force model and the output then becomes alternative forces which satisfy these constraints.

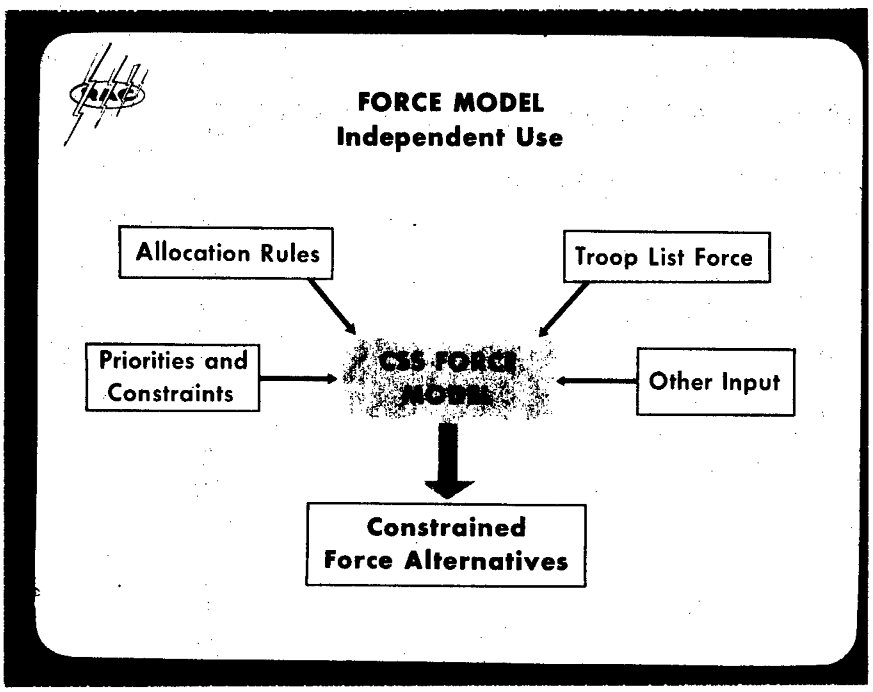

Fig. 2—Conceptual Description of Force Model

Closer examination of the model reveals that it is a linear programming formulation, and shown here in Fig. 3 is the A matrix and the B matrix of the model. Any entry in this A matrix identifies the support needs of a given combat unit. A combat unit of type 2, for example, may need a certain type of support, support type 2. Further, this support unit of type 2 may be required by other support units, possibly even support units of its own type. That entry is found in the B matrix. As an example, transportation units need some type of transportation support so an entry reflecting that need would be in this B matrix of the model. These two arrays - the A matrix, relating the needs of the combat units for their support, and the B matrix, indicating the needs of all of the support units for various types of support - constitute the data base of the model. We also have a C matrix here that can be used to specify the number of combat units required or desired in a given troop list. With the other inputs to the model we can then indicate ratios or preferred mixes of combat units, or we could simply put bounds on the combat units and let them range between some lower and upper bound. In addition, many other constraints can be put into the model. After the objective function is selected the model then is ready to be run.

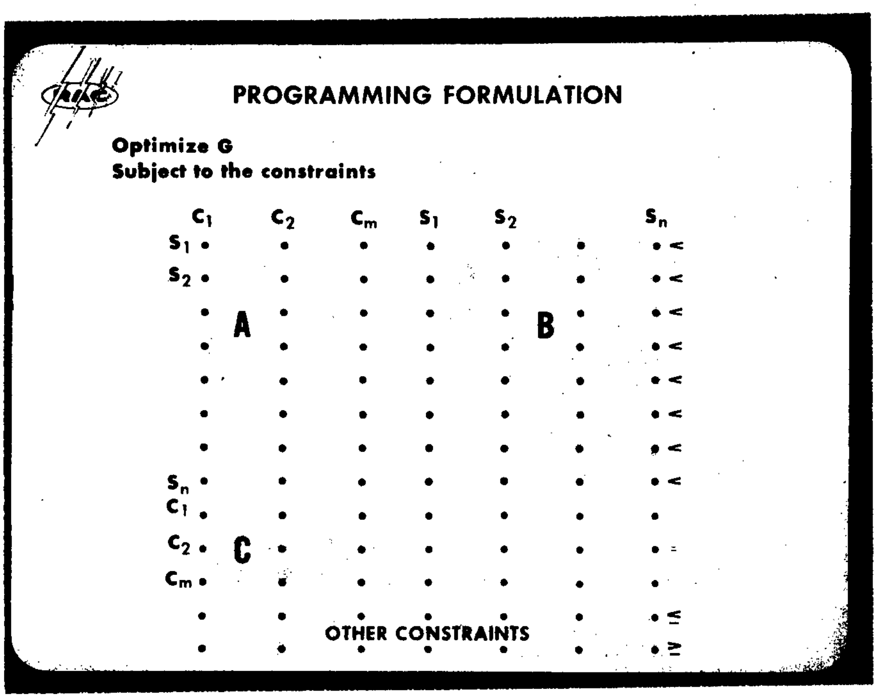

Fig. 3—Linear Programming Formulation of Model

Figure 4 is a list of various user options, that is, various objective functions that the user of this model can select and various constraints that can be added. This is not the entire list, but it is a representative list of the ones which would seem to be used most often. For objective functions, the user can minimize total force strength or he can minimize the total force cost in dollars. He can maximize the total combat strength. He can minimize the total support strength. The mission effectiveness refers to some function that measures the combat power or the combat effectiveness of the set of combat units in the troop list.

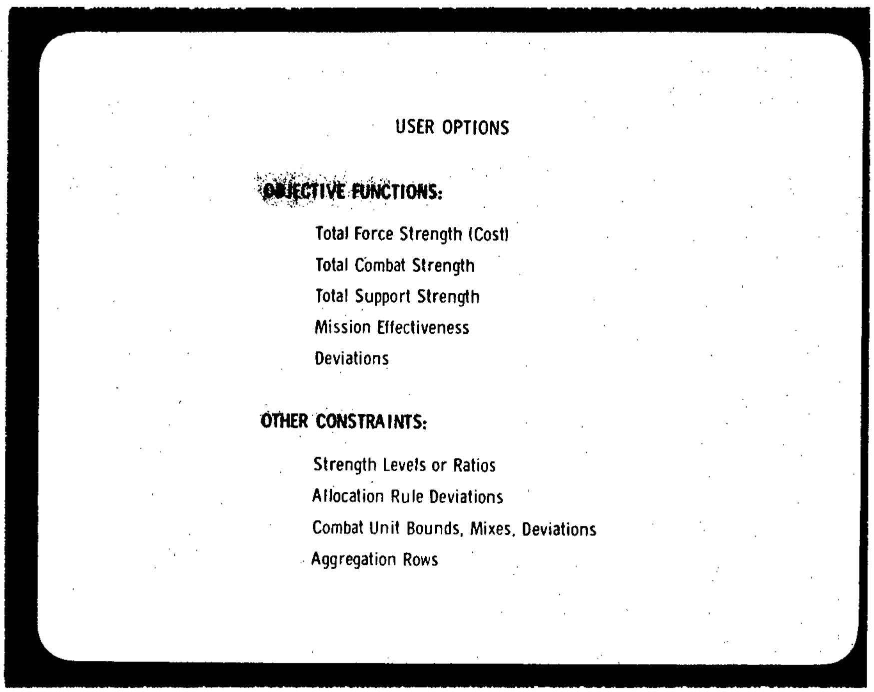

Fig. 4—Objective Function and Constraint Options

The last objective function shown here, deviations, is a very important one, because a troop list is often presented to the planner as the required one, that is, the list of units required to satisfy a given military situation. Now if the planner is faced with the need to reduce the total force strength, he may want to reduce the number of certain types of units, but reduce them in such a way that he does the least harm to the force. Representing this objective function with deviations, he can formulate the program in such a way that the deviations from the stated set of requirements would be minimized. For example, if he has 18 infantry battalions stated as required, 55 tank battalions stated as required, and a number for every other combat unit stated as required, and if he must reduce the overall strength of the force by 10 or 20 percent, he makes the selection of combat units to delete from the force in such a way that the deviation from the stated requirement is minimum. In other words, he stays as close as he can to the 18 infantry battalions, the 55 tank battalions, etc., yet at the same time he reduces his total force strength by 10 or 20 percent. An example of this will be shown in just a few moments. Allocation rule deviations are another example of this type of objective function. The capability to study the effect of changing various allocation rules, that is, the effect on the overall force structure is perhaps the most important result of our study. Determining which allocation rules when changed slightly offer the greatest promise of overall force reduction is most important to the force planner.

Still referring to the constraints in Fig. 4, the first two were already mentioned. The force planner can constrain the overall strength level or the strength level of a given subset of units or he may want the ratio of a certain type of support like medical to engineers be no greater than a given number. This type of constraint is easily entered into the program. We can also insert bounds on the combat units or define preferred mixes of the combat units.

There can be 34 different types of combat units and some 500 different types of support units. Consequently, this total force can become quite large. If one wanted to look only at the aggregated types of support such as all of the medical, or all of the engineers, or all of the signal, it might be much easier for the planner to get a better view of what is in the force by looking at just these aggregations. This is accomplished by adding aggregation rows, the last entry in Fig. 4. These rows are not constraints but rather are simply bookkeeping rows. These rows do not constrain the force but only keep track in the aggregate of various and selected types of units. This proves quite useful to the force planner.

Examples With Allocation Rules Fixed

Proceeding now to the examples, we use as the initial force, a hypothetical European theater force in a defensive posture. It was provided to us by our Army ACSFOR sponsor. It's a very large force. As a description of how large it is, in Fig. 5 is the list of combat units in the force. There are 34 different types. In total there are 346 combat units, 18 infantry battalions, 53 mechanized infantry battalions, 55 tank battalions, etc. The overall force strength of this particular force for the European theater is 751,085 men. The total combat strength as shown in Fig. 5 is 232,803 men. Also calculated is the total IFP, that is, the total index of firepower potential for this set of combat units, as shown here at 6708. This number is computed by assigning an IFP to each of these combat units and then making a total of that list. As can be seen the combat force is large and below these combat units are about 500 different types of support units. The total support strength is 518,282 men.

COMBAT UNITS — INITIAL FORCE

DTM		No.	DTM		No.
901	INFANTRY BN	18	921	FA BN, 155/8 IN SP (DIV)	10
902	MECHANIZED INFANTRY BN	53	922	FA BN, HONEST JOHN (DIV)	10
903	AIRBORNE INFANTRY BN	12	923	AERIAL WEAPONS CO.	12
904	AIRMOBILE INFANTRY BN	9	924	AD BN, CHAP/VULCAN SP D	8
905	TANK BN	55	925	AD BN, HAWK MOBILE	7
906	ARMD CAV SQD, INF/MECH	10	926	FA BN, 105 MM TOWED (NON-DIV)	3
907	AIR CAV SQD, AIRMOBILE	1	927	FA BN, 155 MM TOWED	6
908	ARMD CAV SQD, AIRBORNE	1	928	FA BN, 155 MM SP	12
909	ARMD CAV TRP SEP I/M/A	5	929	FA BN, 8 IN SP	18
911	ARMD CAV TRP, SEP ABN B	1	930	FA BN, 175 MM SP	12
912	ARMD CAV SQD (NON DIV)	9	931	FA BN, HONEST JOHN	6
913	AIR CAVALRY TRP	3	933	FA BN, SERGEANT	3
914	FA BN, 105 MM TOWED (INF)	6	934	FA BN, PERSHING	1
915	FA BN, 105 MM TOWED (AM)	3	936	AD BN, HAWK SP	9
916	FA BN, 105 MM TOWED SEPI	1	937	AD BN, NIKE-HERCULES	6
917	FA BN, 105 MM TOWED SEPA	4	939	AD BN, CHAP/VULCAN TOW	4
919	155 MM SP M/A DIV	24			
920	155 MM SP SEP M/A BDE	4		TOTAL	346

TOTAL FORCE STRENGTH	751,085
TOTAL COMBAT STRENGTH	232,803
TOTAL SUPPORT STRENGTH	518,282
TOTAL IFP	6,708

Fig. 5—Combat Units in Hypothetical European Force

To review exactly what we will do, we shall modify this troop list, generated from military requirements shown in Fig. 6. We shall leave the allocation rules fixed. We wish to reduce the total force strength and this reduction will be performed in increments of 10 percent. The objective is to stay as close as possible to the originally stated combat requirement, that is, we are going to minimize the combat shortfalls. Now how are combat shortfalls measured? We measure this in three ways. One way is the IFP of the combat units. We accept as a requirement the originally stated set of combat units and with their associated IFP, we stay as close to that as possible. That will be one experiment or one computer run. Next, we will stay as close to the number of combat units of the individual types as possible. That will be a second computer run. And third, we will stay as close as possible to the originally stated combat strength.

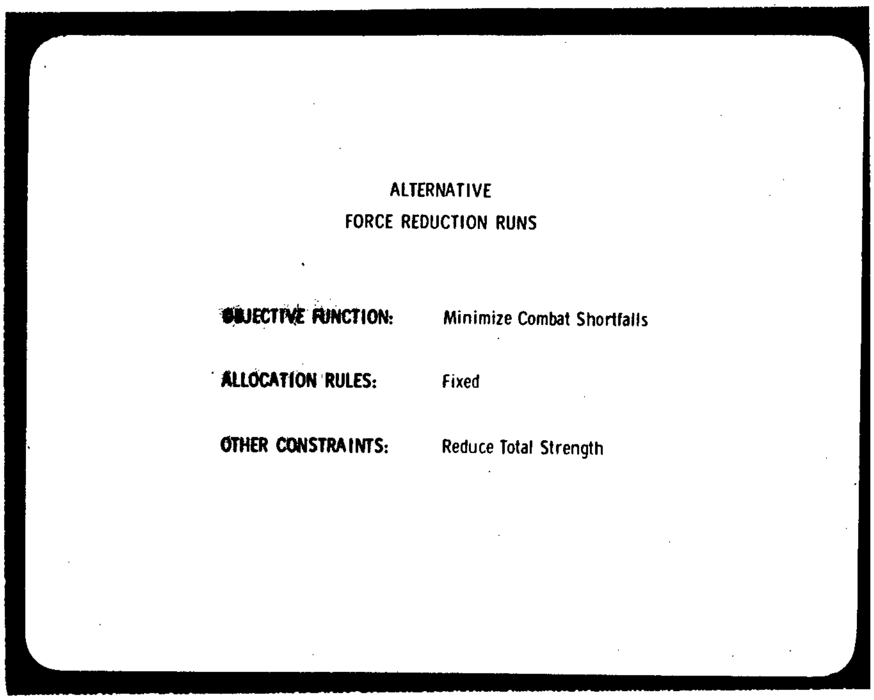

Fig. 6—Objective Function and Constraint Selection

Figure 7 shows the results of the first run. Here we minimize combat unit shortfalls. We reduce the total strength by 10, 20, 30 and 40 percent. This first line represents a zero percent reduction. There are 346 combat units in the initial force, the IFP was 6708 and if the strength is not reduced we have zero shortfalls. Added on the right is another column for comparative purposes. It is a straight-line comparison, that is, a reduction of the total force by 10 percent increments across the board. Taking an equal percentage from each type of unit, the shortfall is registered here. As an example, there are 346 combat units in the force. If we delete 10 percent of them, that is, 10 percent of each type we would take 35 total units away and would reduce the total force strength by 10 percent. By deleting 10 percent of each type of unit we would in fact reduce the force strength by 10 percent. Instead of reducing the force across the board, if we minimize combat unit shortfalls, we would realize a reduction in numbers of units of only 27 as compared to 35. Using the force model, the selection is made in a much more efficient manner.

COMBAT UNIT SHORTFALLS
IN CONSTRAINED TOTAL
FORCE STRENGTH REDUCTION

Total Force Strength Reduction (Percent)	Combat Force Numbers Units	IFP	Men	Minimized Shortfalls Units	Straight Line Comparison Units
0	**346**	6708	232,803	**0**	**0**
10	**319**	6065	209,830	**27**	**35**
20	**291**	5521	183,349	**55**	**69**
30	**263**	5031	158,188	**83**	**104**
40	**234**	4419	134,091	**112**	**138**

Fig. 7—Results of Unit Shortfall Computer Run

On the second run we minimize the IFP shortfalls, that is, we remain as close to the originally stated IFP requirement as possible. The first line on the chart, Fig. 8, again shows zero percent reduction. This is the number of units in the original force, the original IFP, the original number of men. If we take a 10 percent reduction across the board in IFP, that is, 10 percent of infantry IFP, 10 percent of mechanized IFP, etc. we then realize a shortfall of 10 percent of the total number of 6708. This 671 IFP shortfall here is the straight-line calculation. However, if we minimize IFP shortfalls using the force model or the linear programming formulation, we realize only one-half the shortfalls in IFP, namely, 325. So this gives a dramatic example of the efficiency in using this optimization procedure rather than simply reducing units across the board.

The last example shown in Fig. 9 is exactly like the first two except now we minimize combat strength shortfalls. If we reduce across the board 10 percent of the strength we have a shortfall of 23,280 whereas if we minimize our combat strength shortfalls using the model we realize only 17,600 men shortfall in combat strength, still realizing the overall 10 percent force reduction.

COMBAT IFP SHORTFALLS
IN CONSTRAINED TOTAL
FORCE STRENGTH REDUCTION

Total Force Strength Reduction (Percent)	Units	Combat Force Numbers IFP	Men	Minimized Shortfalls IFP	Straight Line Comparison IFP
0	346	6708	232,803	0	0
10	317	6383	210,465	325	671
20	284	5939	187,563	769	1342
30	256	5396	162,082	1312	2012
40	227	4846	137,516	1862	2683

Fig. 8—Results of IFP Shortfall Computer Run

COMBAT STR SHORTFALLS
IN CONSTRAINED TOTAL
FORCE STRENGTH REDUCTION

Total Force Strength Reduction (Percent)	Units	Combat Force Numbers IFP	Men	Minimized Shortfalls Men	Straight Line Comparison Men
0	346	6708	232,803	0	0
10	295	6097	215,139	17,664	23,280
20	262	4951	193,467	39,335	46,560
30	225	3516	171,472	61,331	69,841
40	191	3046	147,919	84,884	93,121

Fig. 9—Results of Combat Strength Shortfall Computer Run

Figure 10 brings these results altogether. The types of combat units in the force are listed again so that one can see the individual units that have been deleted in the three different runs. If we put all three runs together, the second column represents those combat units in the force after a 10 percent reduction in strength, minimizing combat unit shortfalls. This third column indicates the results when the IFP shortfalls are minimized and the fourth column, the number of units in the force when the combat strength shortfalls are minimized. The asterisk on the right indicate units that have been deleted in the three separate runs with a 30 percent reduction in troop strength. Those with three asterisks, the airmobile infantry battalion and the 105-mm towed howitzer field artillery battalion, would be deleted in all three runs. Hence, this analysis reveals that these two units would be likely candidates for removal from the force list when a 30 percent strength reduction is desired and one would be willing to remove selected combat units.

NUMBER OF COMBAT UNITS

			SHORT FALLS MINIMIZED											
			UNIT	IFP	[illegible]	UNIT	IFP	STR	UNIT	IFP	STR	UNIT	IFP	[illegible]
INFANTRY BN	* *	18	18	12	[illegible]	18	0	[illegible]	9	0	18	0	0	[illegible]
MECHANIZED INF BN	*	53	47	53	[illegible]	19	50	[illegible]	0	22	53	0	0	[illegible]
AIRBORNE INF BN	*	12	12	0	[illegible]	12	0	12	12	0	12	0	0	[illegible]
AIRMOBILE INF BN	* *	9	0	0	[illegible]	0	0	0	0	0	[illegible]	0	0	[illegible]
TANK BN	*	55	55	55	[illegible]	55	55	31	55	55	[illegible]	55	55	[illegible]
ARMD CAV SQD, INF MECH		10	0	10	10	0	10	10	0	10	10	0	10	[illegible]
AIR CAV SQD, AIRMOBILE	* *	1	0	1	0	0	1	0	0	1	0	0	1	[illegible]
ARMD CAV SQD, AIRBORNE	*	1	1	1	1	1	0	0	1	0	0	1	0	[illegible]
ARMD CAV TRP SEP I M A	*	5	5	5	0	5	5	0	5	5	0	5	5	[illegible]
ARMD CAV TRP, SEP ABN B	*	1	1	0	0	1	0	0	1	0	0	1	0	[illegible]
ARMD CAV SQD (NON-DIV)		9	9	9	9	9	9	9	9	9	9	1	9	[illegible]
AIR CAVALRY TRP	*	3	3	3	0	3	3	0	3	3	0	3	3	[illegible]
FA BN, 105MM TOWED (INF	*	6	6	6	6	6	0	6	6	0	0	6	0	[illegible]
FA BN, 105MM TOWED (AM)	*	3	3	3	0	3	0	0	3	0	0	3	0	[illegible]
FA BN, 105MM TOWED SEP	*	1	0	0	0	0	0	0	0	0	0	0	0	[illegible]
FA BN, 105MM TOWED SEP A	*	4	4	4	0	4	0	0	4	0	0	4	0	[illegible]
155MM SP M A DIV		24	24	24	24	24	24	24	24	24	24	24	24	6
155MM SP M A BDE		4	4	4	4	4	0	4	4	0	4	4	0	0
FA BN, 155 8 IN SP DIV	*	10	10	10	0	10	10	0	10	10	0	10	4	0
FA BN, HONEST JOHN DIV	*	10	10	10	[illegible]	10	10	0	10	10	0	10	10	[illegible]
AERIAL WEAPONS CO	*	12	12	12	[illegible]	12	12	0	12	12	0	12	12	[illegible]
AD BN, CHAP VULCAN SP		8	8	8	8	8	8	8	8	8	8	8	8	[illegible]
AD BN, HAWK MOBILE		7	7	7	7	7	7	7	7	7	7	7	7	[illegible]
FA BN, 105MM TOWED (NON DIV		3	3	3	3	3	3	3	3	3	3	3	3	[illegible]
FA BN, 155MM TOWED		6	6	6	6	6	6	6	6	6	6	6	6	[illegible]
FA BN, 155MM SP		12	12	12	12	12	12	12	12	12	12	12	12	[illegible]
FA BN 8 IN SP		18	18	18	18	18	18	18	18	18	18	18	18	[illegible]
FA BN, 175MM SP		12	12	12	12	12	12	12	12	12	12	12	12	[illegible]
FA BN, HONEST JOHN NON-DIV		6	6	6	6	6	6	6	6	6	6	6	6	[illegible]
FA BN, SERGEANT		3	3	3	3	3	3	3	3	3	3	3	3	[illegible]
FA BN, PERSHING		1	1	1	1	1	1	1	1	1	1	1	1	[illegible]
AD BN, HAWK SP		9	9	9	9	9	9	9	9	9	9	9	9	[illegible]
AD BN, NIKE HERCULES		6	6	6	6	6	6	6	6	6	6	6	6	[illegible]
AD BN, CHAP VULCAN TOW		4	4	4	4	4	4	4	4	4	4	4	4	[illegible]
PERCENT TOTAL STRENGTH		100	90	90	90	80	80	80	70	70	70	60	60	[illegible]

Fig. 10—Combined Results of Computer Runs Varying Number of Combat Units

Examples With Combat Units Fixed

The next example deals with force changes in which the combat units are unchanged, while changes take place in the quantities, allocation rules, or productivities of the support units.

The tests were essentially of two kinds: first those concerned with the sensitivity of support units and their allocation rules, and second, those concerned with the design or change of a force as shown in Fig. 11. The word coefficient in this vugraph refers to a coefficient in an allocation rule.

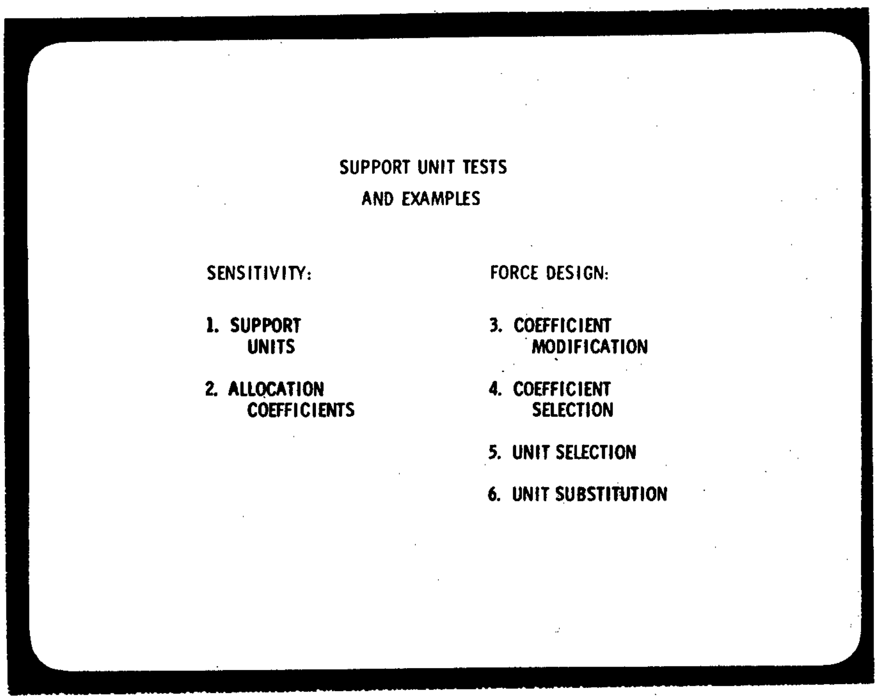

Fig. 11—Allocation Rule Sensitivity Tests

The first sensitivity test was that for particular support units in which the effect on the force of one more (or one less) of a given type of unit was measured. This is the marginal value (at the given force level) for the given type of unit.

Some numerical examples of marginal values are shown in Fig. 12. The purpose here is to show how these values depend upon the problem formulation. The first row, for example, is when the combat units are fixed at their initial force level and the total force strength is minimized. The dimensions of the PI values are therefore force strength and a change of 1 unit of type a in the force causes a change of about 19 thousand men. Similarly for units of type b, c, and d.

PI VALUES FOR VARIOUS LP FORMULATIONS

(at the initial force level for all quantities)

		PI values for four different units			
Main constraint	Objective function	a	b	c	d
Combat units	Min force strength	18.8	20.9	8.4	2.3
Force strength	Max combat strength	9.7	10.8	4.4	1.2
Force strength	Max ICE	175.0	196.0	79.0	22.0

Fig. 12—Marginal Values of Four Types of Units

The second row, however, has combat strength as the objective function, so a unit of type a has a marginal value of about 10,000 combat troops; and in the third row units of type a have a marginal value of 175 ICE units. (Units of type a, b, c, and d are headquarters units and have considerably larger marginal values than other types of support units, for the data provided for these tests.)

A second example is the sensitivity of individual allocation coefficients. Some numerical examples of these sensitivities are shown in Fig. 13 in which the objective function is total force strength and the marginal values have the same dimensions. The top row for example, shows first, that 3/100 of a divisional headquarters company is needed to support one mechanized infantry battalion, and second that a change of 10 percent in this coefficient would result in a force change of 408 men. Another feature to notice is that the marginal values of 1,050 and 1,280 are the largest of the set (for this particular set). And finally, a comparison of the marginal values of equal coefficients reveals a marginal value resulting from equal absolute coefficient changes. For example, the marginal values for the coefficients equal to .03, are 408, 297, and 150 men, reading down the list.

ALLOCATION COEFFICIENT MARGINAL VALUES, EXAMPLES

Supporting unit	Supported unit	Coefficient	Marginal value (10%), (total force change, men)
HHC Mech Div	Mech Inf Bn	.03	408
	FA Bn, HJ	.01	21
Sup & Trans Bn	Mech Inf Bn	.03	297
	FA Bn, HJ	.01	19
HHD Hosp Cen	1000 Bed Hosp	.10	1,050
	300 Bed Hosp	.03	150
Const Bn	Const Bn (EN)	.02	147
	1000 Bed Hosp	.21	1,280

Fig. 13—Marginal Values of Allocation Coefficients

The first two examples have been described, and the third one is described next (Fig. 11). In this example, all the allocation coefficients of all the support units of a given functional category are changed by the same percentage amount. This results in a force strength change and changes in the quantity of units in the given functional category and in other functional categories as well. Figure 15 shows the effect on total force strength of uniform coefficient changes in four different functional categories. The zero change (middle) row is the initial force strength level, and a 20 percent reduction of allocation coefficients for all the maintenance and supply units, for example, reduces the total strength down to 703,469 men. A possible interpretation of this table is obtained by reading it from left to right and assuming that, for example, a 20 percent reduction in support allocation has to be compensated by a 20 percent increase in the productivity (or a 20 percent "surge") of the remaining units. Then the table shows that a 20 percent reduction plus a 20 percent productivity increase results in the following force strength by the functional categories:

Maintenance and Supply	703,469
Engineer	710,187
Medical	721,530
Signal	738,364

Hence the greatest force reduction for the extra productivity effort is in this order (from left to right in the chart).

TOTAL FORCE STRENGTH

Amount of change	Categories whose coefficients are separately changed			
%	Maint & Supply	Engineer	Medical	Signal
+ 40	897,577	858,439	827,031	777,947
+ 20	812,896	799,631	785,760	764,268
0	751,085	751,085	751,085	751,085
- 20	703,469	710,187	721,530	738,364
- 40	665,203	674,984	695,910	726,074

Fig. 14—Sensitivity of Total Force Strength to Allocation Rules

The first three examples have been described, and the other three are next briefly described (Fig. 11). The coefficient selection and unit selection tests were performed so as to identify those coefficients or units to be optimally reduced or deleted under a total force reduction. In both tests, the combat units were fixed (constrained) at the initial force level and the total force strength was set at reduced levels. (Notice that this is equivalent to presetting the combat to support ratio at a lower level than in the initial force.) The objective function was a minimized sum of deviations (shortfalls) from the initial force coefficients (coefficient selection test) or quantities of support units (unit selection test). The coefficient selection test employed a 20 percent constraint level; and a 20 percent reduction of 14 coefficients accounted for a force reduction of about 16,000 men. The unit selection test was performed at both 100 percent and 20 percent constraint levels. At the 100 percent level, 15 different unit types were completely deleted from the force to accommodate a 150,000 man force reduction. At the 20 percent level 110 different unit types were reduced in quantity by 20 percent to accommodate the same force reduction.

The last example, the unit substitution test assumed as input to the model, that a 1000 bed hospital could perform the same services as three and one-third 300 bed hospitals. The total force strength was then minimized in effect, and the resulting troop list included no 300 bed hospitals and an increased number of 1000 bed hospitals.

A UNIFIED SET OF ALGORITHMS FOR CONDUCTING COMMAND/CONTROL SYSTEM ENGINEERING STUDIES

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INTRODUCTION

The type of operation research/system analysis problems addressed by this paper pertain to the assessment of the functional performance capability of a system. The status of the development of the system may be anywhere along the growth cycle; from conceptual evolution to fielded hardware. The utilization of the techniques discussed in this paper will vary according to the status of the system being studied, but valuable system performance information will be obtained from their use in a form that can be directly compared to laboratory and field test data. By application of these techniques it will be possible for the weapon system analyst to maintain an orderly and comprehensive evaluation of weapon system functional performance capability before, during and after procurement.

Specifically, the approach to obtain such a capability has to utilize the basic techniques employed by weapon system designers. The reasoning behind such an approach follows from the argument that in order to understand the operation of a specific weapon system, it is necessary to be able to understand the underlying design philosophy. Once this capability has been attained, the relationship between customer and contractor can be exploited to insure the development of a weapon system capable of meeting the desired performance specifications.

SCOPE OF ACTIVITY

A definition of functional performance capability is required before the scope of the system analysis effort discussed in this paper can be understood. A weapon system is developed to accomplish a purpose. Quantitative measurements of its ability to meet the design specifications is defined as a measurement of its functional performance capability. From this definition it is obvious that the scope of this paper is being limited to a restricted portion of the operations research/systems analysis disclipine. But within this relatively restricted definition of operations research/system analysis are to be found complicated and far reaching questions that must be satisfactorily answered by the weapon system analyst before the total system analysis procedure can be credited with having maximum influence on design specifications of a prospective weapon systems or assessments of battle effectiveness of fielded systems.

During the development of a weapon system it is necessary that the customer be aware of the status of the contractor design effort. In general subsystems such as stabilization systems, electro-mechanical control systems, aeronautical systems, electronic systems and/or mechanical systems will be included in the overall configurations of the weapon system.

The major phases of any system development program can be identified as follows:

1. Definition of functional performance specifications.

2. Development of mathematical models.

3. Initial analysis and simulation studies.

4. Prototype hardware implementation and model validations.

5. Final analysis and simulation studies.

6. Hardware implementation.

7. Hardware acceptance tests.

During each of these major phases system functional performance studies need to be conducted. The extent and depth of the studies will vary depending upon the specific situations. It is therefore helpful that a set of tools or algorithms be available to the customer in order that system analysis studies can be initiated and conducted by the customer that will maintain maximum coordination between the contractor who is charged with the responsibility of producing a weapon system and the government organization responsible for insuring the successful attainment of performance specifications. It is the intent of this paper to suggest several algorithms that when used in a unified manner can provide this type of capability.

APPROACH

The system analyst has as one of his responsibilities the assessment of contractor proposals made in response to requests generated within his or other organizations within the government. Typically, weapon systems such as tactical missiles, antiaircraft guns, and stabilization systems are extremely complicated devices and require vast amounts of analysis and design expertise on the part of both contractor and customer to develop. The better equipped the analyst is in being able to monitor and suggest specific system functional design changes, the more effective his contributions will be to the development of a weapon system that possesses the functional performance capability necessary to accomplish the intended mission.

The utilization of computer aided design techniques employing a unified set of algorithms will greatly enhance the analyst's ability to both monitor and conduct functional performance studies in a fast and efficient manner permitting him to assess and direct the development process.

A key step in the formulation of a method to assess the functional performance of a weapon system, short of testing, is the generation and use of a valid mathematical representation of the system. This validation process, mentioned as a major phase of the system development program has not been addressed in this paper, but the computational techniques to be discussed are based on the assumption that such a procedure has been successfully employed.

PROCEDURES

Since most modern complex weapon systems are feedback in nature, the quantitative assessment of system stability and secondarily system performance is required. An understanding of a system's cause and effect or input and output relationships in terms of its internal parameters or design characteristics is necessary to permit configurations to be responsive to the required performance specifications. Criteria and figures of merit need to be quantitatively determined in order to define a system.

All systems exhibit nonlinear behavior. A methodology has yet to be developed that permits broad generalized predictive conclusions to be reached for nonlinear systems. Another way to express this restriction would be to say that such studies are usually constrained by specific qualifying assumptions. It is this type of study that is required after trade-off studies and initial design studies have been completed. Linearization of inherently nonlinear systems permits a less restricted methodology to be employed but introduces the necessity for introducing qualifying assumptions relating to the conclusions derived from such a methodology.

The unified set of algorithms proposed in this paper contain both nonlinear and linear techniques. The utilization of the various algorithms discussed in this paper is proposed as a methodology to obtain a check and balance procedure relative to the assessment of stability and performance characteristics of weapon systems. Simulation studies utilizing combinations of hardware and software models and eventually full scale hardware tests should be conducted to determine the validity of this approach. If such procedures are practiced, the efficiency of the working relationship between contractor and analyst will be maximized.

STABILITY ALGORITHMS

A powerful method of systems analysis for time invariant systems is to generate linearized equations for each physical phenomenon occurring in the system and combine these individual processes into input-output relationships through the application of Laplace transformations. Studying the resulting characteristic equation of the system will provide insight into the stability of the system. Steady state frequency response of the system will provide another useful characterization of system stability. Qualitative appreciation of a large classification of non-linear systems can be obtained from a modified steady state frequency response. Time variant system stability may be obtained from a tabulation of eigenvalues obtained from the solution of a time varying matrix representation of the system.

The interrelation of information provided by each of these techniques to an understanding of the quantitative stability of a system and the sensitivity of parameters that define the system to that stability is detailed in this discussion.

Regardless of the complexity of a linear closed-loop system, its transfer function can be reduced to the equivalent form shown in Figure 1. For multiple loop systems, the G's and H's are readily expressed as sums of products of polynomials which are identified with individual elements making up the complete system.

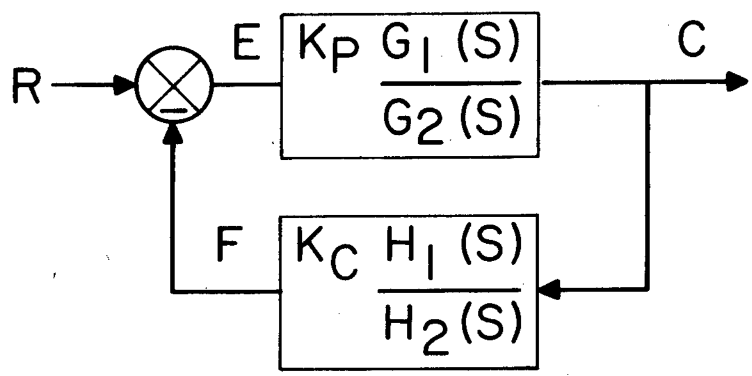

Figure 1. Linear Closed Loop System

The polynomial ratios $K_P G_1(s)/G_2(s)$ and $K_C H_1(s)/H_2(s)$ are equivalent transfer functions of the system and are represented by ratios of polynomials which upon expansion can be put into the form

$$\frac{F}{E} = \frac{s^k \prod_{\mu=1}^{v} (s+z_\mu) \prod_{q=v+1}^{y} \left[s+(\sigma_q+j\omega_q)\right]\left[s+(\sigma_q-j\omega_q)\right]}{s^\ell \prod_{i=1}^{g} (s+p_i) \prod_{t=g+1}^{r} \left[s+(\sigma_t+j\omega_t)\right]\left[s+(\sigma_t-j\omega_t)\right]}, \tag{1}$$

where $y = \frac{n-k-v}{2}$, $r = \frac{m+n-\ell-g}{2}$ and the poles and zeros can be either real or complex in conjugate pairs, $m \geq 1$.

There are several methods of quantitatively obtaining insight relative to the stability of the system described by Equation (1):

1. Closed Loop Characteristic Equation Roots (For Linear Time Invariant Studies)

   The closed loop characteristic equation of Figure 1 is

$$K_c K_p G_1(s)H_1(s) + G_2(s)H_2(s) = 0. \tag{2}$$

   The linear system's closed-loop denominator or characteristic equation, which determines stability, is the denominator of the closed-loop transfer function

$$\frac{C}{R} = \frac{K_p G_1(s)H_2(s)}{K_c K_p G_1(s)H_1(s) + G_2(s)H_2(s)} \tag{3}$$

   A Fortran IV program to evaluate Equation (2) is contained in Reference 1.

2. Open Loop Frequency Response (For Linear Time Invariant Studies)

   The open loop transfer function of Figure 1 is

$$\frac{F}{E} = K_p K_c \frac{G_1(s)H_1(s)}{G_2(s)H_2(s)} . \tag{4}$$

   The steady state frequency response of the open-loop transfer function is obtained by evaluating Equation (4) along the imaginary axis for values of ω between zero and infinity rad/s. The result is a vector quantity,

$$\left.\frac{F}{E}\right|_{o \leq \omega \leq \infty} = K^* \left.\frac{A(s)}{B(s)}\right|_{o \leq s \leq \infty} = M_{oL} \angle \phi_{oL}, \tag{5}$$

   where M_{oL} = scalar magnitude of open-loop transfer function between $0 \leq \omega \leq \infty$, and

   $K^* = K_c K_p$

   There are two figures of merit which provide a measure of system stability. The only restriction is that all roots of the system's open-loop transfer function denominator, B(s) be ≤ 0.

Gain margin is the amount that M_{oL} must be increased or decreased to make it equal to 1, only when the orientation of magnitude of the open-loop transfer function, $\angle \frac{A(s)}{B(s)}$, is 180°

Phase margin is the amount that ϕ_{oL} must be increased or decreased to make it equal to 180°, only when magnitude of the open-loop transfer function, $\left|\frac{A(s)}{B(s)}\right|$, is 1.

A Fortran IV computer program to evaluate Equation (4) is given in Reference 2.

3. Open Loop Modified Frequency Response (For Nonlinear Time Invariant Studies)

V.M. Popov's modified frequency response plots of system transfer functions give some insight into stability of nonlinear systems. Figure 2 shows the system configurations considered in this analysis.

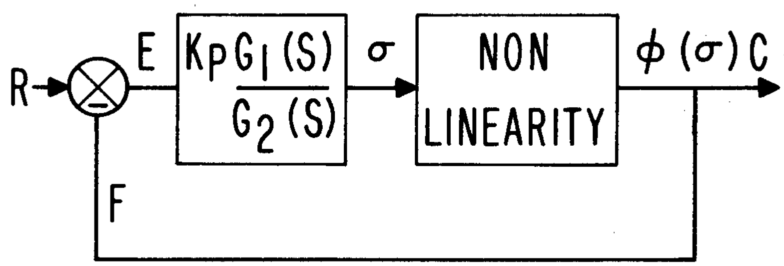

Figure 2. Nonlinear Closed Loop System

Figure 2 contains a linear part similar to Figure 1 and one nonlinear element and is subject to the following restrictions:

a. The roots of $G_2(s)$ have negative real parts and simple or multiple roots on the imaginary axis (one root permitted at origin).

b. $\varepsilon \leq \frac{\phi(\sigma)}{\sigma} \leq K.$

c. The linear system of Figure 2, obtained by substituting $\phi = \varepsilon\sigma$, is stable.

If there exists a non-negative real number q such that

$$R_e\ (1+jq\omega) + \frac{1}{K} > 0 \tag{6}$$

for all $\omega>0$, where G is defined by $K_P \frac{G_1(s)}{G_2(s)}$, the nonlinear system is asympotically stable in the large.

The nonlinear system synthesis problem will be concerned with determining the variation of K for a given linear G(s). Figure 3 shows the boundary constraints of the nonlinearity $\phi(\sigma)/\sigma$ of the system shown in Figure 2.

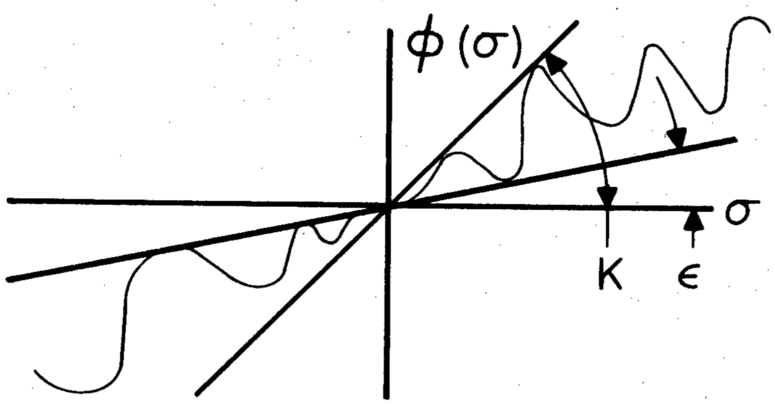

Figure 3. System Nonlinearity

A Fortran IV program to evaluate inequality (6) is given in Reference 2.

4. Closed Loop Eigenvalues (For Linear Time Variant Studies)

The stability of the linear closed loop system shown in Figure 1 can also be evaluated by obtaining its eigenvalues. For the system to be stable, the real part of each eigenvalue must be negative. The eigenvalue algorithm is more amenable for evaluating the stability of a time variant system which is described by state variable equation

$$\dot{\underline{X}}(t) = \underline{A}(t)\ \underline{X}(t) + \underline{B}(t)\ \underline{U}(t). \tag{7}$$

The A matrix completely describes the closed loop system being evaluated. The eigenvalues, λ's, are obtained directly from the A matrix by determining the singularities of the determinant $[\underline{A}-\lambda\underline{I}]$. At time, t, stability can be determined from the eigenvalues or from the roots of Equation (1). The eigenvalue algorithm can be included in a computer program that solves Equation 7 and simultaneously determines the eigenvalue of the A matrix, hence system stability information is provided as a function of time.

PERFORMANCE ALGORITHMS

Once the stability characteristics of the system have been determined it is necessary to evaluate the performance characteristics in relation to a set of specifications or similar constraints prepared to guarantee the capability of the system to meet the operational requirements. In contrast to the stability algorithms which utilize frequency domain techniques, the performance algorithms for the most part use time domain techniques.

Transient (time)responses of closed loop systems characterized by Figure 1 may be determined by using inverse Laplace transforms. State variable representation of a system, coupled with an integration routine permits the determination of the time response of multiple input-multiple output nonlinear time variant systems. Supplementing these deterministic techniques, an assessment of the statistical performance of a system may be obtained by determining the time history of the covariance matrix of the state of the system.

The specific methods utilized to conduct system performance studies are:

1. Transient Response (For Linear Time Invariant Studies)

One method of analyzing physical systems requires the use of Laplace transforms. The inverse Laplace transformation is necessary to analyze a system's time response to a forcing function.

Time constants, overshoots, resonant frequencies and steady state errors are obtained by observing the time response of the system. By analyzing these characteristics, the designer is able to optimize the system response to a particular performance criteria or specification.

Inverse Laplace transforms can be found in a handbook of Laplace transform pairs for the simpler control system equations. For more complex systems it is a tedious task to take the partial fractions representing the quotient, find the corresponding inverse Laplace transform of each individual term and sum them.

The inverse Laplace transform, c(t) for an input forcing function r(t) of Equation (1) is

$$c(t) = \mathcal{L}^{-1}\left[\sum_{j=\ell-k}^{1} \frac{K_j}{s^j} + \sum_{i=1}^{g} \frac{K_{ih}}{(s+p_i)^h} + \sum_{t=g+1}^{r} \frac{\vec{K}_t}{s^2 + 2\sigma_t\omega_t s + \omega_t^2}\right], \quad (8)$$

where K_j, K_h and K_t are the residues at each denominator (pole) singularity of the right-hand side of Equation (1).

A Fortran IV program to evaluate Equation (1) is contained in Reference 3.

2. Transient Response (For Linear Time Variant Studies)

An extension of the linear time invariant transient response program permits the parameters of a system to be changed at arbitrary discrete times and makes use of the linear superposition principle to handle complex forcing functions.

Superposition of simple forcing functions permits the response of a system to complex forcing function to be found. The complex forcing function may be broken down into simple functions, e.g., impulses, steps, or ramps. This program allows the analyst to choose a simple function which most closely resembles the shape of the complex forcing function. The parameters of a system change as a function of time following the initiation of the complex forcing function. For example, a missile's aerodynamic coefficients change with time during the trajectory, thus altering the basic system equation. This program enables the parameters of the system to be changed at discrete points in time.

A Fortran IV program designed to determine the transient response for this type of study is contained in Reference 4.

3. State Variable Technique (For Nonlinear Time Variant Studies)

The classical approach to system analysis represents the dynamical system in the frequency domain and then obtains the solution in the time domain by using the inverse Laplace transformation. This approach is restricted in general to linear, time invariant, single input, single output systems. In addition, the Laplace transform must exist for both the system and the forcing function.

The state variable representation is basically a description of the system in terms of its differential equations. The state variable method is analogous to patching an analog computer to determine system response to specific forcing functions. It has certain advantages compared to the frequency domain approach:

a. The system may be linear time invariant, linear time variant, nonlinear time invariant, or nonlinear time variant.

b. The differential equations describing the system are amenable to direct matrix manipulation.

c. The system equations are immediately suitable for digital computer computations and numerical integration.

d. The technique permits analysis of systems with multi-inputs and multi-outputs.

The form of the state variable equations depend on the type of mathematical relations required to accurately model the system. This discussion is limited to time variant systems which may have a limited class of nonlinearity. The form of the equation describing the system is

$$\underline{\dot{X}}(t) = \underline{A}(t)\ \underline{X}(t) + \underline{B}(t)\ \underline{U}(t). \tag{9}$$

A Fortran IV program has been developed to solve this equation by numerical integration when the A and B matrices are functions of time and nonlinear functions of specific state variables, X_i. The method is discussed in Reference 5.

4. Statistical Covariance (For Linear Time Variant Studies)

An investigation of the performance of a complex system generally involves the solution of a set of differential equations that describe the system. With classical techniques the values of system parameters and inputs to the system are assumed to be known. This analysis provides a deterministic solution. In reality the problem is a statistical one since there exist uncertainties in measurements of the parameters, random noises and random forces acting on the system. An analysis technique to estimate system performance is necessary in order to take into account this randomness.

One method to determine the influence of random noise acting on a system is to solve the statistical variance equation. The technique to estimate the statistics of the dependent variables (system state) by a deterministic computation was developed by R.E. Kalman and R.S. Bucy.

An algorithm has been developed for propogating the covariance matrix when a weapon system model is subjected to random unbiased nosise. The covariance matrix is the solution of the variance equation and is the "best" estimate of the system's state. The statistical characteristics of the random noise are modeled as a Markov process of known but time varying covariance and time correlation. The algorithm, which is general in form, provides an important supplement to standard system design tools. Confidence limits are placed on system designs at a computational cost which is less than either experimental or Monte Carlo techniques would permit. In computational time, the statistical covariance algorithm provides the estimate with one computer run where it would require at least 100 Monte Carlo runs to achieve the same degree of confidence in the results. While the techniques discussed here do not obviate Monte Carlo techniques and experimentation, they do help in identification of critical areas of uncertainty thus leading to better designs for experiments.

The variance equation whose solution provides the covariance matrix is:

$$\dot{\underline{P}}(t) = \underline{A}(t)\, \underline{P}(t) + \underline{P}(t)\, \underline{A}(t)^T + \underline{B}(t)\, \underline{Q}(t)\, \underline{B}(t)^T, \qquad (10)$$

where $P(t)$ is the covariance matrix

$A(t)$ is the matrix describing the system

$B(t)$ is the matrix operating on the noise

$Q(t)$ is the noise covariance matrix $[\underline{Q} = E(\underline{U} \cdot \underline{U}^T)]$

$U(t)$ is the vector rms value of the random noise

The elements of the covariance matrix P_{ij} are the variances of the state when $i = j$ and the covariances of the state when $i = j$. The products of the square roots of P_{ij} and the confidence factor are the system rms errors within a rigorously specified confidence limit.

A Fortran IV program written to evaluate Equation (10) is given in Reference 5, Volume I. Volume II is an application of the techniques.

APPLICATIONS

The AMSAA has utilized the techniques discussed in this paper to conduct stability and performance studies for several weapon systems.[5-9] The utilization of the methods continues to be an evolutionary process. Table 1 identifies the applications of each of the algorithms with several system studies that have been conducted at the AMSAA. It is planned to extend the capability of the statistical covariance matrix algorithm to the general estimation of filtering process. This requires adding an additional term, $-\underline{P}\, \underline{H}^T \underline{R}^{-1} \underline{H}\, \underline{P}$, to Equation (10) which takes into account observations and measurement noise (H is the observation matrix and R is the covariance of the measurement noise.) The variance equation then becomes the well known Matrix Riccati equation whose solution is the essence of Kalman filtering. Once this has been accomplished, techniques will be developed to handle biased noise effects and solve parameter identification problems.

SUMMARY

Four algorithms for evaluating system stability and four algorithms for evaluating system performance have been discussed for application to a classification of models ranging from linear time invariant to non linear time variant. Application of one or more of these methods will

TABLE 1. APPLICATIONS OF SYSTEM ENGINEERING ALGORITHMS

STABILITY ALGORITHMS	AMSAA SYSTEM ENGINEERING STUDIES
Characteristic Equation Roots AMSAA TM No. 21 (LTI)*	Pneumatic Actuation System AMSAA TR No. 25 (Ref. 6)
Frequency Response AMSAA TM No. 69 (LTI)	LOSMAD Guidance and Control Concept, AFAADS AMSAA TM No. 31 (Ref. 7)
Modified Frequency Response AMSAA TM No. 69 (NLTI)	SHILLELAGH Missile Stability and Performance in a CM Environment AMSAA TR No. 38 (Ref. 8)
Eigenvalues (LTV)	
PERFORMANCE ALGORITHMS	
Transient Response AMSAA TM No. 60 (LTI)	System Engineering Study of Vulcan Air Defense System Fire Control System ARDC TM No. 17 (Ref. 9)
Transient Response AMSAA TM No. 95 (LTV)	
State Variable Techniques (NLTV)	Statistical Covariance Matrix Application to Shillelagh AMSAA TR No. 48 Vol II (Ref. 5)
Statistical Covariance AMSAA TR No. 48 Vol I	

*LTI - Linear Time Invariant

NLTI - Nonlinear Time Invariant

LTV - Linear Time Variant

NLTV - Nonlinear Time Variant

permit the system analyst to effectively assess the functional/performance characteristics of systems.

A tabulation of the methods along with the type of information obtained from each program is shown in Table 2.

TABLE 2. COMMAND/CONTROL SYSTEM ENGINEERING ALGORITHMS

STABILITY ALGORITHMS	TYPE OF STUDY	INFORMATION OBTAINED
1. Characteristic Equation Roots	LTI*	System modes, damping ratio
2. Frequency Response	LTI	Steady state gain and phase
3. Modified Frequency Response	NLTI	Qualitative stability
4. Eigenvalues	LTV	System modes, damping ratio
PERFORMANCE ALGORITHMS		
1. Transient Response	LTI	deterministic: time constants, overshoots, errors
2. Transient Response	LTV	deterministic: time constants, overshoots, errors
3. State Variable	NLTV	deterministic: time constants, overshoots, errors
4. Statistical Covariance Matrix	LTV	statistical: rms errors, variance or covariance

*LTI - Linear Time Invariant

LTV - Linear Time Variant

NLTI - Nonlinear Time Invariant

NLTV - Nonlinear Time Variant

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EXECUTIVE SUMMARY

Results of Model Review Committee

Dr. John Honig
LTC Robert W. Blum

A steering committee, composed of LTG DePuy, Dr. Payne, Mr. Golub, and MG Roberts, appointed an ad hoc committee for the purpose of conducting a technical review of selected Army models which are designed to assist in analyzing force level, force structure, force mix and related problems.

This review had the immediate purpose of determining the weaknesses and strengths of several particular war games and simulations and making recommendations about improving them. However, the review was also concerned with the general question of the utility of gaming and simulation as an aid to decision-making, and therefore also considered the broader questions of how various games and simulations might be used in a mutually supporting system, what should be done about providing adequate data, and what further research would advance the state of the modeling art. In attempting to evaluate these models, it was found that no generally accepted methodology existed for doing this, and therefore the review tried to define some steps toward such a goal.

The results of this study can be considered to be fourfold:

1. An analysis of the strength and weaknesses of the models reviewed, identification of deficiencies and detailed comparative analysis of comparable models. A hierarchy of a family of models is proposed. (Theater level models in Chapter II, Division level models in Chapter III and High resolution models in Chapter IV.)

2. Proposed research areas, including an indication of priorities, to improve the Army's modeling and model application capability (Chapter V).

3. Proposed field experimentation and data acquisition program to improve the inputs required for Army studies (Chapter VI).

4. A discussion of the use of models in the Army including identification of certain deficiencies. Approaches to solution of some of these problems are proposed in Chapter VII.

A glossary defining some of the terms used in this study is found as Appendix B to Chapter I. The conclusions from each of the Chapters are brought together in Chapter VIII and the recommendations are found there, too.

The models were classified by type and by command echelon. The types of models ranged from war games, in which human players perform all the decision functions and in which human controllers determine engagements and pace of battle to computer simulation in which all decisions are reduced to computer routines and the analysis proceeds without human intervention. Even further in the level of abstractions are analytical models in which sets of mathematical equations are used to describe all the combat activities and processes.

Models were also classified into three levels; theater level models with resolution to division or brigade size units, division level models with resolution to battalion size units and high resolution models with resolution to individual weapons or weapon teams. The models that were analyzed and their classification are shown below.

WAR GAME	COMPUTER ASSISTED WAR GAME	PLAYER ASSISTED SIMULATION	SIMULATION AND MATHEMATICAL ABSTRACTIONS
THEATER LEVEL			
JIFFY GAME TBM/TWGM QUICK GAME (Manual)	THEATERSPIEL	TARTARUS	ATLAS TCM
CORPS/DIVISION LEVEL			
TBM-DOM	CORPS BM (DIV BM)1/ ADVICE TACSPIEL2/	LEGION DIVTAG EINFALL	
BATTALION LEVEL			
			DYNTACS IUA CARMONETTE BONDER

1/ Under development

2/ Obsolete

Criteria for reviewing the models were derived. One set dealt with the validity of the model, including its logical consistency and mathematical correctness, the degree to which the model appears to represent real life processes, and the visibility of the model to the analyst. Another set of criteria dealt with the ability of the models to answer sets of questions appropriate to the decision level being modeled. Furthermore, utility included sensitivity of the outputs to important parameters, responsiveness and the efficient use of resources.

Each level was analyzed separately: theater level models (Chapter II), division level models (Chapter III) and high resolution models (Chapter IV). Models were analyzed to determine their validity as well as their applicability to the appropriate set of problems. Model limitations are stated and possible improvements were listed. Where possible a preferred model was selected where a number of models appear to perform essentially the same job.

Theater Level Models

At the theater level it was concluded that a war gaming capability is required to be used, in conjunction with historical analyses and test data to analyze poorly understood processes, to serve as a research tool to advance the state-of-the-art in modeling and to develop information necessary to "validate" simulations.

All of the models can address force level problems; however, TCM appears to be the best model for this purpose because of its representation of the multi-echelon command structure and allocation decisions. Its ability to generate engagement type distribution should still be checked against a war game. In addition it should be noted that all the theater level simulations reviewed are probably valid only for periods lasting no more than about a week, without human evaluation. It is felt that cumulative errors resulting from poor casualty and FEBA movement data would most likely make the results very unreliable. In addition, relatively crude modeling of allocation and commitment decisions and the lack of consideration of large scale maneuver contribute to the problem.

In view of the current lack of data reflecting capability of units as a function of mix of subunits, none of the theater level models reviewed are able to address force mix or force employment problems. However, both TCM and TARTARUS are structured to be able to handle such problems, if unit capabilities which reflect organization, tactics and weapon systems can be developed.

In spite of its appealing simplicity continued use of ATLAS is questionable since the various combat processes are not considered explicitly in ATLAS but must be reflected in the aggregated measures employed. It is difficult, if not impossible, to make adjustments to compensate for the obsolescence of the data used.

Because of lack of adequate information, it was not possible within the time constraints of the study to complete the evaluation of TARTARUS. Although the model includes many combat processes not explicitly considered in ATLAS and TCM it is our impression that many of these nominal capabilities lack physical or empirical basis and that data for their use are not available. In order to provide meaningful results, TARTARUS would require a major effort to validate the factors and functions employed, even if feasible, as well as continuous support to develop better input data and conduct sensitivity analyses.

Division Level Models

At the division level all current models are either war games or player assisted simulations. At this level intelligence information from different sources must be used by a commander who has many options open on how to employ his resources. Consequently, algorithms do not yet exist to simulate the division process of the division commander. War games tend to be slow and costly in resources, but until the decision process is better understood it would not be useful to develop a division level simulation as a production model to analyze many alternatives quickly.

With regard to specific models, the most promising area of current development is in the joint use of CARMONETTE and DBM for the Equal Cost Firepower Study, particularly since DBM appears able to adapt some of the capabilities of ADVICE. Considerations should be given to how the outputs from DBM might be used to provide inputs to theater level models. Although DBM is in development it is a modification of an operational model, CBM, and the development of DBM is sufficiently advanced to be considered a preferred model.

The Committee's review of DIVTAG indicates that it has logical errors, numerous areas of inadequate modeling (acquisition, close combat and others), is not responsive and is costly to maintain. These deficiencies strongly suggest that the use of DIVTAG be discontinued. An improved version, DIVWAG, is currently under development and could not be reviewed by the Committee.

It appears that LEGION contains excessive complexity, lacks the necessary input data, a number of its submodels have uncertain validity, it is expensive to run in manpower and running time. The availability of DBM as a competition research tool and LEGION inability to be used as a production model do not, in the opinion of the Committee, justify its continued support.

High Resolution Models

High resolution games are designed to reflect principal weapon systems and small unit characteristics. It was concluded that DYNTACS is the most realistic and complex model considered. It requires at least three to five times as much computer time per replication to execute as the other two models. Consequently, the current model is most useful as a research tool which can provide insight on the interactions involved in small unit combat.

It was further concluded that CARMONETTE be the preferred current production model and that IUA not be maintained as a preferred model.

Complementary to the above simulation models, a capability to use analytical models for sensitivity analyses and to check simulation assumptions and routines must continue to be developed.

It is further concluded that at each level a research model is required to perform detailed analysis of processes that are not well understood, e.g., the decision process at the theater and division level. An improved understanding should lead to an improved capability to simulate the process automatically and to produce "production models" that can analyze many force mixes or situations in a short time and with limited resources.

The need for a hierarchy of models was discussed, in which the outcomes of lower level models are used as inputs to higher level models and the higher level models determine the situations and conditions to be examined with higher resolution models. These links do not currently exist although some developments are under way. It was concluded that research is urgently needed to develop these links based on a better understanding of how operational capabilities of units can be aggregated synergistically.

Data Problems

A careful analysis indicated a serious problem with input data. This analysis was less concerned with the common, measurable inputs, such as TOE, weapon characteristics, etc as it was with modifiers, such as suppression and neutralization factors, effect of countermeasures, etc which are "nominally" treated in the various models but without much experimental or phenomenological basis. Much of the discussion deals with input data that are built into models and though the player cannot influence them they are no less important. There are many "virtually" structural inputs which could be changed, but in general are considered to be part of the model and are usually not changed or even validated. In many cases model builders, particularly of older models, do not know the models well enough to be aware of many of these inputs selected "long ago" and never validated.

The data voids which appear to affect the Army's models most severely are discussed in Chapter V.

It is concluded that the two areas of experimental data acquisition requiring the most urgent attention are target acquisition and suppression/neutralization.

Research Required

In a number of cases the processes involved are not sufficiently understood. This is the case, for example, with night operations, the effect of suppression and neutralization, and others. It is concluded that research needs to be conducted on understanding the process using some simple conceptual models of the particular process with field testing to test the hypotheses being modeled. In other areas models include conversions and functional relationships which require more research for validation. These include such factors as converting personnel losses to materiel losses and vice versa, and the expected rate at which the FEBA moves as a function of engagement type and outcome. A number of crucial areas requiring research are discussed in Chapter VI.

The following six research areas are considered the most important to be pursued to improve the Army's modeling effort.

1. Problems of Aggregation. That is, the determination of measures of effectiveness and other performance characteristics of aggregated units. The mid and high level games of necessity need aggregated operational performance characteristics to a very large extent. Most of our good experimental data is related to the performance of individual weapons and other hardware, but the most pervasive measure of effectiveness for aggregated models, the firepower scores, depend for their validity on gross aggregations of weapons effects. The process of aggregation must be better understood before it can be effectively modeled.

2. Target Acquisition. That is, the detection of units by units. This is in addition to the data collection effort which involves distinct sensors. Surveillance and target acquisition present serious problems for all models - high resolution through theater level - because the representation of target acquisition has a pervasive influence on other aspects of combat models; from allocation decisions to intensity of combat and casualty rates. For example, particularly with reference to aggregate models, we have virtually no knowledge about unit versus unit detection.

3. Night Operations. Here we conclude that there is a need to conduct research into the modeling of Night Operations. It is believed that this work should start with careful conceptual studies since these operations may be qualitatively different from operations during the day. The Army is spending considerable resources on developing a much improved capability of fighting at night. Evaluation of the various materiel proposals and innovations as well as operational concepts requires realistically modeled games and simulations that consider all the pertinent parameters affecting night operation.

4. Information Processes. Research is needed concerning the process of information collection, integration, interpretation and dissemination. Army developmental efforts emphasized the opportunities to increase the effectiveness of tactical units through automated information processing. And yet our current knowledge about this important area is so meager as to preclude any reasonable evaluation of these opportunities.

5. Suppression and Neutralization. Research is needed which can lead to the quantitative understanding and successful modeling of this important feature of combat. It has long been recognized by students of combat that suppression and neutralization is a primary weapons effect. This fact has been recognized in models since they all attempt to model suppressive effects. However, these effects are not sufficiently understood and therefore the validity of current efforts cannot be determined.

6. Decision Process. Research is needed to model this process so that the realism of simulations can be improved. It is especially needed to permit development of division level simulations.

Use and Management of Models

Chapter VII is divided into two parts. The first section deals with models, modeling groups and the users of the results which generally are the study sponsors. The second part deals with a proposed organizational adjustment in the DA Staff to fix more firmly the responsibility for coordination of model review, improvement, and research.

It became quite evident to the Committee members that in many cases the available documentation, together with discussions with the model groups were inadequate to thoroughly evaluate the models. This was particularly true with regard to models that were developed some time ago and where the original development team could no longer be identified. In some cases, models have been used occasionally, then retired and then are used again by different individuals. More continuity of personnel associated with a useful model is required.

In many cases models are not subjected to detailed technical review and are not validated in any other way. Some of the complex simulations contain many implicit inputs such as detection factors, decision factors, transition probabilities. The rationale for such inputs in most cases is not documented and they have never been reviewed, improved or updated. There is rarely enough funding for sensitivity analyses and, if performed, they are not documented.

The lack of continuity of personnel and the great complexity of the models often have resulted in models being used like "black boxes" with neither the modeling group nor the sponsor subjecting the model to careful review to make sure that the model is really valid for the purpose employed.

Documentation rarely points out the weaknesses in the model or suggests necessary research or critical data requirements.

The following recommendations are proposed to improve the above weaknesses:

1. Reduce the number of models retained and employ the scarce professional talent more effectively.

2. Require detailed, independent review of models to be retained and perform sensitivity analysis where possible.

3. Models should be validated against other models, war games or historical experience where possible.

4. Documentation should be much more complete, include implicit assumptions, the rationale for "hidden" inputs and be subject of independent, technical review, just as models themselves.

5. Detailed reviews should be performed to determine whether the model to be selected is valid for performing the required analysis.

6. Acceptable models should be maintained on a continuous basis throughout their useful life, at a level of about two TMY for each model, in order to maintain the expert knowledge, perform sensitivity analysis, and improve the data base.

7. Before requesting development of a new model, the requesting agency should be required to do the following:

a. A careful definition of the specific objectives which the new model is suppose to analyze.

b. A detailed examination of all existing and recent models that are related to the objective analysis.

c. A detailed examination of all problems encountered either with the structure or with the input data of existing models.

d. Proposals of specific approaches for overcoming previous model limitations or difficulties.

In the second part of the Chapter, it is recommended that a Scientific Advisor for Studies and Models with a small organization (4-5 professionals) be formed, reporting directly to the AVCSA and working in close coordination with the Coordinator of Army Studies. The principal responsibilities of this group should include:

1. To coordinate and integrate model development plans, submitted by the major commands, into an Army Model Development Program.

2. To identify major data requirements for current and future studies and model development efforts; to assist in making data collection efforts more responsive to study needs.

3. To identify urgent model research requirements and to assist in assuring that the required model research is carried out.

FEDERAL AIR POLLUTION CONTROL PROGRAM: AN EVOLVING BLUEPRINT

by

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When I received General Gribble's invitation to address this research symposium, I was at first surprised--pleasantly, I must confess--to learn that the U.S. Army is interested and concerned enough about the environment to allot time on your busy agenda for consideration of the problem of air pollution and what is being done about it. I should have known better than to have been surprised, for I have dealt with Department of Defense personnel on many occasions and always found them sympathetic with our objectives and anxious to improve environmental quality by controlling pollution from their installations. Each of you, I have found, regardless of your primary duty, is first and foremost a breather.

I need not remind you that the disquieting air pollution problem has many equally serious parallels in other areas. You know perhaps better than I that there are no easy answers, that there is no unilateral attack that will meet all our needs. And our needs are many.

Burgeoning cities with seemingly unmanageable problems, campus disorders, dying lakes and unbreathable air--President Nixon summed it up in his 1970 State of the Union Message when he said: "Never has a Nation seemed to have had more and enjoyed it less."

But until recently, the science and technology that produced the Industrial Revolution and the most comfortable and affluent societies that the world has ever known were unquestioned in their devotion to production. We all wanted the good life, we all wanted the same things--we wanted more of them, and we wanted them without delay.

We have known for centuries that air pollution can damage or destroy vegetation, corrode and soil property, create transportation hazards, make us and our animals uncomfortable and sick--that it even can kill us. That was brought home dramatically in 1948 when some 20 people died and thousands were made ill in Donora, Pennsylvania, during an air pollution episode lasting several days.

Still, it was not until 1955 that a Federal air pollution law was passed, and that original authority was limited to research and technical assistance. As knowledge was acquired under that Act, concern intensified. It was obvious, although there remained--and still do remain--many gaps in knowledge, that we were not even applying the knowledge we had. For years, we have had the technology to prevent or control many types of air pollution; application of that technology was needed, concurrent with research and development of new technology.

Congress and the Executive Branch sought ways to stimulate both the development and application of control technology, and the Federal law was amended in many important ways in the 1960's. In 1963, program grants were authorized to promote the initiation, establishment and improvement of State and local air pollution control agencies, and provisions were added for Federal intervention to abate air pollution in certain cases; also, the Federal government was called upon to begin getting its own house in order by controlling emissions from Federal facilities.

In 1965, Federal pre-emption of motor vehicle pollution control was added, and program grant authority was expanded in 1966.

While each of these amendments advanced control efforts to a degree, corrective action was spotty and air quality improvement was almost indiscernible--or negative--in many places. At the same time, public awareness and demands for action were increasing logarithmically. In typical fashion, citizens raised the traditional clamor, "there oughta be a law," either not knowing that there was a law or expressing their dissatisfaction with its provisions or its cumbersome implementation. I assure you their cries did not fall on deaf ears.

In 1967, a whole new blueprint was developed to foster a systematic action approach to clean the air. Since air pollution, in large metropolitan areas, is an inter-jurisdictional problem, Congress authorized Federal designation of air quality control regions which transcend political boundaries. We were called upon to issue air quality criteria--compilations of scientific knowledge on cause-and-effect relationships of various pollutants, singly or in combination, when present in certain concentrations over various time periods. Simultaneously, we had to issue control techniques documents reporting the state-of-the-art, the effectiveness and the cost for controlling each pollutant.

Armed with such information, the States were called upon to adopt air quality standards and an enforcement plan for achieving them within a reasonable time. Congress required public hearings for the selection of clean-air standards, thus providing a ventilating point for concerned citizens who never, theretofore, had had any real opportunity to influence such decisions. Hence, there was born a serious constituency for cleaning the air--a constituency the New York Times called the "Breather's Lobby."

While the 1967 amendments constituted a rational approach to better air quality, little abatement and control of air pollution was accomplished under its provisions. It appeared only to enhance the realization that much more speed is necessary. Public outcry, if anything, increased. So it was back to the drawing board for Congress and the Administration, which brings us to the Clean Air Act amendments of 1970 and the implications they have for all of us.

Truly, we have entered the "Era of Environmental Concern," and the environmental decade began in 1970. On the last day of that year, President Nixon signed the new air pollution control law. Without question, it is tough. It is complicated, to say the least. It has been described as having more mandatory deadlines per square inch than any other piece of legislation enacted within the past 20 years. It is, however, the best blueprint for clean air this Nation ever has had.

Along with the new law, we have a new Environmental Protection Agency and a new Administrator. In fact, it's pretty much a whole new ball game with many new players, new managers, new umpires, new demands by the paying customers for spectacular performance, and new ground rules, many of them still to be established.

The new law has something for--or, depending upon your viewpoint, against--everybody. There are requirements and deadlines for each of us--be we industrialists in any business, government officials at any level, or simply citizens and consumers.

The Clean Air Act, as amended, is extremely broad. Congress was deadly serious in attempting to respond to an obvious social problem and their constituents' demands--now coming through so loudly and clearly--that something be done about air pollution promptly. I think the 1970 Act reflects Congress' and the public's discontent with the lack of progress under the Air Quality Act of 1967, which is an indictment of both public and private sectors.

Congressional determination that corrective action will result is reflected in the many mandated deadlines; a few action dates are nebulous and discretionary, but even then Congress made it clear that action is expected "as promptly as possible." Generally, however, a very precise 30, 60, 90 or 180 days is specified; and ample checks and balances are provided to assure that the requirements are met or that the responsible party is held answerable for his failure.

Our new Administrator, Mr. William Ruckelshaus, taking his direction from the President, has laid out the goals and charged us with doing our best. It will not be accepted graciously by him if we fail. Each of us shudders to think that he might be the one who has to try to explain to Mr. Ruckelshaus why something went wrong or a deadline slipped. He projects total dedication to an action program which will achieve results quickly, and anybody who has read or heard his remarks cannot mistake his resolve. Mr. Ruckelshaus is, first of all, a lawyer, and he has declared that he will not hesitate to use all the legal authorities at his disposal to attain the quality of air that will protect health and welfare.

These are the basic principles Congress followed in formulating the 1970 Act:

1. It preserved the fundamental policy that primary responsibility for air pollution control rests with State and local agencies, but it greatly expanded and strenghtened Federal opportunities and responsibilities to intervene where States and localities fail.

2. Congress recognized that the greatest need is to protect health--not "normal" health, whatever that is, but also the health of sensitive groups, such as asthmatics and emphysematics; in fact, the Senate Committee said forthrightly that sources which cause or contribute to human health problems should be controlled or closed.

3. Air pollution control considerations must be expanded to include land-use planning, highway location and traffic flow, mass transportation, restriction of motor vehicle use and fuels policy.

4. Public participation is an essential ingredient of policy making, and public oversight of governmental action is legitimate to assure that public desires for clean air are met.

With those principles in mind, let us look at some of the Act's provisions.

The new Act continues and expands features of the 1967 amendments relating to designation of air quality control regions and the issuance of criteria and control techniques documents. We were permitted 90 days to complete the designation of regions and, by April 1, every portion of the United States was included in the nearly 250 Federally designated air quality control regions.

Thirty days were allowed for EPA to propose national primary and secondary air quality standards, rather than require the slower process whereby each State had to go through the standard-adopting procedure. The initial group of standards--including sulfur dioxide, suspended particulates, hydrocarbon, carbon monoxide, oxidants and nitrogen dioxide--was proposed on January 30 and promulgated on April 30, as mandated by law.

Primary standards must protect human health, based on the published air quality criteria plus a margin of safety.

Secondary standards must protect welfare from known or anticipated effects, so it is clear that Congress did not intend that the last scientific fact must be irrefutably established before secondary standards are set. The definition of welfare is exceedingly broad. It includes, but is not limited to, effects on soils, water, crops, vegetation, man-made materials, wildlife, weather, visibility and climate; damage to or deterioration of property; hazards to transportation; economic values; and personal comfort and well-being.

EPA also had 90 days to publish the first list of categories of stationary sources which may contribute significantly to air pollution which causes or contributes to endangerment of public health or welfare. The first such list, published in the March 31 Federal Register, included large fossil-fuel fired steam generators, municipal and other large incinerators, contact sulfuric acid plants, nitric acid plants and portland cement plants. On or before July 28, we must propose emission standards for new or modified sources in those categories. Standards are to be based on the latest available control technology--not that which necessarily is in actual routine use--just available. And economic considerations are relegated to a decidedly minor role in determining what is available. Final rules must be promulgated before October 27 of this year. The list and standards will be expanded and revised from time to time to include some 30 categories of sources.

Ninety days also was allowed for publication of an initial list of hazardous air pollutants, which are defined as substances that may cause or contribute to an increase in mortality, serious irreversible illness or incapacitating reversible illness. We are investigating some 30 potentially hazardous pollutants, but the first list, published March 31, included only asbestos, beryllium and mercury. Before September 27, regulations must be proposed establishing emission standards for these hazardous pollutants and, after public hearings, final standards must be promulgated before March 25, 1972. They will apply to both new and existing sources.

In the field of motor vehicle pollution control, Congress specified that hydrocarbon and carbon monoxide emissions from 1975 models must be reduced at least 90 per cent below the emissions permitted in 1970, and similar reductions in nitrogen oxide emissions are required in 1976. Although any manufacturer may apply for a one-year suspension of these effective dates, the Administrator has made it clear that extensions will not be granted lightly or haphazardly. On the contrary, a clear good-faith effort at meeting the standards must be demonstrated. Traditional arguments, such as adverse economy and poor drivability, will not be accepted and, if one manufacturer reports that he is able to comply with the standards, no manufacturer will be granted an extension on the grounds that technology is unavailable.

The new law also contains provisions authorizing assembly-line testing of production vehicles to assure that they meet the standards when built, and it requires that manufacturers warrant vehicles, throughout their useful life, to be free of defects in materials and workmanship which would cause them to fail to conform with regulations. There are recall provisions under which a manufacturer may be required to remedy, at his expense, any condition which causes such nonconformance.

The 1970 amendments closed a loophole which should be of interest to this audience. Whereas uncontrolled foreign-built vehicles formerly could be imported for private use--a prerogative frequently exercised persons ordering directly from foreigh manufacturers and by tourists and servicemen returning to the United States--importation of vehicles not conforming to the emission standards now is prohibited. Also, the law prohibits manufacturers and dealers from removing or rendering inoperative any portions of emission-control systems either before or after sale of vehicles.

There are, in addition, provisions authorizing control over fuel composition and the use of fuel additives, and a section of the law specifically is devoted to the development and acquisition by the Government of low-emission vehicles. Another provision requires--not authorizes--promulgation of aircraft emission standards by the end of this year.

So much for standard-setting authority which, I am sure you will agree, is quite comprehensive under the amended Act. Let us now take a look at the enforcement mechanisms that are provided.

Within nine months after adoption of national air quality standards--that is, by January 30, 1972--each State, after public hearings, shall submit implementation plans to achieve primary standards in three years and secondary standards in a reasonable time. The plan must include emission limits, schedules and timetables for compliance; measures such as land-use and transportation controls--matters over which, to date, no air pollution control agency has had any but the most peripheral influence; provision for monitoring and analyzing air quality; plan review authority; intergovernmental cooperation provisions; requirements that sources monitor and report emissions; means whereby the State must correlate such reports with emission limitations and make the results available for public inspection; and powers to prevent air pollution emergencies.

EPA must approve or disapprove a plan, or portions of it, within four months of the date it was due--i.e., by May 30, 1972. If a State fails to submit a plan, or it is found inadequate, EPA must propose and publish one. If the State did not hold public hearings, EPA must hold them in that State, and final regulations must be promulgated within six months of the date a plan was due from the State; i.e., by July 30, 1972.

A Governor may apply for and, if he can show good cause exists, may be granted a two-year extension to achieve the primary standards; but he must show that all available technology and alternative control means have been applied. Submission of implementation plans for achieving secondary standards may be delayed for 18 months, if the Administrator determines it is necessary.

The Act also contains adequate powers for Federal enforcement. When the Administrator finds a source in violation of an implementation plan requirement, a new source performance standard or regulations relating to hazardous emissions, he shall notify the owner and the State. If the violation continues 30 days after notification, the Administrator may issue an order to comply or he may bring civil action for relief, including permanent or temporary injunction. He has similar authority when he finds widespread violation of an implementation plan because of ineffective State enforcement.

For knowing violation after receipt of the Administrator's notification, criminal penalties up to $25,000 per day of violation and/or imprisonment for not more than one year may be assessed. Subsequent convictions may result in doubled fines and/or imprisonment.

Knowing falsification of records, reports plans or other statements or documents, tampering with any required monitoring instruments or rendering them inaccurate may be punished by fines up to $10,000 and/or imprisonment of not more than six months.

The Administrator must request the Attorney General to bring suits and appear for EPA. If the Justice Department does not act in a reasonable time, however, the Administrator may appoint his own attorneys to represent him. So Congress even included a way, at the Federal level, to get around the complaint frequently voiced by States and municipalities that the legal department is not cooperating with the air pollution control department.

For any phase of enforcement, the Administrator may require reports, records, use of monitoring equipment, and sampling of emissions. He has right of entry and subpoena power. Records and reports are public information, except upon satisfactory showing that trade secrets would be divulged--and the law says specifically that emission data are not trade secrets. I never did believe that emission data are trade secrets, and now Congress says we do not even have to listen when an industrialist contends that they are. If a competitor has no better means of gathering intelligence than by checking on a plant's air pollution emissions, industrial espionage is in a primitive state indeed.

Congress included in the 1970 amendments ample provision to see that its intent will be carried out. First of all, many of the Administrator's actions are subject to judicial review upon petition by anybody to the appropriate United States Court of Appeals.

Secondly, any person may initiate civil action against any other person, including the United States or another government instrumentality, who is alleged to be in violation of an emission standard or limitation or of an order issued by the Administrator or a State with respect to a standard or limitation. Additionally, actions may be taken against the Administrator for alleged failure to perform a non-discretionary act or duty. Technical legal arguments formerly employed in defending against environmental suits, such as improper plaintiff and standing-to-sue, no longer are pertinent; cases will be heard and decided on their merits.

Congress added two other provisions which demonstrate its resolve that maximum effort will be expended to improve air quality. First, no Federal agency may make grants or loans to, or contract for goods and services with, any person who has been convicted of a criminal offense under the Act until the Administrator certifies that the condition giving rise to the conviction has been corrected.

Second, to assure that technology is available to all parties needing it to comply with standards, there is a provision whereby patented systems must be licensed for use by others under reasonable terms and conditions.

Congress also provided for a greater Federal role in advancing technology. Authority for combustion research was clarified and expanded to include control of combustion by-products, removal of contaminants from fuels, improving combustion efficiency and producing synthetic or new fuels.

By this time, I am sure you are all confused by the many new provisions and mandated deadlines in the amended Clean Air Act. I must confess that I find it confusing, complicated and comprehensive. Each time I study it, I discover new provisions and nuances in meaning or intent. Preparing speeches like this forces me to review the Act; but I do not even pretend, as yet, to understand its many ramifications and complexities or how its several new features will be implemented. Nobody can foresee all the controversies and difficulties, although many already are painfully clear. Policies and procedures will evolve gradually as deadlines approach and legal and administrative decisions become necessary and, perhaps, as court rulings are rendered.

I think we all can appreciate, however, that Congress has responded forcefully to the public demand for clean air. They have provided potent tools, and the Administration has vowed to put them to the fullest use. All of us, regardless of our individual positions, will be called upon to do our share so that the sought-for goal--clean air--can be obtained for the betterment of all our citizens.

Critique Chairman

Brigadier General George M. Snead, Jr.

At this time, I would like to express my own personal thanks to all who contributed so magnificently to this symposium. The thought, the hard work, and indeed the threads of interleaving of one presentation to the other has been quite a pleasure to me. I said at the beginning I intended to enjoy your company. I not only enjoyed your company, I greatly enjoyed the presentations. I would at this time like to call on Dr. George Nicholson for the Critique.

Critique
Dr. George Nicholson

In preparing the critique, I have asked several of the chairmen, or the representatives of chairman who had to go early at certain sessions if they would be good enough to respond at my invitation to give a little bit of assistance to developing some of the discussion which will help us try to wrap this up.

A critique is essentially a determination of the extent to which the activity has, in fact, achieved its objectives. This tenth symposium is a symposium which, in fact, marks the end of a particular era and brings us to the beginning of a new one. Ten years ago, when we had this first symposium, those of us who were involved with it were very pleased to see a large number of uniforms in the audience. We were glad that we had been able to attract the attention of the Army to Operations Research. We were happy that we could get officers to come down and to become familiar with this new kind of an activity. We felt that this was one of the primary contributions that a symposium of this kind could make to the Army. We had to get people to know what Operations Research was all about. We talked about training, we talked about the importance of putting in Operations Research groups at various levels, and what levels and where they should be. We don't see very many uniforms here for a reason I think different than that that might be indicated. This is a thought that I think we should all be very much concerned about - the fact that we, at this point, have a job to do, which we hope Operations Research can help us do in re-establishing, to a large extent, a loss of confidence in the military establishment on the part of the public in our ability to go ahead and actually conduct our affairs confidently and efficiently. So I think this is one thing. We have sold the idea of Operations Research and Systems Analysis, well, we haven't sold it completely, but at least we've got the base of appreciation for it. Now I think we all definitely have to recognize the need. We certainly have to have the need. What does Operations Research and Systems Analysis promise us. It promises that it will help us make better decisions, help us make our operations more effective, help us develop indices for effectiveness that will, in fact, enable us to determine whether or not we did in fact do a good job and show us how we may improve in the future. And this I think is crucial for the Department of Defense. We are being weighed in the balance and we don't want to be found wanting. Now, General Norton in his keynote address used this little example about the weights. He said we've got to be able to do more than one thing at a time.

Can we develop four weights that will weigh these packages, one through forty pounds, and he kept referring to it throughout the talk. I think we all felt that General Norton's keynote address was one of the high spots of this symposium. He really did a very good job and set us off very well. Now, one of the things that he emphasized was the desirability, and I would say, the necessity of doing Operations Research on Operations Research. How effectively are we conducting this activity? To what extent are we really doing the job we ought to do? Because unless we are constantly evaluating ourselves, I do not believe that we are going to make the sort of contribution to the decision-makers that are absolutely essential if we're going to manage a big complicated, difficult to control, or even to understand, organization that we have now. I must confess that I wasn't quite able to pay as close attention to all of the talks and to try to solve this problem, at the same time, as I think General Norton felt the really competent individual ought to be able to do. I kept thinking about the problem and in thinking about the problem, I began, and I think this is a tendency that probably some of us have, to possibly go further into the problem than perhaps was warranted by the importance of the problem or by the necessity for paying closer attention to other jobs. Some of you are involved, say maybe with chemists, and I checked up on a little bit on this in the chemical balance in which the weights are used in one pan. The set of weights are more like one gram, one gram, two, five, ten, ten, twenty, fifty, one hundred, one hundred, two hundred, five hundred, and one thousand. This is a standard set of thirteen weights. With these thirteen weights, you can weigh any interval amount up to one thousand nine hundred ninety-nine grams. Some of you may be surprised at that. This is thirteen weights. Now, actually an improvement can be made. One can, by using only eleven weights, measure up to two thousand forty-seven, if one uses the weights one, two, four, eight, sixteen, and so forth. Now this is already an improvement. You have fewer weights, you can go ahead and you can weigh more things. So we've already improved. If we want to use the same number of weights, thirteen, we could weight eight thousand one hundred ninety-one grams - a big improvement, Now, let's suppose that we go to the weights on both pans. By using the weights in both pans, if you only use eight weights, you can weigh three thousand two hundred eighty separate one-gram packages. If you use thirteen weights, you can weigh seven hundred ninety-seven thousand one hundred sixty-one individual grams. Isn't this fantastic - isn't this amazing. Now General Norton said try to do it with three weights. Well, let's see if there's any kind of a moral we can put into this sort of thing. I wasted a lot of time, I wasted your time in going ahead and taking a problem, which had ceased to be any really important kind of a problem, and elaborating it. It's interesting. I think most of us are interested in this, but is this really the sort of thing we should be doing. Yes, if we can do both things at the same time. That is, solve this sort of a problem which is the kind of thing that most of us or many of us are intellectually tend to like to do but at the same time, let's try to keep our mind on what it is we are really suppose to be doing. I apologize for wasting your time with this elaboration but I just couldn't help it. That's my nature and that's the nature of a great many of us. Now, why don't we completely revolutionize the scale industry and tell them forget about the thirteen standard weights that you're supplying with all these chemical balances. We can do it with fewer weights because we have to think about people actually use these weights. Now, the chemist - he's thinking in a decimal system. He can take these thirteen weights that I mentioned two one-gram weights the five, the two, and so forth, and very quickly figure out any of the possible combinations. If you go to the system that I mentioned, one, two, four, eight, sixteen, and so forth, if you think in the binary system, which maybe more people think in the binary system than I'm familiar, that's a good way to think about it but most of us don't think that way, and if you think in a number scale to the base three, which I think probably none of us do, then perhaps the system of weights that we were talking about might be something sensible too. The point there is here is a problem that we could spend a lot of time on, and should spend some time on, but once we've failed to keep constantly in mind what it is, what is the objective, what are we trying to accomplish, we are simply wasting our time unless we are able to do two things at once. Now, I think then, we have constantly got to do Operations Research on Operations Research to determine whether or not we are, in fact, able to do the job of keeping our attention on the problem that needs to be solved and at the same time, not suppressing our natural inclinations, the things we are trained for, to do these other things. Because if we neglect the elaboration of these problems, we're going to lose the ability to solve novel problems, to see generalizations. This is the whole point of basic research, we've got to do it to keep ourselves sharp. But we must not confuse our basic research with the necessities for the applications. It isn't easy, it's very hard. But to maintain high quality, and that's my next point, I believe that we simply have to be able to do the two things that General Norton mentioned we should.

Now, high quality. I was looking at the critique sheets, some of them that came in, and there was something I immediately noticed. Most of them were face-up but a few of them were face-down. Those of them that were face-down were the ones that said, "Gee whiz, this was a terrible symposium, the whole thing was a waste of time." The ones that were face-up were, "Everything was first class, the steaks were magnificient and I never had a better piece of roast beef than I did last night". In general, the sheets told us, if I can summarize, some of the sessions were dogs, but most of them were dog acts. Most of you who were not at the Modern Volunteer Army presentation might not understand that; but I think, in general, most of us were highly pleased with most of these sessions. Some of these sessions were really outstanding, I felt, in the obvious care and thought that had gone into the presentation. Some of them were not quite so good but overall I believe that those of us who came to a session like this, prepared to pay attention to what was going on, found something along the way that should have helped us either restoring our confidence in what we were doing when we go back to our regular jobs, maybe making a contribution of a more specific kind in helping us with some technical problem that we were working on, or perhaps putting us in contact with somebody else who's working on a problem similar to our own who we can correspond with or communicate with to have a very fruitful interaction.

Now, some of the summary remarks, what did you think of the whole thing - "it is the greatest thing I ever came to," reminded me of a very old joke I first heard, I think, in connection with one of our past Presidents. Dear President, I want you to know that I think you're doing one of the greatest jobs of any President of the United States. I believe that you're handling of our foreign policy, of our domestic problems, of our gold flow problems is simply superb, outstanding, and I cannot express to you how great I think you are, signed so and so. P.S. Please excuse the crayon, but where I am now, none of us are allowed to have anything with a sharp point.

Clear away the fog. That's a constant criticism, and it's a valid criticism; but as in any criticism, one has to look at it very, very carefully. Many of us are guilty of a little intellectual arrogance or carelessness in failing to understand that the point that we get across sometimes has been the result of a difficult train of reasoning, but it is up to us to decide how to make the decision-maker understand this, how to make it plausible to him. I teach statistics and statistics is a subject that has a basically mathematical foundation, and in order to really understand it you do have to understand something of mathematics. So I have tried this experiment with a class. The introductory course in statistics usually has no mathematics involved. One can go ahead and take it. Now, how can you do that? You look at the class and say, we're not going to have any mathematics here, I'm going to explain the subject to you. Let's just see now where we are. We've got to establish a relationship between us. I said you know one of the great discoveries of the ancients was the fact that the ratio of the diameter of a circle to the circumference is a constant. In other words, these are proportional to each other. You all understand that - sure that's a very simple concept. Proportionality, is one of the most fundamental quantitative concepts. Everybody knows that, everybody nods. Right? I say, let's consider this problem we have for some reason, maybe NASA has ordered a steel band to be manufactured so that it can be fitted precisely around the equator for some big experiment that's coming up in 1972. And so the manufacturer manufactures it, it comes down, and he starts fitting it and finds it three feet too big - some defect in the manufacturing process. Well, what are they going to do, send it back? They can't cut it, so what are they going to do? Well, they decide to distribute the excess around the equator. How far do you think that band is going to extend above the surface of the earth? Well, they all think about that for awhile and say, "Would you believe six inches?" Well, you can see they're not too convinced, but it doesn't really mean anything to them. And now, let's consider another case. Suppose that somebody has ordered a band to go around a ping-pong ball. The same thing. There's something wrong with this manufacturer because this one comes out three feet too big. Again we distribute the excess. How far does it extend? Would you believe six inches? Well, they begin to worry about that a little bit. Well, didn't you all agree about this great discovery of the Greeks in proportionality. Now there are three ways you can go about this because we're going to go through this course. I'm going to be telling you things that are going to be much more difficult and complicated, based upon much more abstract reasoning than what we're talking about now. So you can do one thing, you can accept a proof of this and I can write it up on the blackboard in two lines or so, indicating to you that this is true, or you can do it by experiment, at least part of it you can. The other kind is going to be more difficult. You can take it on space - go back and come back on Friday (this was a Wednesday class). So they all come back, and you ask if they believe what you said? Now I'm a professor, a chairman of a department, and I've told you that something is true. Now I proved this for you - I wrote it up on the board Wednesday. Do you believe it? Well, they're kind of annoyed and bored with this thing by now. Do you believe it enough to bet your roommate? Would you bet your roommate that this is true? Well, what's the problem there? Some of us have to rely upon one of these three attitudes toward us, Operations Research. Whether the person we're talking to will, in fact, accept a proof, will he go ahead and on the basis of some sort of an experiment that we can make and say, o.k. I'll accept it, or state whether he has faith in us. We can't really rely on this. Some of us have established strong bonds of confidence between ourselves and the people with whom we work. They say, o.k., you're a professor, you're a Doc., you know this stuff and I'll buy this. But would he bet his roommate? Would he go up to the chief and say do this, or would he be prepared to defend what he did to a Congressman? Well, anyhow, this fog business, we do in fact have to keep this constantly in mind. This is a critical problem with regard to our role in operations research. We also have to keep another thing in mind, and that is timeliness. Most of the studies that we do are useful only within a very very narrow time frame. It's not as if we were say developing, for the first time, a proof of the Pythagorean theorem. This is timeless, this is valuable, no matter how long it takes us. But I'm afraid a lot of the problems that we work on, if we don't get the answer by tomorrow afternoon, will not be worth anything. It may satisfy us, but it isn't going to be worth anything. Now how do we do this? We are frequently given very unreasonable time limits. We've got to work faster. We've got to anticipate more and possibly those are some of the things that we have to do. But certainly if this particular activity that we're involved in is to really do what we say it's suppose to do, that is, help out decisions, make them better. Decisions: irrevocable allocation of resources. Somebody has defined it to be that way. Then we must in fact be able to fit it into the sort of constraints and guidelines that the decision-maker himself has to adhere to. Well, I do, in fact, want to call upon several people here. We have about six minutes and I'm going to ask anybody who takes more than a few seconds to sit down. Dave, would you comment on your particular view of this symposium?

Comment:

I wanted to comment on some of the interesting talks. One of them concerned the use of the computer stimulation as a tool to predict a device. I thought this was a very interesting talk because it showed that we don't have to construct an actual device but we can sometimes use a computer as a useful predictive tool. Another talk by Mr. Pao concerned the performance analysis of proposed materiel options. It was a wonderful scheme of all kinds of weights and measures and subjective scores arriving at a decision by committee method. I thought this was a very very strange and interesting way of making decisions concerning materiel options.

And then the third talk that we heard in that session concerned the application of probability measures to survival structures under atomic attack, I guess it was. And so I thought there were three widely different applications of Operations Research techniques that shows that the people we have here are spreading out in quite a few directions.

Comment:

Dr. Nicholson: Thank you. We do not really have time for summaries of the various sessions, so what I'd like to do is ask anyone here who has some general comment about the whole symposium. We had intended to summarize, but if we have any general remarks about the whole symposium in terms of do you think we did, in fact, accomplish our major objectives and if you have any broad macro-observations, we would be happy to entertain them.

Comment:

I think the session that Dr. Payne had, where we had a lot of people in very important positions, outlined a number of problems that they thought existed in the OR field. I was quite concerned that I didn't hear from any of these people what they were doing to solve these problems. It seems to me there's quite a few things that need to be done and I didn't hear anyone really moving out and saying we're going to do this and they were in a position where I thought they should do it.

Comment:

I think as an innocent bystander because I have not produced things in Operations Research, I was just listening, is the surprising lack of quality. As a matter a fact overall was a few notable exceptions. I would say it was even shoddy, and I would like to suggest that we take a few well qualified people, scholarly people, academic people, high-quality people to look into this situation. What appears to be fog to some people, may not be fog to all.

Dr. Nicholson: Thank you. Would somebody like to respond?

Comment:

I'd like to suggest that perhaps we shouldn't have so much competition between the contributed papers and the panel. I thought that there were some good papers but they were extremely poorly attended. I think you could get more from them because they were well prepared and a lot of work went into them. There weren't many people there.

Dr. Nicholson: Right!

Comment:

I'm Lieutenant Colonel Ian Meibusch from Austrialian Army Staff and I'd just like to record my thanks for the opportunity to attend this symposium. I wish we had a measure of effectiveness which would allow us to predict the value of the symposium ahead of time and that way I might have been able to convince the decision-makers that they could afford to send someone more expert than I from Austrialia rather than an Austrailian representative from Washington to this symposium. As a guest of this symposium, I don't feel as though I've got any moral right to make any suggestions. However, I do succumb to immoral impulses now and then and so here goes. The one that I'd like to see discussed a little bit more in future symposia of this nature is what's the future of Operational Research in the personnel business. The Army is a man-orientated service. The Navy and Air Force are both equipment orientated services and I've got a feeling after listening to the papers presented in this symposium that Army Operational Research tends to be equipment oriented. Therefore, to my mind at least and I might be a little out of step here, Army Operational Research is a little bit out of step. I got this impression when listening to that excellent presentation by Colonel Butler and Major Dawkins.

Dr. Nicholson: Well, General Snead, it's 11:30 and I'll turn it right back to you.

Brigadier General Snead: I know there are planes to catch - I thank all of you for your participation, for your candid comments and we quite sincerely mean we worked, we the sponsors worked, to make this be what you want and what you need. If you would like, after reflection on your visit here, to follow-up later with a critique sheet, we would very much appreciate that. We do identify that there are many areas that we are talking about a great deal, we are not focusing on a clear attack on the problems we're talking about. That is one of the purposes we see when we sponsor these is to give you, the interested people, the opportunity to get together and reach agreements on priorities of attack. With that, thank you very much for coming and staying with us. The symposium is adjourned.

SOME CONSIDERATIONS IN PLANNING FOR AN ASSAULT AIRFIELD CAPABILITY WITH A SEVERELY CONSTRAINED BUDGET

By

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The air mobile concept has been applied and proven in Vietnam. Both the engineer support and the logistical support of the air mobile concept were adequate in Vietnam and it has now become a firm part of future military doctrine. However, the ready availability of materiel to support the proven air mobile concept has not been introduced in our long-range planning. We have not postured ourselves to adequately provide the necessary support. To be responsive, we must be able to provide the necessary hardware in the quantities and time required, else the entire concept will be penalized.

The advent and adoption by the U. S. Army of the air mobile operational concept in the early and mid-60's massively increased requirements for both tactical and logistical air aupport missions. Since that time, the requirements for air support to ground combat operations have increased significantly and are continuing to grow. Examples of this increase are evidenced by the reliance on airlines of communications (ALOC) dependence on close tactical support as a substitute for heavy artillery and upon tactical and observation aircraft systems operating on the battlefield. Both of these situations provide more flexibility in the theater of operations (TO). Present planning in both general and limited war situations and for sustained ground, airborne, and air mobile operations calls for an unprecedented volume of Air Force and Army aircraft for such air missions as inter-theater strategic lift, close tactical support, air assault operations, intra-theater airlift in an ALOC, and intra-Division airlift to front line units. Additionally, the concept of total air mobility as developed by the Army Tactical Mobility Requirements Board has created many new aircraft missions within the front line division area (Illustration 1).

Current Army construction capabilities in support of these concepts are not compatible with requirements in terms of time and geographical areas of employment. A conventional military airfield (rigid or flexible pavement) can normally be constructed in 1-1/2 years and if accelerated in nine months. Although our posture has changed from truck to aircraft support, we have not oriented our base so that hardware is available to do the job in three days. Ideally, in times of national emergency and during a major conflict, the time period involved from commitment to deployment through winning the war is short. Realistically, as was the case in Vietnam, the facts show that this is rarely the case, and, therefore, even with the flexibility of the air mobile concept there are requirements for stockpiling for contingencies and for readiness for future conflicts, as will be shown.

Concepts dictate that airfields be readied in the early stages of troop deployment in air mobile operations and that they be located in proximity to the supported forces thereby ensuring that the mobility of the Air Force is consistent with strategic and tactical objectives. The proposed airfield surfacings will provide rapid means for preparing and/or improving airfields and landing areas capable of accommodating all types of aircraft in support of military operations including strategic and tactical lift and tactical air support. The surfaces must provide all-weather operational capability and be capable of installation during all times. Current airfield surfacing methods require either a site where the California Bearing Ratio (CBR)(i.e., the strength) of the soil will sustain aircraft loadings or a site which with extensive preparation of the subgrade will provide the necessary soil strengths. In few, if any, areas of the world where deployment of U. S. air mobile forces is foreseen, do required airfields exist, in sufficient number, which can sustain the loadings of supporting aircraft. For example, when we first went into Vietnam, there were only three airfields capable of supporting sustained operations of the C-130 and fighter aircraft. Today, there are approximately 52 C-130 airfields, seven of which can support fighter bomber operations. This is typical of the tremendous response which will be required in providing necessary airfields for the air mobile concept. Most military combat areas will be similarly underdeveloped. In contrast, even here in the State of North Carolina, which is slightly less in size than South Vietnam, there are today in excess of 19 civilian and 5 military airfields which will support C-130 operations. Also, construction materials for preparation of airfield subgrades and surfaces are not available or necessitate disproportionate demands for time and effort to locate, transport, emplace, and compact granular materials for airfield construction. The conventional methods of constructing airfields do not permit the development of air landing facilities for airborne and air mobile forces throughout the world on a selective basis within envisioned time parameters. For example, the Swift Strike Exercises proved that with adequate hardware support an airfield could be built in three days. This was repeatedly validated by engineer experience in Vietnam. Without the construction capability to support airborne and air mobile forces, their employment is seriously jeopardized if not totally prevented. Currently, development efforts are being directed toward providing expedient surfacing materials which will reduce to a small fraction the construction times otherwise required. These expedient or prefabricated surfacings provide the Army with improved capabilities to produce the required aircraft landing facilities, which are essential for support of air mobility concepts in TOs. Development of landing mats and membranes permits rapid airfield construction flexibility in landing facility design. The landing mats (XM19, truss web, and AM2 for example) provide a bearing surface capable of supporting specified aircraft loadings on low-strength soils. For example, the XM19 aluminum honeycomb core sandwich-type mat will support 14,600 sorties of the F-4C loading (25,000-lb single-wheel load and 250-psi tire pressure) when the mat is placed on a 4-CBR subgrade, or, in simpler terms, it will replace 10 in. of concrete. The Dow truss web extruded mat will support 8400 sorties of the F-111 loading (50,000-lb single-wheel load and 250-psi tire pressure) when placed on a 4-CBR subgrade and will replace 14 in. of concrete. Both of these mats exceed the coverage requirement stipulated in the QMR of 1000 coverages which is equivalent to 7140 sorties of the F-4C and 5260 sorties of the F-111 (Illustration 2). The use of landing mats will greatly reduce the time and engineer effort required to construct airfields by substantially reducing the need for subgrade preparation and by providing a surface which can be rapidly emplaced. The membranes will provide a rapid means of waterproofing and dustproofing airfields in areas where soil strength is adequate and of waterproofing subgrades beneath landing mats. Since these items must be air transportable, it is required that all surfacings be lightweight, consistent with meeting operational requirements, reusable with rehabilitation if undamaged, and packaged for ease of handling.

A complex of airfields is an essential ingredient for the Army's concept of air mobility as well as for similar concepts tailored for the employment of joint forces. This complex includes several levels of operational capability as required to support the various logistical and tactical air missions.

Depending on the general geographic location, the complex may exist in part; but in no area of the world are these airfields to be found in the quantity necessary to satisfy all of the requirements in such operations. In some cases, all aspects of the complex will be totally nonexistent. As a generality, the time available to bring this airfield complex to a state of sufficiency will be short, with periods of four to 72 hours representing the maximum construction time for various facilities. Approximately three days of basic supplies are available on site within various units; therefore, due to the rapid depletion of these supplies on D-Day, we must establish an ALOC within three days of unit deployment. Thus, it becomes evident that construction of conventional rigid and flexible pavements is not feasible. Furthermore, the use of soil stabilization and similar expedients generally will prove to be not feasible both from logistic and construction time considerations. There may be isolated instances where construction of conventional pavements, use of select materials, or soil stabilization could represent solutions. Information currently available indicates that these conditions will prevail infrequently, and can be considered only as special cases capable of being preplanned for specific purposes.

One solution to meeting the rigorous construction time requirements is in the employment of expedient surfacing items such as prefabricated landing mats and membranes. Here again, the severe overall logistical demand of a TO controls what is feasible. The movement into a theater of the large bulk of materiel necessary to satisfy airfield surfacing requirements may, in many instances, determine the scale of the operation itself. In the rear areas of a theater, weight of the surfacing expedients generally will control their usage. A calculation has been made which indicates for each one-tenth of a pound per square foot of weight saved in a given landing mat design, one less C-130 will be required to move the mat required for an airfield. As the movement of this materiel is toward the forward areas of a theater, both weight and bulk become critical. These limitations are imposed by the capabilities of the aircraft supporting an ALOC. Even though air delivery of surfacing materiel may not always be employed, the system has to be such that aircraft can be employed when the requirements of the operation so dictate. Furthermore, it is likely that in remote or underdeveloped regions of the world as well as in the more forward areas of a theater air delivery represents the only satisfactory delivery means that can be employed.

Today there are three landing mat manufacturing processes; namely, extruded aluminum, rolled steel or aluminum, and fabrication of an aluminum sandwich-type structure. Of these processes, only the extruded aluminum and aluminum sandwich-type mats have resulted in designs which satisfy all requirements of the QMR. Although the rolled steel mat (M8A1) is relatively inexpensive and has a high production base, it will not satisfy the necessary performance requirements; it is a very heavy item, weighing 7.5 lb per sq ft of placing area (Illustration 3). A problem ever present is the time required to establish fabrication facilities in the CONUS and the additional time required to fabricate expedient surfacing materials. Today, the production base for extruded-type mats is estimated as 3-1/2 million sq ft per month, although it was never more than 2 million sq ft per month during the early crisis in Vietnam and for sandwich-type mats the base drops to 1/2 million sq ft per month. However, assuming an adequate mat had been designed, tested, and previously type classified, the time required for establishing fabrication facilities capable of producing the mats at these rates would range from 3 to 12 months, depending on the type of mat desired, thereby prolonging the CONUS reaction time to TO needs. These data are realistic since today the depot supply of mat is at a low level, dictating fabrication of new mats when required because of a hostile situation.

Based on operational experience gained since deployment of the 1st Calvary Division (Air Mobile) and 1st Infantry Division to Vietnam in 1965, a format was adopted for developing and maintaining an ALOC in support of tactical operations involving brigade and larger size units. This format stipulates that deployment usually will be accomplished to the battle area by utilizing Army aviation. Additionally, because of the high payload capability, the C-130 cargo aircraft will be used to augment Army aviation anytime an existing airfield can be located sufficiently near the objective area to respond to the tactical and logistical requirements. To the engineer there are two basic problems associated with the C-130. First, a facility must be rapidly established that is all-weather and has a guaranteed life of one month (approximately 400 sorties). Second, the phasing-in of additional construction effort during the initial month of operation to upgrade at least the runway portion of an airfield that will remain essentially maintenance free under C-130 operations for two years (approximately 5000 sorties).

During the first few days following tactical deployment, resupply of ground forces is again maintained by Army aviation, primarily helicopters, until a C-130 facility is established. In Vietnam, only a few operations were supplied by a ground line of communications due to the general lack of existing roads or enemy interdiction in areas where roads existed.

In a single brigade action, resupply air missions for some classes of supplies may be expected to begin within three hours following initial deployment. Resupply for all classes reaches as high as 280 tons per day beginning on the fourth day, and averages more than 200 tons per day throughout the duration of the operation. Petroleum, oil, lubricants, and ammunition are the major items of this resupply.

Until C-130 service is established, the bulk of the resupply tonnage in the major classes is delivered by the CH-47 (helicopter). However, from the viewpoint of the tactical commander, use of the CH-47 as a resupply vehicle is a necessary evil that imposes severe penalties in two areas. First, it greatly reduces artillery mobility which is primarily dependent on the CH-47. Second, it imposes a critically high "in-commission" or utilization rate on the CH-47 system. The intra-theater transportation cost per ton for the CH-47 is almost five times the cost of using a C-130; but to use C-130s, the support facilities must be available.

Resupply deliveries may be expected to fall behind during the period prior to establishing C-130 capability. Once the airfield is opened to C-130 traffic, it must be ready to accept 75 to 100 sorties the first day in a catch-up operation. Operations of the C-130 beyond the first day range from 10 to 20 sorties per day and average approximately 100 per week during the period in which the brigade is fully committed. Thus, the airfield must be capable of supporting some 400 C-130 sorties for a single tactical operation. To satisfy the requirement established by the Commander of the U. S. Military Assistance Command in Vietnam that the C-130 airfield network provide a capability for brigade and larger size deployment to any point in Vietnam at any time, a design life of 5000 sorties or approximately two years has been established as being appropriate for these facilities. It is desired that air delivery and emplacement of a landing mat should require no more than three days for a 3500-ft runway. Here again, there is the assumption that the mat quantities required will be available on D-Day.

During the initial stages of the Vietnam conflict, the depot stocks of existing mats were depleted and approximately 168 million sq ft of an existing mat design (M8A1) were produced by five fabricators over a two-year period. In addition, to be responsive to requirements for heavier fighter-type aircraft loadings, it was also necessary to procure 1.8 million sq ft of XM18, 9 million sq ft of XM19, and 100 million sq ft of AM2. Two of these mats, XM18 and XM19, were still in the development stage and production lines had to be established to respond to these requirements. This experience shows that a one- to two-year lead time is required in production time alone to have mat available on D-Day in quantities needed. This erroneously assumes however that a mat design will be available which will satisfy the current aircraft requirements, and that the requirements will not change during the course of production once commitment is made on one design.

New aircraft requires new landing mats, new membranes, and new dust palliatives; thus, there is an added problem of "just keeping current." With the additional usage of landing mat fields in Vietnam, for example, where the situation was relatively static, the coverage or sortie criteria changed from 200 to 1000 coverages or a 400-percent increase in coverages just due to additional usage alone; whereas, the F-4C fighter had a 25,000-lb single-wheel load, the F-111 dictated designing a mat for a 50,000-lb single-wheel load. The C-5A imposes additional requirements due to the enormous mass and blast effects of the aircraft landing on the expedient surfaced airfields. The advent of the heavy-lift helicopters must also be considered. These additional time considerations must be added to the production lead time in preparing for D-Day mat requirements so that the U. S. air mobility capability will be enhanced. A recent cost-effectiveness study conducted by a private firm indicated that presently we should be updating our requirements to meet the objectives of the 1975-1980 time frame.

The present posture indicates that normally under ideal funding situations, a development program involving expedient surfacing materials, including readjustment for aircraft changes and establishment of production capabilities requires two to five years from design through field testing to type classification. However, from a technical viewpoint, any constraints on the budget should consider the lag that will occur. We must stockpile for contingencies. The solution is to anticipate early and restock. We cannot anticipate when or where the next conflict will occur, but to support the air mobile concept which provides unlimited flexibility, we must be ready to respond to its requirements and, hopefully, have a minimum of time lag. Ideally, we must be so organized that we will have a procurement production capability so X million sq ft of material is available at all times for D-Day, Y million sq ft is available within 30 days after D-Day, and Z million sq ft is available per month thereafter.

llustration 1

LANDING MAT CHARACTERISTICS

TYPE	DEVELOPER	USE	WEIGHT LB/SQ FT	PLACE RATE SQ FT/ MAN-HOUR	STRENGTH: WHEEL LOAD LB	STRENGTH: TIRE INFLATION PSI	STRENGTH: CBR	STRENGTH: COVERAGES	ESTIMATED PRODUCTION COST DOLLARS/ SQ FT	U. S. ESTIMATED PRODUCTION BASE SQ FT/ MONTH
LIGHT DUTY REQUIRED:	ARMY	ALL ARMY AF THRU C-130	3.0	400	30,000	100	4	1000	N/A	N/A
M8A1	ARMY		7.4	250				285	1.00	12.0M
HARVEY	HARVEY/ ARMY		3.1	370				367	3.00	4.0M
MEDIUM DUTY RE-QUIRED:	ARMY/AF	C-130, C-141, C-5A, F-100 SERIES, F-4C	4.5	250	25,000	250	4	1000	N/A	N/A
XM19	KAISER/ ARMY			390*				2050	5.25	0.5M
XM19 (WP)	KAISER/ ARMY		4.2	174				1785	5.75	0.5M
XM19 (ALL-BONDED)	KAISER/ ARMY		4.2	450				4840	4.25	0.5M
XM18	DOW/ARMY		4.8	270*				1100	3.75	4.0M
AM2	NAVY		6.3	180*				500	2.60	3.3M
HEAVY DUTY REQUIRED:	ARMY/AF	F-111, C-141**, C-5A**	6.5	150	50,000	250	4	1000	N/A	N/A
XM20	DOW/ARMY		6.1	445				610	3.50	3.3M
TRUSS WEB	DOW/ARMY		6.3	778				1612	5.20	3.3M

* BASED ON FIELD RATES
** SIX-MONTHS LIFE AND LONGER

Illustration 2

QMR REQUIREMENTS FOR LANDING MATS

Mat Classification	Single-Wheel Load lb	Tire Pressure psi	Nominal Contact Area sq in.	Coverage Level	CBR
Heavy duty	50,000	250	200	1000	4
Medium duty	25,000	250	100	1000	4
Light duty	30,000	100	300	1000	4

Mat Classification	Desirable Weight lb per sq ft	Essential Weight lb per sq ft
Heavy duty	5.0	6.5
Medium duty	4.0	4.5
Light duty	2.5	3.0

Mat Classification	Desirable Placing Rate sq ft per man-hour	Essential Placing Rate sq ft per man-hour
Heavy duty	400	150
Medium duty	400	250
Light duty	600	400

Illustration 3

PROJECTION OF MOBILE ELECTRIC POWER
FOR THE DOD WITHIN THE NEXT DECADE

Prepared by: Mr. T. W. Lovelace
Office: DOD Project Manager
Mobile Electric Power

At the end of the Korean conflict, power requirements for our military forces were pegged at approximately .5 kw per man. The capacity of power generating equipment delivered to Vietnam approached 2.5 kw per man during the peak build-up. Partial explanation for the tremendous need for power in Vietnam is the nonexistence of adequate commercial power for use by our military forces. The major cause of this great increase of electrical power, however, is our ever increasing use of electronic equipment. Searchlights, radar, computers, and complex communication systems all consume great amounts of electrical energy. Electrical power for military use is far out of the convenience category and is now an essential element in almost every phase of military operations. In the past, to meet this growing need, any and all types of generator sets were procured and allowed to get into the military logistic system. Most of these sets were either gasoline engine driven (spark ignition, Otto cycle) or diesel engine driven. The primary efforts of the Project Manager-Mobile Electric Power are being directed at standardization of the existing types of mobile electric power sources. A secondary effort of the Project Manager is to standardize on mobile electric power generating sources projected for the future.

To get a better picture of future trends, several considerations must be pointed out. In the past, emphasis was placed on reduction of size and weight. However, the present and growing emphasis is on increased reliability and life. Current gasoline engine driven and diesel engine driven sets have meantime between failures (MTBF) of approximately 200 and 250 hours respectively. As a result of several inputs, including a report of a visit by Dr. Foster (DDRE) to Vietnam, an Emergency Program was started to increase the reliability of existing gasoline engine driven and diesel engine driven sets. This program placed special emphasis on increasing reliability of engine accessories such as ignition systems, fuel systems, and filter systems. Also, in keeping with the trend toward greater reliability, the diesel engine driven members of the DOD standard family of mobile electric power generating sources now under procurement have a specified MTBF of 500 hours minimum. It is anticipated that future mobile electric power sources should be able to attain a MTBF of 1200 hours. Another factor impacting upon the future development of mobile electric power generating sources will be air pollution (exhaust emission) controls. Obviously, military equipment will not be exempt from applicable regulations and efforts in this area will be essential.

In the future, programs directed at development and procurement of mobile electric power generating sources will be placed under better guidance and control. The application of risk analysis, configuration management, and integrated logistic support will be used to avoid costly and unnecessary development and/or procurement changes. In the past, application of these disciplines was controlled by the project engineer or the contracting officers representative. The new systems will integrate the skills of various specialists and provide visibility necessary so as to avoid unnecessary cost. Research and development programs will be scrutinized to ascertain that the results will be sufficient to meet the requirements of the field and perform specified missions. "Nth" degree engineering or pushing technological advances for their own sake can no longer be tolerated in the light of austere research and development budgets. Development programs must be critically analyzed to determine the net benefit to be gained even if all technical objectives were attained.

As we consider the restrictions which must be placed on research and development, it would be well also to consider the restrictions which must be placed upon the establishment of unnecessary and unrealistic requirements. Requirements must reflect the realistic needs of field users and be attainable within a reasonable time frame. Also, as was stated by Colonel Tucker in his memorandum, CRDCM, 21 October 1969, subject: Use of the DOD Family of Mobile Electric Power Plants, systems should not expect mobile electric power generating sources to be tailored to using systems which in many cases are just a gleam in a developers eye. Following the approach of tailoring generator sets to meet any and all needs which a system developer said he must have, has almost led us to a point where standardization and logistic control of mobile electric power field was an impossibility. It is felt that some requirements placed on mobile electric power sources in the past have been the result of a user specifying total system precise power, when in actuality the need for precise power may be less than 10 percent for any given application. In these cases, the development of power conditioners able to meet the relatively small requirement for precise power could be developed and fielded at a much lesser overall cost than the cost involved in requiring an entire family of generator sets to be precise or to have other specialized characteristics. Also, when a system user declares that a standard mobile electric power generating source cannot be used with his equipment, because it is six inches too long, it should be cause to believe that he has not designed his using system in an economic and practical manner. The use of standard mobile electric power sources must be considered during the development concept of a using system.

It must be recognized by the military that an industrial production base is essential in times of national mobilization. Therefore, development of highly specialized mobile electric power generating sources such as turbo-alternators, fuel cells, Rankine cycle for general purpose tactical use, must be carefully reviewed in light of the trends and capabilities within industry. On this premise, we can prognosticate that reciprocating diesel and gasoline engines having an obviously well established industry base will serve as the prime movers for the great majority of mobile electric power sources within the next ten years. As I stated in the beginning, gas turbine engine driven sets and some advanced power sources (fuel cells, etc.,) will begin to come into the military logistic system, but until such time as industry begins to produce and market these power sources, the military would be ill-advised to run far ahead without the vital support industry must provide. Obviously this philosophy does not apply to all military equipment. Machine guns, rocket launchers, and the future "death ray" will have little commercial application. Mobile electric power sources, however, should not be considered in the specialty category.

As to actual hardware trends, let us look at each of the foreseeable technologies:

Otto Cycle

This power source has well established commercial base. It has a relatively high efficiency, is fairly simple, and provides rapid response. Part load efficiency is not as good as the diesel cycle and efforts to improve the Otto cycle will probably taper off with the exception of efforts in the emission control area.

Diesel Cycle

This source offers long life, reliability, and excellent response. Efforts to improve this power source will continue. However, it will probably be 10 to 20 years before the diesel cycle will match the low weight to horsepower available from the Otto cycle.

Stratified Charge Engines

The efficiency of these engines is lower than that of the diesel. They are more complex than the Otto cycle. The major advantage of the stratified charge engine is reduced exhaust emission.

Wankle Engine

This technology thus far has been able to demonstrate long life. The major problem with this engine is seals. It does offer simplicity and compactness.

Stirling Cycle

This cycle has not been able to demonstrate high efficiency. It is complex, bulky, and heavy. It does offer low emissions and quiet power.

Rankine Cycle

This has become one of the most promising silent power sources projected for the future. Efforts are now underway to evaluate this cycle in comparison with fuel cells.

Gas Turbines

At present, these power plants are not as efficient as the Otto cycle and diesel cycle. This is especially true at part loads. Gas turbine engines for ground use have been on the brink of practicality for several years now. If development costs were ignored, the life cycle of gas turbine engines would not be significantly higher than that of diesel engines. A primary advantage of gas turbine engines is size and weight. The 10 kw turbo-alternator now in development is an example of the size and weight reduction which can be expected by using gas turbine engine driven sets. Specifically, the 10 kw turbo-alternator will weigh approximately 250 pounds as opposed to 850 pounds for the air cooled military designed gasoline engine driven 10 kw set. The turbo-alternator concept also affords another advantage. That being the ability to furnish either 60 or 400 Hz from the same machine at the option of the operator.

Thermoelectrics

Major problems with this technology are materials and fabrication. They are low power machines.

Thermionics

While this approach offers higher efficiency than thermoelectrics, materials are still a major obstacle.

Fuel Cells

Problems encountered with these units are the inability to use logistic fuels, use of exotic materials, and high initial cost.

Nuclear

For some time to come these units, due to extreme high cost, size, and weight, will be restricted to use in space and other highly specialized applications.

It should be noted that with the Stirling cycle, Rankine cycle, thermoelectric, thermionic, and fuel cell power sources, control becomes a problem due to inherent slow responses.

Summary

Taking into account the observations made above, a reasonable prediction can be made as to mobile electric power sources for use by the DOD in the next decade. The bulk of military mobile electric power needs will be met by the use of Otto cycle (gasoline) engine driven generator sets and diesel engine generator sets. During this next decade, the trend toward diesel engine driven generator sets will become more prominent. The use of gas turbine engine driven generator sets will increase while Otto cycle engine driven units will tend to phase down. Certain silent power units, e.g., fuel cells, thermoelectrics, and Ranking cycle, will see limited service in the field. These predictions are shown in Chart 1 which reflects the percentage use of the different power plant types within the DOD for the period through 1990. For comparative purposes, Chart 2 shows the total kilowatt generating capacity of the various types of power sources in the future. This prediction takes into consideration all of the observations made above and the simple fact that the tremendous industrial base of reciprocating engine precludes reasonable competition by any other power source in the near future.

TYPE OF POWER PLANT

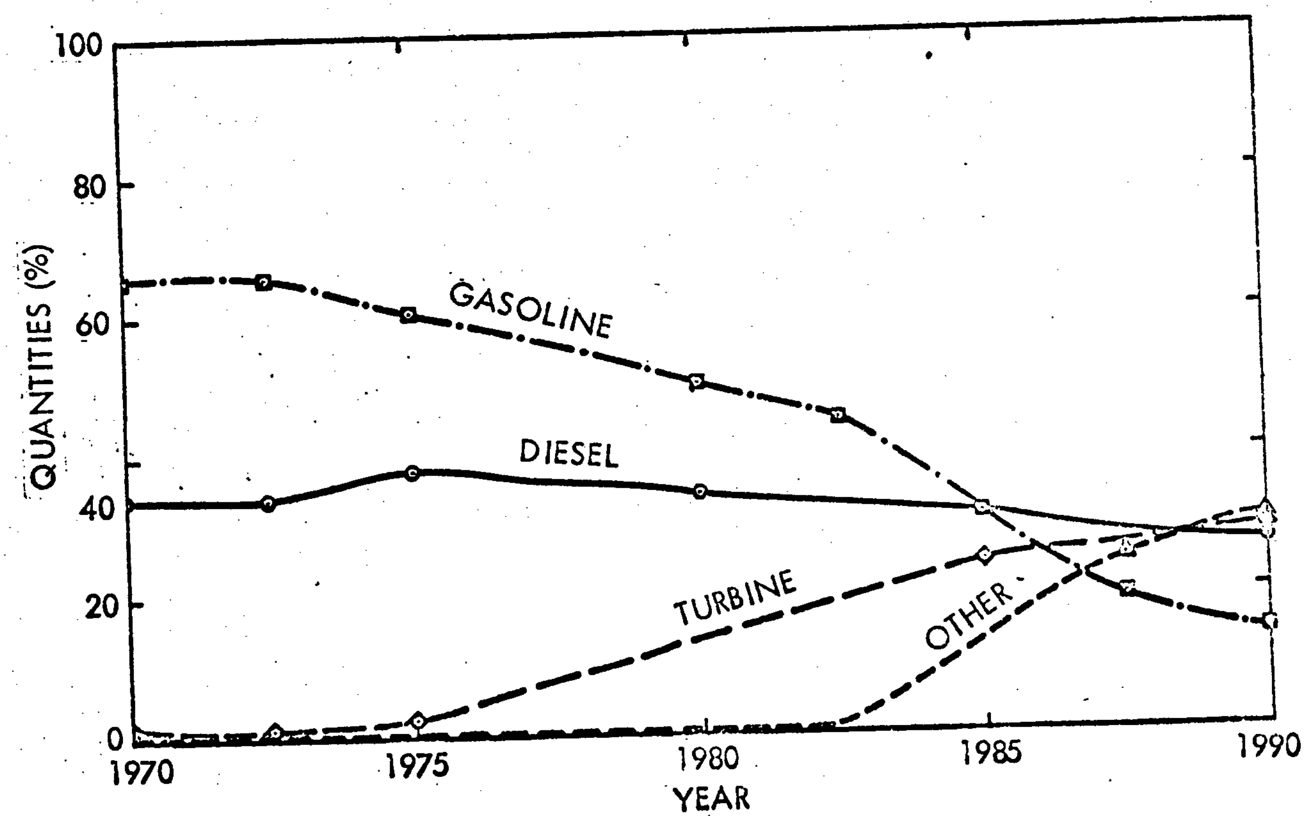

CHART 1

KILOWATT GENERATING CAPACITY

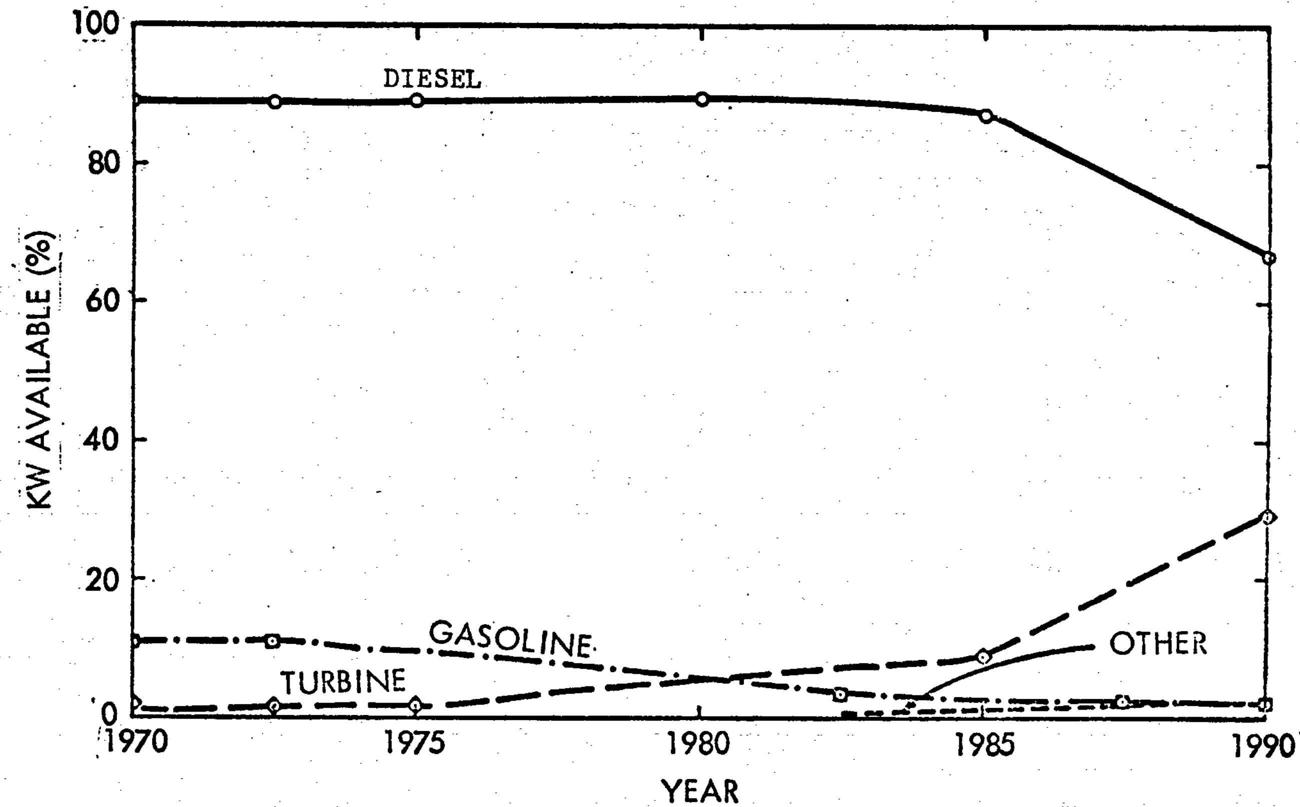

CHART 2

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