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Operations Research Symposium

U. S. ARMY RESEARCH OFFICE-DURHAM

DURHAM, NORTH CAROLINA

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24-26 May 1967

Proceedings - Part I

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OFFICE, CHIEF OF RESEARCH AND DEVELOPMENT

DEPARTMENT OF THE ARMY

539

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PROCEEDINGS

for the

United States Army

OPERATIONS RESEARCH SYMPOSIUM

24-26 May 1967

PART I
(Unclassified Volume)

Sponsored by

Office, Chief of Research and Development

Department of the Army

Hosted and Conducted by

U. S. Army Research Office-Durham

Durham, North Carolina

U. S. ARMY OPERATIONS RESEARCH SYMPOSIUM

24 - 26 May 1967

FOREWORD

The 1967 U.S. Army Operations Research Symposium is the sixth annual symposium in the Army series which is sponsored by the Office, Chief of Research and Development, Department of the Army. This symposium was planned, managed, and hosted by the U.S. Army Research Office-Durham in Durham, North Carolina.

This volume, Part I, is unclassified and contains all invited and contributed papers and major addresses which were presented in the unclassified sessions. A second volume, Part II, contains the papers and addresses which were presented in the classified sessions.

ALBERT G. THOMPSON
Major, GS
Commanding
U.S. Army Research Office-Durham

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WELCOME

Major Albert G. Thompson
Commanding Officer, ARO-D

General Betts, Colonel Billingsley, Members of the Symposium:

It is a great pleasure for me to welcome all of you to the U.S. Army Research Office-Durham for this Sixth Annual U.S. Army Operations Research Symposium.

In a sense, we might call this a "home-coming" symposium. Those of you who have attended earlier meetings in this series will know this, but for the benefit of those of you who are new to these meetings, I should add that the first two symposia were held at Duke University in 1962 and 1963. This is, however, the first Operations Research Symposium to be held here at ARO-D.

The years that have elapsed since 1962 have run their course very rapidly. With respect to these meetings, there is one thing that happened since the 1966 Symposium which requires mention here. This is the death of Dr. John J. Gergen, of Duke University, on January 16 of this year. This is a sad event to report to you, but I believe it would be inappropriate for me to fail to do so. Dr. Gergen was the valued friend and colleague of many of you who are in this room today. He was for many years head of the Department of Mathematics at Duke University. He made countless contributions to the Army's program in mathematics. He was very closely associated with my office. Dr. Gergen was the Program Committee Chairman of the First Army Operations Research Symposium held at Duke in 1962. He was General Chairman of the 1963 Symposium.

His role was really pioneering, with respect to these meetings. Indeed, the entire concept of these symposia was largely his, with the active cooperation and interest of the late Colonel George W. Taylor, who was Commanding Officer here in 1962.

I should like to couple these welcoming remarks with a brief look at the change in focus and impact that these Operations Research Symposia have undergone during the past five years. It is fairly clear from the record that at the first of these symposia, considerable time was spent discussing what Operations Research is all about. There were appropriate references to the British origin of these techniques, as "operational research", during World War II. At that first meeting there was a lot of attention paid to the fact that in the Army there was a lack of opportunities for training in Operations Research. Finally, there was a good deal of evangelistic expression of urgency that the Army make increased use of Operations Research in solving its problems.

At the 1963 Symposium these topics came up again. But there were other things too--such as generalized discussions of the use of simulation techniques in tactical and logistical problem solving.

The 1964 Symposium was highlighted by a Panel on Special Warfare, with international representation. Since then, special warfare, war gaming, and cost effectiveness have received increasing attention.

As one man put it to me, "Having in 1962 and 1963 gotten to the brass, in 1964 we began getting down to brass tacks."

Last year the theme of the Symposium was "Life Cycle Management of Materiel." . This year the theme is "Uses of Operations Research in Developing Countries." This includes ways of trying to put out insurgency situations before they start. It also covers the matter of getting back to normal after a difficult situation has arisen. In this connection , the theme has increased significance now that the role of pacification in South Vietnam has been made a military responsibility.

This Symposium is also being attended by a number of people from the academic world who are interested in problems of special warfare.

There is a further trend that relates to the Army's use of Operations Research. Last year, and again this year, quite a number of people who would logically have been attending these symposia have been unable to do so. They are too busy working with Operations Research techniques on hot problems generated by the Vietnamese conflict.

All of these changes in the atmosphere of these symposia demonstrate the changing and expanding role of Operations Research. We have a large number of Army people receiving training in Operations Research each year. We are focussing on problems, and there are plenty of problems on which to focus.

Once again, I wish to extend a cordial welcome to each of you, and to express my best wishes to you all for a very successful meeting.

OPENING REMARKS

Colonel John D. Billingsley
United States Military Academy
Symposium Chairman

Good morning, ladies and gentlemen. I am Colonel John Billingsley, Professor and Head of the Department of Ordnance, United States Military Academy. I will act as General Chairman for the Symposium. This is the Sixth Annual Operations Research Symposium to be sponsored by the U.S. Army.

As I stand here before a group such as this, I feel very much like the hunter described by John Daley a few years ago, who suddenly found himself confronted by a very vicious lion in the jungles of Africa. He was so startled when this lion made an appearance that he immediately dropped his weapon. The only thing for him to do then was to resort to prayer. He dropped to his knees and started praying. When he opened his eyes, he saw the lion also was on his knees. He said, "Are you praying too?" The lion said, "Oh no, I'm just saying grace." I feel very much like that hunter. I hope that you are all saying grace.

The Symposium will be conducted on a very punctual time schedule. The sessions will open promptly. The only single session involved will be the one this morning and the one on Friday afternoon. During the interim, we will have simultaneous sessions. These will be conducted by the chairmen designated for each of these sessions. Speaking for those chairmen, I urge you to be prompt at these sessions as shown in your program.

I think today we are very fortunate in having as our keynote speaker for the Operations Research Symposium a man who, I'm sure, needs no introduction to most of you here. For those of you who have been in R&D work, I know that you have, at one time or another, come in contact with or come under the influence of this speaker. He has spent most of his time since 1945 in Research and Development activities. Since 1952, each of his assignments has been in the Research and Development area. He is a graduate of my alma mater, the United States Military Academy, Class of 1934. He received his Master's Degree in Civil Engineering from MIT in 1938. In 1949 he was assigned to the Research and Development section of G-4 in Washington, and then he was with the Research and Development Board from 1950-1952. In 1961, he was assigned to duty with AEC, and since 1964 has been the Chief of Research and Development, U.S. Army. It is certainly a privilege and a pleasure for me to present to you Lieutenant General Austin W. Betts.

OPENING ADDRESS

Lieutenant General Austin W. Betts
Chief of Research and Development

Today I would like to say a few words about the management of Research and Development, and the part that Operations Research should play in that management process. I am sure I do not need to tell this audience the importance of Operations Research today in system development programs. The business of study and analysis is a way of life; in fact, in my judgment, we fall far short in the amount of study and analysis we really ought to do. Of the many problems inherent in managing Research and Development, two are particularly relevant to this discussion.

First, R&D by its very nature, must deal to some extent in unknowns. And second, the very large commitment of resources to military R&D is something, in the big picture, relatively new. Consequently, we really don't have the depth of experience in this field that the situation demands. The military services, as users of the lion's share of the national R&D dollar, are well aware of these difficulties. We are also aware that solutions don't come cheap. In the Army, we've recently completed a very extensive analysis of our R&D management problems that has shed some light on this subject. I would like to take this opportunity to report to you on a planned organizational change that grew out of the studies that were made. We have discovered no Panacea, but I am sure the steps that we propose will improve the situation. But first, I will give you a little history to illustrate the sort of difficulties we hope to correct: Now very long ago, July, 1965, to be precise, the Army cancelled a major development program, the Surface to Air Missile Defense System, the Mauler. That was to be a field Army Air Defense guided missile system. I assure you, it was a traumatic experience, one the Army won't forget for a long, long time. Some $200 million dollars worth, as a matter of fact. Though it was not the first major development program to be cancelled nor will it be the last, it was certainly the most costly of any in which the Army has been directly involved, and surely it is important we learn what lessons we can from this experience. Now, the original concept of Mauler was simple and quite straightforward. The idea was to take the components of the very effective HAWK Air Defense Missile System and by making them smaller, by sacrificing something in the range, that one would require for this system, one could package a whole new air defense system on one tracked vehicle. The concept was simple, but the execution was complex. We learned the hard way that technical feasibility cannot be taken for granted. We ran into very difficult technical problems that stretched out the development cycle and resulted in greatly increased costs. Furthermore, and perhaps this is the most important factor, the slippage in the schedule tended to undermine the user's confidence in the development team. When the ultimate user, the Field Army, came to understand the full impact of the cost of Mauler as well as its complexity and the difficult maintenance problems that would be involved, it was decided to stop the development. The question is, could we have foreseen this before we made a firm commitment to Systems Development? Perhaps not, but I think we could. The Army's decision to create a new organization is a major move to avoid similar problems in the future. We think the changes will result in considerable improvement in our way of doing business in R&D.

If you will recall, prior to World War II, we really did not do very much R&D. We bought items pretty much off the shelf. And that seemed to satisfy our immediate needs. Three things changed this. The scientific and technological surge in the post World War II era, greater national emphasis on military Research and Development, and the soaring costs of new materiel. Not only in production prices, but in R&D costs. We quickly learned we had to do a better job of planning what we needed, not only to determine what we could afford, but to eliminate that which we clearly could not afford. That step is always the tough one. One step toward improving our planning early in this period was the creation of what we chose to call Combat Developments, with which I am sure you are all familiar, just a simple process of determining how the Army should be organized and how it should be equipped and how it should fight. You will recall that that was then the function of Army Field Force Headquarters, and was later changed to Continental Army Command, or CONARC. As part of the major Army reorganization in 1962, the need to elevate this function to a major separate command status was recognized, and we created the Combat Developments Command. And currently we gathered Research and Development, procurement and testing activities into the Army Materiel Command. It was recognized that a collage of advances had overtaken the old idea of division into commodities by technical services such as Ordnance, Signal, Quartermaster, and so forth.

Over the past few years, we have been building and adjusting the interface between the Combat Developments and the laboratories of AMC responsible for materiel development. The goal has been to respond more effectively to the material requirements that have emerged from the studies of the laboratories. We have made considerable progress; however, in this recent organizational study (actually, there were several involved), we recognized that there are some inadequacies in this system. Witness, for example, the fact that in spite of outstanding technical progress that has been made in Ballistic Missile defense technology, we haven't been able to persuade the Secretary of Defense to approve production and deployment of the Ballistic Missile Defense System, the Nike-X. In this case, we have certainly not lacked system analysis-operational effectiveness studies. In fact, more money has been spent in studying this problem than was required to develop the M-16 rifle. The lack of study, therefore, hasn't been a problem. The problem is that we have not been sufficiently persuasive to convince the Secretary that this analysis is sound. I recognize there are many other factors than purely military that go into this equation. It is not a purely technical decision; for example, there are very important Arms Control provisions that have to be taken into account--much more political than military in character. Nevertheless, as has been brought out very clearly in the public statements of both Mr. McNamara and General Wheeler, Chairman of the Joint Chiefs of Staff, there are important fundamental differences of opinion about the potential effectiveness of the deployed Ballistic Missile Defense System. Those differences reflect differences in operations analysis that has been under the office of the Secretary of Defense on one hand and that has been done in the Army on the other. Well, today's forum is no place in which we should debate the specifics of this issue. That is not my intention. I raised it merely as an example of how important it is that we in the Army must have Systems Analysis competence in great depth and at a very high quality level.

Recently, the Chief of Staff of the Army made a decision that I believe will go a long way toward improving the Army's posture in this field of activity. In its simplest terms, that decision said we will take an element of the Combat Developments Command that is concerned with requirements, and we will take the element of the Army Intelligence Community that is concerned with threat analysis, and then we will take a third element, representing the Army Materiel Command that will be concerned with technical feasibility. These three elements will be co-located somewhere in the greater Washington area. By detailed day-to-day interaction among them, we may do a better job of creating new requirements concepts. We intend to call the CDC portion of this the Institute of Land Combat. As a matter of fact, that's already under way in the Army. This unit, we expect, will improve our capability to formulate and evaluate alternative conceptual designs of the Army of the future. From this effort will come the concept of a balanced, unified, combat system. Part of that process is, of course, an analysis of the potential future threat. Under the Assistant Chief of Staff for Intelligence we've created a group that we call the Threat Forecast Group. They will have full access to the entire intelligence community, will also have access to sufficient technological information to make an adequate forecast of what the enemy threat may be over the whole spectrum of military systems that we may face in the future.

The third element in this triple threat team we will call the Army Materiel Concepts Laboratory. It will be the mission of that laboratory to interact with the Threat Forecast Group and the Institute of Land Combat to be sure that the limitations as well as the capabilities of technology are thoroughly understood and form a solid basis for the future Army concept of the growth and the studies of the Army of the future. The objective, then, will be a close, realistic exchange of planning information, resulting in a clearly feasible concept of future land combat. From this, it should be possible to forecast what development programs we need to pursue, in order to support the chosen concept of future operations. Since the end products are to be requirements, it is clear that CDC must assume the leading role in this three-pronged effort. From this effort, CDC will produce Land Combat Systems study, conceptual design in land combat forces for some given period of the future. It is intended that this will replace the current CDC concept study programs that we have called, Army 80, Army 85, and so forth. The new approach will produce a more comprehensive concepts document designed to explore adequately the sort of weapons and equipment our land forces could have at appropriate times in the future. Our present organization has not been able to do this as well as we would like. Adequate technical and analytical capability has not been available in CDC. This is a feature we hope the Institute of Land Combat will correct.

Having created a conceptual design in future land combat forces, our next step will be to draw from the broad organizational and operational concepts justification for specific hardware developments. The chief problem will be to justify adequately the need for a new weapon system, both to ourselves and to the office of the Secretary of Defense. For major systems, OSD requires that certain definite prerequisites be met prior to approval of the program; these are the familiar six prerequisites of contract definition. This organization will pursue the step by step process during the concept formulation phase. This process includes refinement of needs expressed by the user, CDC, and a technical definition of needs available to meet these prerequisites. At the risk of boring those who are thoroughly familiar with this study and the results that came from it, I would like to review the steps that evolved. First, I will review the development. From a background of research and exploratory development, current technology and technological forecasts, the Advance Material Concepts Laboratory will undertake parametric design studies to identify possible technical solutions to the problem of obtaining the desired operational capabilities revealed in the Land Combat studies. The designed studies will establish relationships between cost and performance among the various technical proposals. The user, as represented by the Institute of Land Combat, will analyze these parametric designs and relate possible mission and performance requirements with the very technical approaches that have been proposed by the Army. From this, they will derive the operational missions and performance capabilities that warrant further exploration. The AMC element will then explore in greater detail the specific technological approaches most likely to produce the performance desired. They will estimate the approximate time and cost to develop the probable costs in the production commitment, the probable size, weight, and technical risks, as well as the personnel implications in the materiel items or systems proposed. They will also define the trade-offs involved in the several approaches they study. Their studies will reveal the clear advantages of some selective approach. Now, obviously, the selective technical approach may or may not require advance development effort in order to clarify costs or reduce the risks inherent in some new idea. We assume that the AMC element has adequate answers to feasibility, cost, and performance among various systems considered and operational trade-off evaluations can be made by the Institute of Land Combat. The relationships among the principal performance capabilities and the cost of the competing systems can then be prepared. For example, at this point one might consider range accuracy, payload weight, and operating personnel requirements of competing systems, as for example, missiles versus guns in support of the field Army. These trade-off investigations should then include varying configurations, seeking the best balance among cost, development schedules, human factors, and operational effectiveness. It is a step by step process that we expect will come from this organizational structure. These analyses will be made in the framework of the missions and performance envelopes that the earlier studies have revealed as important.

It should be possible then firmly to identify the best technical approach, the system characteristics, and the logistic support requirements of the selective system. At that stage, we should be ready for engineering rather than further experimental or study effort. In fact, it is our goal to have then in hand all the prerequisites for contract definition as well as the full study justification for going ahead with the development we desire. This whole process sounds a little bit Utopian; perhaps it is. We are fully aware that an organization alone will not solve all our problems. In the first place, it is going to be difficult to find the requisite quality level of officers and civilians to put in this organization. We are well aware that they are in short supply both in the military and in the civilian market. Nevertheless, we are determined to try. In fact, if we had this organization fully staffed and available today, I, for one, would like nothing better than to give it the task of analyzing what the Army should do about night vision devices. At the moment, the technology for making these devices is well in hand. The reports we have had of their effectiveness are very encouraging. The devices themselves are effective even in the limited application which has been possible up to now with first generation devices. With the development of second generation night vision devices underway, the capability that we could give the field Army will undoubtedly be measurably improved. The question is, has the formal doctrine kept up with the hardware developments? As I see the problem, it is that we have not had adequate time and people to thoroughly explore the question of operational employment. For example, it is not clear that we know whether we should have night fighting maneuver battalions and day fighting maneuver battalions so that we can keep pressure on the enemy around the clock, or whether we should just furnish all units night vision devices and then just use them if the operational situation demands. Obviously, this is a matter for study from the point of view of the operational concept, not the hardware. Yet, just as clearly, the study must be done in the context of a competent prediction as to just what kind of equipment can be made available in a reasonable time frame.

There is another problem coming up that might be tackled: and that is that of the antitank weapons. Technology today is at a point that semi-active and passive seeking antitank missiles are clearly feasible. Either promises considerable improvement over the antitank weapons now available and those in development. Presumably, we could go into their development, but that is pretty expensive. As a matter of fact, the fiscal year '68 budget as now seen does not have adequate funds to pursue this program the way it should be pursued. We really ought to be smart enough to do operational concept studies that would help us choose between semi-active and passive seeking approaches. I am sure that there are a host of other questions or systems to which we need similar answers from operations analysis. With the fact of the exploring of technology staring us in the face, it is clear that we will never run out of things that we would like to do that need study and analysis to help us in the decision process. Operations analysts in military services, in my judgment, have never faced a greater challenge. Even with a multi-billion dollar budget available in R,D, T, and E, we can't afford to develop everything we would like to have. We have recently been reviewing the projection of fiscal '69 budget. I predict that if we are held to the kind of budget guidance that we are given reason to expect we will receive from OSD, we will fall some 300 to 400 million dollars short of the hard requirements we see in the Army R&D budget, and so we have to be selective. Operations analysis will have to play one of the most important roles in this whole work. Good luck.

Dr. Hugh Cole
Research Analysis Corporation
Session II

Ladies and Gentlemen: To put the record straight, my name is Cole and I come from the Research Analysis Corporation. Today we are going to discuss in a rather informal manner the problems of the management of Operations Research and Systems Analysis. The Army now, as contrasted with a very few years ago, has put so much effort in these fields that the problems of management are far beyond the concern of the project officer and the contract officer. Today, the three speakers have been selected to represent three different aspects of the management end of Operations Research/Systems Analysis. One will represent that portion of such research that is by the Army and for the Army. The second will represent the point of view of the management done by contract for the Army in the field of Operations Research. But in all of this work, the problem of managing research in terms of the future environment is extremely important, the future environment many, many years hence. Our third speaker will address this problem of the environment in which Operations Research decisions will function in a very major field as far as the Army is concerned, the field of transportation. These gentlemen will direct themselves to questions of various sorts which bother and perplex us all.

These gentlemen will also talk to you about the problems of communication and misunderstandings; communication with the people who work under your direction and your communication with the decision makers whom you inform of your research findings. These gentlemen will also address you from the point of view of Operations Research/Systems Analysis, a really flourishing profession, broad enough in scope that it requires management, good management.

In order to devote the greatest possible time to the question period, we will not introduce these gentlemen separately, they will follow one another as seen here on the program. You will notice that in order to avoid squabbles about rank between military and civilians, this is an alphabetical listing. Brigadier General Clement, Director of Personnel Studies and Research, DCSPER, is known to many of you. He is presently concerned with the management and direction in the military of Operations Research/Systems Analysis, applied to problems related to personnel. A graduate of the US Military Academy, he has, as you will note, the Distinguished Service Cross, won during the Second World War. He is a gentleman with whom I think many of you may have done business at a time when he spent four years at the Operations Research Office, where he was a project leader on some of the most important military studies that ORO ever undertook.

Dr. Schorr, known to many of you, is President of Technical Operations, Inc. He has a PhD from Yale; early in his career he was a ballistics expert. He has undertaken work in Operations Research for all of the armed services. He has actually administered, personally or through his company, major contract efforts at CDEC, at Fort Belvoir, and at Fort Ord. He is presently involved in many areas of Operations Research. He is, as are all of these three men, a director personally of research in this area.

Mr. Foster Weldon, I must explain, does not represent the Sales Department of the Ford Motor Company. He is, rather, the Manager of the Transportation Sciences Department. Mr. Weldon graduated from the University of Minnesota and was one of the earliest men in military Operations Research, particularly participating in a very important application of this then new science in the Korean War. He spent a number of years at ORO and then went to the Matson Navigation Company, where he set up their Operations Research Department, and where he applied in industry a number of the techniques he had developed in the course of a long association with the military. Following his job as Vice President of Matson Navigation Company, he became the head of a new department at Ford Motor Company. This department has as its objective to look to the future and attempt to predict, using such techniques as may be available, what the future of transportation throughout the world, in all forms, will be many years hence.

These gentlemen will, without further introduction, succeed one another here as indicated on your program.

AN APPROACH TO A PERSONNEL STUDY PROGRAM

Brigadier General W. L. Clement
Office, Deputy Chief of Staff for Personnel

The Directorate of Personnel Studies and Research, established in ODCSPER a year ago, was charged with the broad mission of developing personnel research requirements and conducting and coordinating long-range studies in the personnel area. Our approach to this problem may be of interest to those engaged in managing or conducting operations research efforts for the Army.

1. Total System (Chart 1).

Describe in terms of output (forces), input (human resources), operation (personnel functions), controls and feedback. Will deal principally with output, operations, and time, as a control feature.

2. Force Development (Chart 2).

Describe in terms of concept, doctrine, materiel, organization and evaluation. Although geared to the field Army, it also applies to the total Army, or to major weapons systems. Elaborate.

3. Personnel Functions (Chart 3).

Describe briefly procurement, training and education, distribution, sustainment, separation and management. DCSPER organization to handle these functions.

4. The Time Factor (Chart 4).

Briefly touch on the Army plans system, a primary control mechanism.

5. Personnel-Development-Time Matrix (Chart 5).

Personnel aspects of force development over time. Now the matrix is completed -- good or bad. We are heavily engaged in the short-range to correct current deficiencies. But we must project to mid and long-range to effect changes -- so that the now grid doesn't become a constant. Therefore, the Directorate of Personnel Studies and Research, long-range studies and research.

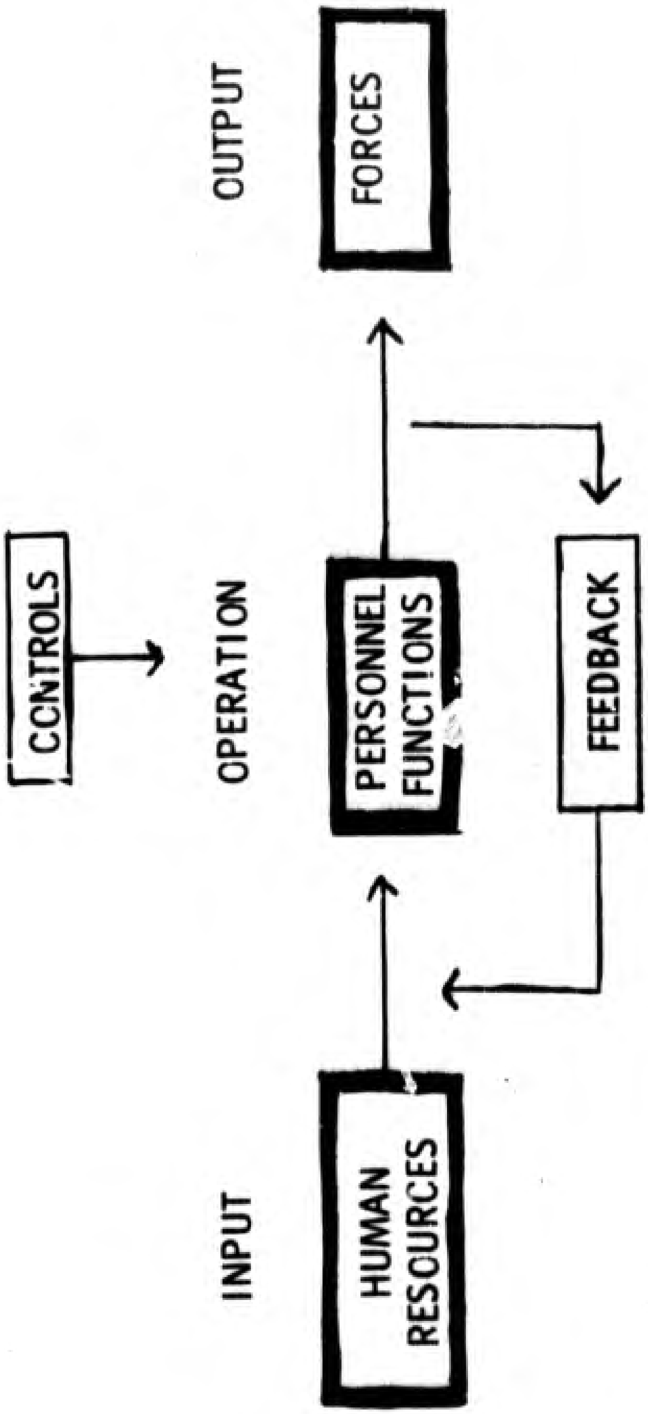
6. Managing the Functions (Chart 6).

Have established the total system, and having related personnel to force development, now let's examine management of the personnel operation itself.

Define management (Chart 7). Discuss the matrix, managing the personnel functions. Give examples: Enlisted Grade Study, Army 75, Motivation.

7. <u>Summary (Chart 1).</u>

Have outlined the personnel system in terms of total force development. Have related personnel functions to the force, and have discussed briefly the management of these functions, as a framework for a broad study and research program in this field.



THE PERSONNEL SYSTEM

Chart #1

FORCE DEVELOPMENT

CONCEPT

DOCTRINE

MATERIEL

ORGANIZATION

EVALUATION
Highly aggregated

Analysis of: Kinds of war
Functions (FP, Mob, C^3, Int, Log)

Applies to weapons systems also

Chart #2

DCSPER FUNCTIONS

* PROCURE
* TRAIN
* DISTRIBUTE
* SUSTAIN
* SEPARATE
* MANAGE

Chart #3

TIME FACTOR

Long range

Mid range

Short range

Now

Chart #4

PERSONNEL - DEVELOPMENT - TIME MATRIX

PERSONNEL FUNCTIONS

Manage
Separate
Sustain
Distribute
Train
Procure

TIME

Long
Mid
Short

Concepts
Doctrine
Materiel
Organization
Evaluation

FORCE DEVELOPMENT

Chart #5

MANAGEMENT OF THE OPERATION

PLAN

- Goals
- Objectives
- Policies

ORGANIZE

DIRECT

CONTROL

- Coordinate
- Program/budget
- Evaluate

Chart #6

MANAGEMENT OF FUNCTIONS

	Procure	Train	Distribute	Sustain	Separate	Manage
Plan						
Organize						
Direct						
Control						

DCSPER FUNCTIONS

Chart #7

Marvin Schorr
Technical Operations, Inc.

"MANAGING OR"

Abstract: A manager of large military oriented OR/SA groups must come to terms with the often divergent professional requirements of his client and his OR group. This problem affects both the internal and external affairs of the group and should be acknowledged and recognized in recruiting, training, problem definition and result communication.

Gentlemen:

The title of our session is "Managing OR Efforts". In view of the audience and my own experience in these matters my remarks will be limited to managing large military oriented OR efforts and particularly those involving close interaction with the customers' problems. Some of these remarks will apply equally well to commercially oriented OR efforts but I will not elaborate on the differences or similarites.

For discussion I'd like to break the managing problem into two artificial segments: one dealing with the internal problems of the group such as recruiting and retaining talented workers, training them in new skills and in new environments; and the other dealing with matters which require close communication with the customer, such as problem definition, establishment of reasonable goals, and the communication of results.

Fundamental to an understanding of either area is the frank recognition of two major realities in this type of work. One is the existence of the "two culture" problem in the C. P. Snow sense. In this case the two cultures are the professional soldier/officer and the professional scientist/analyst/technician with the important differences in the training, inclinations, aims and aspirations, value systems, reward and incentive structures between the two professions, as there should and must be. The second is the existence within OR itself of a dichotomy between the need to be involved in real, complex problems and yet somehow not get too involved and thereby acquire all the problems of the operating manager. In my experience the unhappiest and least productive OR groups are those where they and their customer do not recognize or refuse to acknowledge these problems and hope they will go away by being ignored.

These problems are normal, are natural, are there. They usually cannot be avoided, or "solved" or eliminated. As a result perhaps the key problem of a manager of such groups is to find a way to harmonize and rationalize the disparate relationships between the cultures and within the OR group itself.

A large part of both problems derives from the very nature of OR itself. In most professions there tends to be a separation between the creative members who formulate the new theories and develop the new skills and the practicioner who applies these skills. But in classical OR work such a separation is neither condoned nor productive except in a very narrow sense. The very process of taking a complex real world problem, distilling the essence from it, constructing a model subject to meaningful manipulation and analysis, and drawing new and revealing information from it is a sort of creative act in itself--almost if you will in the sense that a painter can look at an extremely detailed landscape and in a comparatively few strokes of his brush produce a canvas which conveys the essence of the real scene.

However, the painter has one very great advantage--his finished canvas does not have to be closely representational of real life as a camera would see it. (And at least to this layman there seems to be an inverse relationship between how closely he represents the real physical world and the value of the picture). Not so the OR man--he must not only "create" but his creation must meet the rigorous test of real world applicability. Therein lies the dichotomy of the profession--the simultaneous involvement in a creative act, model building, and the pragmatic compromises necessary in real world problem solving.

The creative role in OR leads to two other problems. It is well known that creative artists, actors, and musicians are a little bit odd, unconventional, unreliable, messianic. What is perhaps less well appreciated is that creative anythings are a little of all these unpleasant things too--even physicists, engineers, mathematicians, TV producers, marketing men and, yes, even soldiers. Without belaboring the point I simply ask you to accept the wealth of data which supports the precept that molding creativity does tend to destroy it and to recognize that if one wants important new insight into old operating problems one must simply put up with a certain amount of undisciplined behavior.

The second unpleasant fact about creativity seems to be that in technology the most creative years occur in the middle twenties and early thirties at the latest, and with rare exception its down hill from there. On the other hand the skills of an operating man tend to increase with age, at least well into the fifties. Thus the ideal OR team consists of young, brash, free-wheeling creative people working with and for a group of older, mature, experienced operating managers. A great theory and highly desirable--but truly a psychological nightmare. To further compound the difficulty the customers are usually operating people in whom experience and judgement are highly prized, and hence tend to be more mature and conservative (in the good sense of the word) than the average OR man working on his problem.

In view of these basic problems how do we ever get anything useful accomplished? The essence of managerial skill in our large OR groups is the balancing of these diverse factors to provide an adequate level of creativity, maturity and realism within the organization and at the same time constantly striving to encourage the customer in a sympathetic understanding of the necessary environment, and the types of problems, under which OR can be productive.

This process should start with the frank recognition by the professional ORers that a great deal of what gets done in large military oriented OR groups is not really OR in the scientific sense, but down to earth practical problem solving using any tool we can lay our hands on. In many cases the studies have "short fuzes" and it is impossible to bring new thinking, or much analytical thinking of any kind, to the problems. It would be irresponsible to walk away from such jobs on the basis that its not OR. Someone is going to make a decision partly based on this short study and he deserves the best analysis he can get even if its far from what could be done with a lot more time. In such a situation the premium is on informed intuition usually based on relevant experience rather than on brilliant deductive reasoning.

Consideration of this fact should show up right at the recruiting stage where 5 or 10 or 15 mature problem solvers and non-creative professionals are needed for every good creative one. A certain maturity is important (and not just in years) in this work just so that a recruit can really recognize the demands of the situation and is willing to accept the environment. Fortunately it is an environment which most of us here know can be an exhilarating and satisfying one because of its very involvement with real problems and decisions.

But the training of new men must recognize these problems. In addition to the usual technical skill development which continues through life and nurtures any professional field we must provide the coupling into the complexities of the real world which is the essence of OR. Our greener conferes must be exposed to customers and their problems in order to ripen. This implies a certain preference for the mother-hen approach on the part of good OR managers rather than a sink-or-swim approach useful in other environments. Sinking, even on a relatively small problem, usually takes a good deal of carefully nurtured customer good will with it even under the best circumstances.

The good manager also has an obligation to his professional staff to see, by hook or by crook, that they can have the time to keep their professional skills well honed. This often requires a certain amount of ingenuity. In some environments it is literally impossible. Where this is so it may be better to acknowledge it and adopt the military practice of tours-of-duty by rotating men through the organization both to bring in new skills and ideas and to provide a more fertile new environment for the departee. Managers who don't do this consciously often wind up with a high turnover rate and wonder why. The customer must of course recognize that planned rotation in such an environment is infinitely more preferable than the unplanned.

The training function must also seek to help men understand the importance of setting attainable goals in each project. One small problem solved is worth a large number of half-solved large problems. The tendency to bite off too much must be resisted. This is another area where there are few rules and experience is the best teacher.

In problem definition and goal setting we get into that other basic problem area that I called the two culture problem. It seems axiomatic that problem definition in both context and scope must be jointly established by the client operating man, in our case usually military, and the OR manager. This in turn implies that a meaningful dialogue must develop between the client and the ORer. The customer must appreciate the real world environment necessary to the application of OR/SA techniques, and its limitations, as thoroughly as the ORer must understand the real world problem of his customer. The OR managers objective here is not to discuss, not to propose, not to suggest, not to sell--but to communicate. Inability to do so leads to great frustration and loss of confidence on both sides and serious reduction in productivity of the group.

The same problem arises in communicating results. Again the key word is communicate--not report, not brief. The job is not finished until the result is understood by the client in a form that permits him to utilize it.

These then are I think the most important problems of our larger group OR Manager and hence the areas in which he should spend most of his personal time and energy. The rewards attendant to even small successes are usually immediately apparent in the increased productivity, satisfaction and moral of both the ORers and the customer. Failure to adequately assess the importance of these areas and to act on them can and has led to the most unpleasant consequences.

The remarks of Mr. Foster Weldon, Manager, Transportation Sciences Division, Ford Motor Company, were not available at the time these Proceedings went to press.

Research Planning and Resource Allocation

Burton V. Dean

Case Institute of Technology

A paper presented at the Sixth Annual U.S. Army Operations Research Symposium, Durham, North Carolina, May 24-26, 1967.

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RESEARCH PLANNING AND RESOURCE ALLOCATION

Burton V. Dean

Abstract

This paper is concerned with the development of mathematical models, computer programs, and data requirements to conduct development systems planning in large Research and Development organizations.

The specific planning decision problems are (1) the selection of technical alternatives, (2) the funding of system components, and (3) the funding of systems. Mathematical models have been constructed which relate decision variables to organizational objectives. Cost-effectiveness relationships are developed. A manual is available for use in the training of planners in the utilization of computer results. Tests have been conducted incorporating simulated cost, risk, and value data.

Introduction

Case Institute of Technology is conducting a study of large scale Research and Development (R and D) planning and decision making. The complex problems of R and D planning and decision making require the development of quantitative methods. The principal uses of these methods are to consider the effects of different decisions on organizational objectives and to determine the optimal courses of action under constrained resource conditions.

The R and D decision problems of concern in this study are technical approach selection, component development funding, and system planning. Mathematical models, computer programs, and available information concerning costs, uncertainties, and values provide quantitatively based solutions to decision problems. The mathematical model is the basic tool, used to translate organizational objectives, technical approaches, and resource constraint statements into computer programs and cost effectiveness analyses.

Since R and D planning requires the evaluation of future alternative courses of action, uncertainty is an important aspect of R and D planning. Removal of this uncertainty would result in a considerable loss in the potential for future system development. The Case study utilizes the available information on uncertainty in achieving technical alternatives or approaches, and develops a systematic procedure for dealing with this uncertainty.

Large organizational R and D planning requires the investigation of many approaches. For example, there are 2^n possible courses of action on funding in the case of go-no-go decisions involving n technical alternatives. The Case study has developed mathematical models for handling the large number of alternatives through the use of a series of simple computerized methods, where the results of one stage are used in the succeeeding stage.

It is expected that any systematic quantitative procedure ought to be adaptable to considering different organizational objectives and to be capable of investigating different decision criteria. The Case study methods are capable of being applied to different objectives and criteria, where the output solutions that are optimal for each objective can be analyzed by R and D planners.

R and D Decision Problems

The R and D decision problems of concern in this study are as follows:

(1) Technical Approach Selection

What technical approaches ought to be followed for different amounts of funds, and what is the effect of different funding levels on the probability of achieving a system component concept?

(2) System Component Funding

For a range of potentially available funds for system development, how should the system componets be funded, so as to maximize the probability of achieving the system?

(3) System Planning

For a range of potential budgets to be allocated to a set of systems, how should the systems be funded, so as to maximize the total expected value (or other decision criteria)?

For study purposes, a system can be represented as the end result in a network of tasks leading to the solution of R and D problems and the development of system components.

We say that a system is composed of several system components in the form of "Materiel Concepts." In order for a system to be achieved, all necessary materiel concepts must be achieved. Considered, for example, a system which represents a new anti-ICBM missile. In this case, the essential components for this missile system would be a guidance system, a warhead, including fuzing, a propulsion system, and a structure for the missile (Figure 1). If the system is to have a new or extended capability, perhaps all or several of the components must develop new capability over existing components. All components are essential to the development of the anti-ICBM missile system.

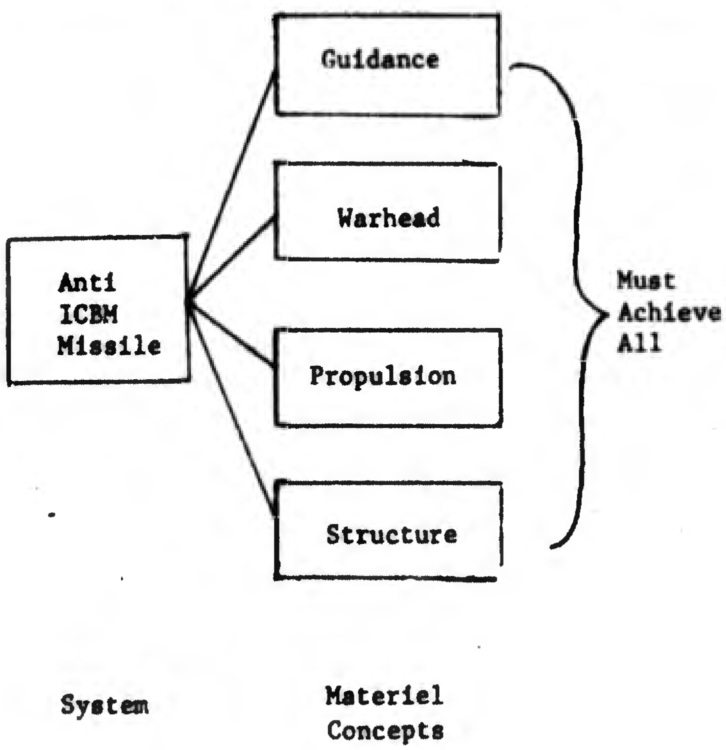


Figure 1. The Relationship between the System and its Material Concepts.

In this example, suppose that there are requirements for a new guidance system, and that there are several possible technical approaches which may be followed in order to achieve the required guidance capability (see Figure 2). Clearly, even if only one of these several technical approaches is successful, then the materiel component capability has been achieved. At least one of the several possible approaches must succeed.

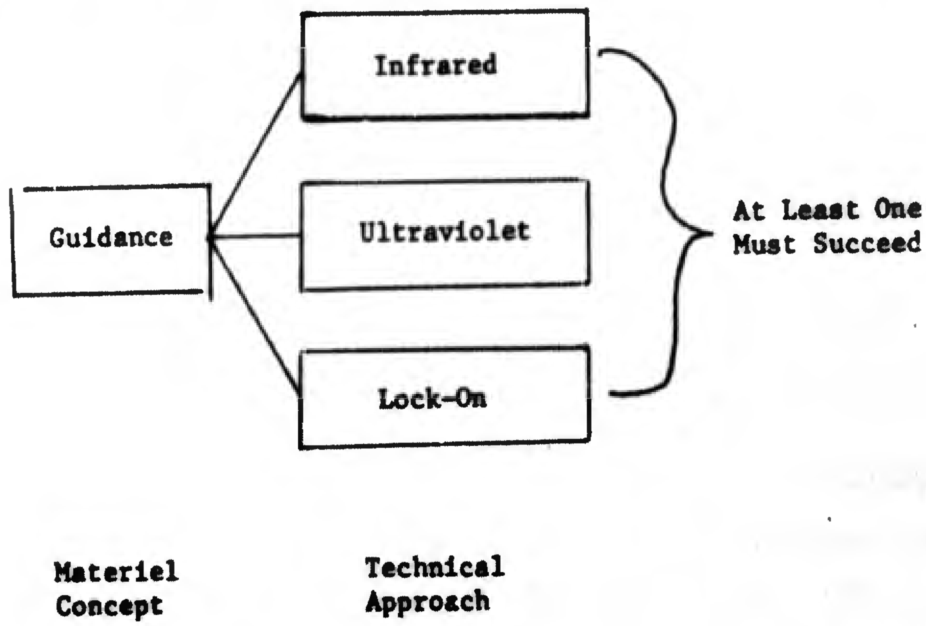


Figure 2. The Relationship between a Materiel Concept and its Alternative Technical Approaches.

The Structure of the Decision Models

As a basic part of the Case study, the underlying structure for decision making must be carefully developed. In each of the following statements the structure of the decision problem is briefly described.

(1) Technical Approach Selection

A set of alternative technical approaches may be funded, where it is assumed that a forecast of the chance of success and the estimated cost are known. The purpose of a member of this set of approaches is to achieve a component concept, where any one of the possible parallel approaches, if successful, will satisfy the requirements for the component concept. A number of parallel approaches may be funded. The problem is to select the optimal set of technical approaches that maximize the probability of achieving the component concept, parametrized for a range of possible funding levels.

(2) System Component Funding

For a specified system and associated set of system components, the problem is to determine the optimal funding levels for each system component development so that the probability of achieving the system is maximized. This is to be answered for a range of available budgets.

(3) System Planning

Consider that a large number of systems are to be funded, where the systems have corresponding values or priorities. In each case the systems have associated components and technical approaches. The problem is to determine the optimal allocation of funds to the systems so as to maximize a stated organizational criteria of effectiveness, such as total value or proability of achieving all systems. A range of total available funds is to be investigated.

(3) Cost-Effectiveness Analysis

In each of the three basic problems descrived in (1)-(3), the outputs (effectiveness) are related to inputs (cost). In each case the planner is able to relate the cost of system or component funding to value or probability of success. The cost-effectiveness relationship may be used to determine the proper organizational budget.

Optimization Criteria

To develop a mathematic model and corresponding computer programs it is necessary to consider specific organizational criteria. The Case study has not been concerned with the development of these criteria, but rather with the formulation of the models and programs that incorporate the criteria. Our concern has not been with a critique of these criteria, but rather with the development of methods that enable the planner to synthesize the large amounts of available information so that alternative criteria may be examined. In each case of the cases, a cost-effectiveness relationship has been developed for the specific criteria.

The criteria that have been used in the Case study are:

(1) Minimize expected cost to achieve a technical approach.

(2) Maximize the probability of achieving a system component for a specified cost.

(3) Maximize the probality of achieving a system for a specified cost.

(4) Maximize total expected value for a specified cost, with

(i) no priority on systems,

(ii) priority on certain systems to be funded at maximum effort, or

(iii) all systems to be funded.

(5) Maximize proability of achieving all systems with

(i) no priorities on systems, or

(ii) priority on certain systems to be funded at maximum effort.

Mathematical Methods

The application of operations research is to develop decision models and solutions to the problems that are parameterized by the dollar amounts to be made available. In this way it is possible to construct a cost-effectiveness approach to research planning which presents a relationship between the amount allocated to R and D and the maximum expected value to be achieved.

The basic method that is proposed for use in research planning is dynamic programming. Dynamic programming is a mathematical method for determining the optimal allocation of resources to activities so as to best achieve an organizational objective. For example, if an organization is engaged in a number of tasks, and can estimate the expected costs and benefits of each task, then dynamic programming may be used to find the optimal amount to allocate to each task so as to maximize the performance of the organization. In non-technical terms, this is accomplished by solving a number of one-dimensional decision problems, instead of the many-dimensional allocation problem as originally formulated. Since planning involves the allocation of resources to activities, it may be observed that dynamic programming is a useful planning tool. In particular, the measures of performance of alternate plans that correspond to different budget levels are obtained as a direct result of the dynamic programming solution. Because dynamic programming is an iterative method it is capable of being easily converted into a computer program. Dynamic programming is utilized in the solution of the decision problems (1)-(3). The outcome of the computer programs, which incorporate dynamic programming models, are cost-effectiveness relationships.

The Mathematical Models

(1) Optimal Selection of Technical Approaches (Model T)

For a specified materiel concept we define

P_i -- the probability that the i^{th} technical approach is successful, if it is selected for funding,

C_i -- the estimated cost of funding the i^{th} technical approach, if it is selected for funding, and

$f_i(C)$ -- the maximum probability of accomplishing the materiel concept, choosing an optimal set of the first i technical approaches, with C dollars available to allocate across the technical approaches in a materiel concept.

Then underlying assumption is th only one of several parallel technical approaches need be successful for attainment of the materiel concept.

Then

$$f_1(C) = \begin{cases} P_1, & \text{if } C_1 \leq C \\ 0, & \text{if } C_1 > C \end{cases}$$

$$f_2(C) = \begin{cases} \mathrm{MAX}[1 - (1-P_2)(1-f_1(C-C_2)),\ f_1(C)], & \text{if } C_2 \leq C \\ f_1(C), & \text{if } C_2 > C \end{cases}$$

and, in general,

$$f_N(C) = \begin{cases} \mathrm{MAX}[1 - (1-P_N)(1-f_{N-1}(C-C_N)),\ f_{N-1}(C)], & \text{if } C_N \leq C \\ f_{N-1}(C), & \text{if } C_N > C \end{cases}$$

(2) Optimal Funding of Materiel Concepts (Model M)

For a specified QMDO comprised of j materiel concepts, the solution of Model T yields probabilities $P_j(C)$, the maximum probability of achieving the j^{th} materiel concept if C dollars are allocated to it. Furthermore, tnis optimal solution for all increments of C dollars is derived by noting the choice (yes or no) in the maximizing criteria at each step. Considering an amount to be allocated to a QMDO. The decision problem is to find how much to allocated to each materiel concept within the given QMDO.

Define

$F_i(C)$ = the maximum probability of achieving materiel concepts 1,2,...,i.

The underlying assumption is that each materiel concept must be successful before the QMDO is achieved.

Then

$$F_1(C) = R_1(C)$$

$$F_2(C) = \max_{0 \leq x \leq C} [R_2(x)\ F_1(C-x)],$$

and ingeneral,

$$F_M(C) = \max_{0 \leq x \leq C} [R_2(x)\ F_{M-1}(C-x)]$$

(3) Optimal System Funding (Model S)

Now suppose there are W distinct OMDO's to which funds must be allocated. Each OMDO has a military value, or priority, V_i assigned to it which describes its importance relative to the other OMDO's.

The decision problem is to determine how to allocated the total budget, B, so as to maximize the total expected military value,

$\sum_{K=1}^{W} V_K G_K(C_K)$, subject to $\sum_{K=1}^{W} C_K \leq B$, where

$G_K(Y)$ = the maximum probability of attaining OMDO K, with Y dollars to allocate across it. The G_K functions are determined, of course, by Model M.

Let

$H_i(B)$ = the maximum attainable expected military value of OMDO's 1, 2,..., i.

Then

$$H_1(B) = V_1G_1(B),$$

$$H_2(B) = \max_{0 \leq x \leq B} [V_2G_2(x) + H_1(B - x)], \text{ and}$$

in general

$$H_W(B) = \max_{0 \leq x \leq B} [V_WG_W(x) + H_{W-1}(B - x)]$$

Simulation

Data Requirements. The models require specific data for selection purposes. These requirements are

(i) the System - Materiel Concept - Technical Approach descriptions,

(ii) estimates of probability of success for each potential technical approach, and

(iii) estimates of expected cost during the planning period for each technical approach.

(iv) assignments of user military value or priority systems

The Military Value Concept. Although all systems are assigned a priority level which describes their military importance, it is necessary to derive a numerical value for this rating in order to maximize total expected military value. In this case, all systems are assigned a relative military value, with the range of the scale of values and the actual values to be determined by the planner. It is possible to vary the numerical military values, in order to test for the sensitivity of decisions on estimates of military values.

The AMC Data. In order to test the efficiency of methods and sensitivity of solutions developed by the Case mathematical models, AMC provided input data.

Specifically, 18 simulated materiels systems were selected and coded, and for each of the 18 systems, a QMDO plan was simulated which consisted of the following:

(i) planning networks including the technical approach level.

(ii) estimated annual R and D cost for each technical approach and the and the laboratory where the work would be performed.

(iii) three sets of military values, each set of values being arrived at by means of a different order ranking technique based on estimates of future strategic needs.

The order randing values given by AMC are displayed in Table 1.

Table 1 Order Ranking Value Assigned by AMC

System	Code	First Technique (*)	Second Technique (*)	Third Technique (*)	Priority Class (CDC(*)
1	A	10.00	9.65	1.90	1
2	B	9.00	8.20	10.00	1
3	C	9.75	6.40	9.00	1
4	D	8.95	4.60	5.30	1
5	E	8.65	2.80	3.35	1
6	F	8.35	2.60	5.90	1
7	GAC	7.25	8.00	7.75	2
8	GA	6.95	7.50	7.35	2
9	GB	6.95	7.50	7.35	2
10	GC	6.95	7.50	7.35	2
11	H	4.45	6.40	9.75	2
12	I	5.85	10.00	8.60	2
13	J	5.85	9.85	1.00	2
14	K	3.95	2.05	2.65	2
15	M	3.10	6.60	8.20	3
16	N	2.55	4.80	9.35	3
17	O	1.70	4.05	4.70	3
18	P	1.00	1.00	4.10	3

* Estimated by AMC

** CDC - Combat Development Command

Table 2. Description of Optimization Criteria

A	Run I	maximize expected military value using first order ranking technique
A	Run II	maximize expected military value using second order ranking technique
B	Run III	fund all priority class 1 systems at maximum level; maximize expected military value of remaining systems using first order ranking technique
B	Run IV	fund all priority class 1 systems at maximum level; maximize expected military value of remaining systems using second order ranking technique
C	Run V	maximize expected military value using first order ranking technique, under constraint that all systems must be funded at a level to give them a positive (non-zero) probability of attainment.
C	Run VI	maximize expected military value using second order ranking technique, under constraint that all systems must be funded at a level to give them a positive (non-zero) probability of attainment.
D	Run VII	fund all priority class 1 systems at maximum level; find allocation across remaining systems which maximize the probability of achieving all of them
E	Run VIII	maximize the probability of achieving all systems
A	Run IX	maximize expected military value using third order ranking technique.

Optimization Criteria. At the outset, AMC asked for optimal solutions to the problem "maximize expected military value," and provided two order-rankings for the eighteen systems. When the solutions were developed, there were some unexpected results -- under both order-ranking techniques, there were several systems which were not funded in the optimal solutions for the budgets rated high, average, and low by AMC.

When these results were presented, it was decided that perhaps the decision criterion used was not entirely suitable, and AMC began to suggest new constraints which should be satisfied by any "optimal" solution. One comment was that all systems should have some funding, in order to satisfy user requirement, that all systems receive attention. Another comment pointed out that by allowing "no funding" solutions, continuity in research programs could be lost, as an on-going project one year could be dropped the next year, then possibly re-instated later.

Also, it was pointed out that perhaps all priority class I systems should be funded at their maximum level, in order to provide such systems with the best chance of success. In this case, any remaining funds would be allocated across systems in priority classes II and III according to some optimization criterion.

These new decision criteria were programmed and more test runs were made. In all, nine different computer runs have been made for AMC. Descriptions of each of these runs are given in Table 2.

Comparisons of Solutions Generated by Different Optimization Criteria

Table 3 compares the solutions for optimal $14 million allocations for the nine runs made to date. ($14.8 million was required to provide minimum funding in run VII).

Runds I, II, IX are identical except for the military values assigned. Comparison of the optimum allocations given with the military values listed with the AMC data reveals that significant discrepancies usually occur only when there is at least a three-fold difference in the military value weightings given a system.

Table 3. Comparison of Solutions Generated by Different Optimization Criteria in Millions of Dollars

(Budget - $14 million except in VII, where $14.8 million was required)

System	I	II	III	IV	V	VI	VII	VIII	IX
1	1.6	2.4	2.4	2.4	1.6	1.6	2.4	1.0	—
2	1.2	1.2	1.2	1.2	1.0	1.0	1.2	.7	1.2
3	1.3	1.3	1.5	1.5	1.3	1.0	1.5	1.0	1.3
4	1.1	.9	1.1	1.1	.9	.9	1.1	.5	1.1
5	1.5	—	2.3	2.3	.4	.4	2.3	.7	.4
6	.6	—	.8	.8	.6	.3	.8	.6	.8
7	.9	.9	.9	.8	.8	.8	.3	.6	.9
8	.6	.6	.6	.6	.6	.6	.3	.5	.6
9	.5	.5	.5	.5	.5	.5	.2	.5	.5
10	.8	.8	.8	.8	.8	.7	.3	.6	.8
11	1.3	1.3	—	—	1.0	.9	.5	1.1	1.3
12	—	—	—	—	1.5	1.5	1.3	1.9	—
13	1.1	1.2	—	—	.4	.9	.4	1.0	—
14	.4	.4	.6	.4	.4	.4	.4	.4	.6
15	.8	1.3	1.0	1.3	.8	.8	.4	.8	1.3
16	—	—	—	—	.7	.7	.7	1.3	1.8
17	—	.9	—	—	.4	.7	.4	.7	1.1
18	.3	.3	.3	.3	.3	.3	.3	.3	.3
Expected Military Value	35.607	34.112	34.059	30.767	33.469	31.992	(32.3)*	(33.1)*	37.991

*Approximate expected military value, using first order ranking technique, listed for purposes of comparison.

Runs III - VIII are all constrained solutions; however, the Case method permits direct analysis of budgets and values, providing a cost/effectiveness relation to be developed. For example, run V is identical to run I, except that run V does not permit any system to be omitted in funding. The tradeoff for this benefit (funding all systems) is seen to be a drop in expected military value from 35.6 to 33.5, or about a 5.8% loss. The important fact is that the analyst can determine what must be lost in relative military effectiveness for additional organizational constraints that are to be imposed on the solution.

Further Research

This paper would not be complete without a brief indication of the potential and actual limitations in the methods developed-to-date and the need for further research:

(1) The model is dependent on the ability to obtain probability/cost estimates that are sufficient, accurate and consistant.

(2) The solution is sensitive to major differences in opinion as to future values of proposed systems, and is also sensitive to the total range of possible values.

(3) Although, the discretization of cost estimates is somewhat unrealistic, more complex cost-probability functions could be handled if it were possible to obtain such functions from programmers of the technical activities.

(4) Computational times increase exponentally with the number of systems. However, approximations in costing would reduce computational time.

(5) As a result of (4) and since it is quite expensive to perform simulations to estimate the sensitivity of solutions generated, further research is needed to provide analytic forms of solutions.

(6) The consideration of "time to completion" of various technical approaches is not considered in the models. Scheduling problems will be investigated.

Current research is devoted to analyses in (1)-(6) above.

Summary

This paper presents the basic methodology to be used in the solution of decision problems in large R and D organizations where uncertainties in outcomes and values are major factors.

The essential element of a management science is the use of scientific methods and models. Through the use of mathematical models of R and D management decision problems, it is possible to plan and control R and D programs efficiently. Because the models are probilistic in nature, the parameters are subject to errors of estimation. However, computer programs utilizing mathematical models permit the R and D planner to analyze the impact of technical, economic, and political changes and uncertainties on plans and to provide for the effective use of scientists and engineers to meet organizational goals.

This paper presents an integration method for analyzing three basic decision problems involved in research planning.

1. Selection of technical a ernatives (Model T)
2. Funding of material concepts (Model M)
3. Cost allocation across sys*ems (Model S)

The models are sequential in that the results of each decision problem are used in the subsequent decision problem. The solutions are parameterized in that all results are presented in cost-effectiveness form so that the decision maker can select the minimal cost level to achieve necessary effectiveness objectives. In addition, the solutions are adaptive to changes in the values of the model parameters.

To implement and make effective use of the models, data and information on parameter values is required as inputs to the models. However, only limited amounts of data are required for the initial decision problems. Problems (1) and (2) require estimates of the probability of success and costs. However, in addition, military value is required in the case of problem (3). It may be observed that an estimate of military value is not required in order to solve problems (1) and (2).

Computer programs have been developed and applied to the analysis of sample Army Materiel Command (AMC) problems. A small number of simulations have indicated that decisions are not sensitive to variations of parameter values within a range of 2:1 to each parameter. A manual has been developed which describes the procedures to be used by the R and D planner. A technical memorandum has been prepared for distribution, which describes in complete detail the methods and results that have been obtained-to-date. Current research is continuing in extending the methods described in this paper.

A PROPOSED METHODOLOGY FOR MISSION ORIENTED RESOURCE ALLOCATION

HAROLD F. DAVIDSON

ARMY RESEARCH OFFICE

1967 ARMY OPERATIONS RESEARCH SYMPOSIUM

ABSTRACT

1. Purpose. The purpose of this paper is to present a proposed methodology for mission oriented military research and development resource allocation.

2. Methodology:

Dollars for research and development are beginning to plateau and may in the near future dip slightly. Inflationary pressures will make the dip move noticeable; it therefore is incumbent for the research and development community to give its dollars more SENSE and CENTS.

Project TORQUE consists of several basic steps which may be summarized as follows:

Each service defines a set of Operational Capability Objectives. These state what operational functions the Service thinks it will be required to carry out in each of several time frames.

Numerical weights are assigned to these Operational Capability Objectives reflecting the relative importance of each with respect to the other.

Interdisciplinary teams analyze the Operational Capability Objectives to determine ways these requirements can be met and in what time frame.

Technological capabilities sought by the interdisciplinary teams are examined and arranged into single technologies by the technology teams. The single technologies are then arranged in increasing levels of difficulty with funding and time requirements.

The data generated is fed to a computer which is expected to determine the utility of each of several budget levels for the next fiscal year in each technology area.

It should be emphasized that this is purely a tool to supplement and not to supplant management judgment.

I would like to express my personal pleasure at having been given the opportunity of addressing the Sixth Human Operations Research Symposium.

The problems of resource allocation for science and technology in the Department of Defense and for that matter in all large organizations is not new. It has been with us for a long time. The only thing new is an increasing tempo of heavy Congressional, Presidential and public interest and the resultant leveling off and possibly diminishing R&D budget in some areas of governmental support. The latter is something the R&D community has not had to be concerned with since the period between World War II and the Korean War.

R&D dollars, therefore, are going to be more scarce or at least the utility challenged.

Congressional interest in R&D has been quite evident to most of us but the extent is rather amazing. I refer you to a recent congressional committee print title "An Inventory of Congressional Concern with Research and Development" dated December 15, 1966. This publication lists approximately 1650 Congressional documents related to R&D. A most appropriate Congressional comment is taken from the Mahon Committee report on the Department of Defense Appropriations Bill for FY 1966. "The Committee believes that improved management and critical selection procedures such as those which are being applied to complex and costly weapon systems could well and profitably be extended to the supporting efforts included in the "Military Sciences" category. The reductions recommended by the Committee in the various Military Sciences budget activities are primarily based on the conclusion that funds in the area are not presently well managed." I would also refer you to the President's numerous remarks about Federal research, particularly, a recent remark wherein he questioned NIH expenses for research by asking "What are we getting for our money; couldn't the funds be spent more profitably elsewhere?"

So much for history. In response to these environmental factors and additionally motivated by a desire to use the best available management tools the Director of Defense Research and Engineering requested the three Services to aid him in developing a resource planning rationale for Research and Exploratory Development. Two individuals from each of the services were selected as the working party of six. The committee began its chores in October 1966 and submitted to DDR&E approximately five month's later a report consisting of six volumes. The acronym applied to the study was TORQUE, Technology or Research Quantitative Utility Evaluation. (Slide 1).

Now what is TORQUE really and what is it like?

TORQUE is a proposed analytical procedure for achieving balance in the allocation of Exploratory Development and Research funds by answering two questions: (1) what is the total cost and (2) what is the best balanced allocation of these funds? (Slide 2) The basic data for the analyses are provided by the operational judgments and decisions by the Secretariats and Service Chiefs of the Military Departments and by systems and technological analysts, by the military user and by the RDT&E community. If proved by test to be feasible, the technique will provide additional input data to our DoD management judgments and decisions that impact on the Exploratory Development and Research Program.

TORQUE will not replace informed judgments, nor can it operate in the absence of these judgments. The required judgments come from individuals expected to be most knowledgeable, and the conclusions flow from a consistent, objective, analytic process. Each step is fully identified. Any contested conclusion can be examined readily, and corrected if necessary.

In theory, the TORQUE procedure provides an analysis to assist the allocation of Research and Exploratory Development funds. However, the consideration of Research programs must follow a demonstration of the over-all feasibility of the procedure for the Exploratory Development category.

Two general goals can be assigned to the Research and Exploratory Development efforts of the DoD. First, the larger portion of the effort and funds is directed specifically toward generating technology needed for operational objectives. Where R&D effort is motivated by such an end-product application, a more systematic method of relating magnitude of effort to urgency of need would be helpful. Second, some of the effort is, and always should be, expended to seek and capitalize on unexpected developments in science or technology. TORQUE is intended for use in balancing those efforts designed to fulfill the first goal, while placing no arbitrary restrictions on expenditures related to the second goal. Given a constraint on total funds, however, TORQUE will indicate the cost of the more speculative efforts in relation to other, more oriented investigations which might not be funded.

The TORQUE procedure now has certain recognizable deficiencies. The deficiencies will be discussed later in the paper. In the interim we will examine the TORQUE procedure in greater detail.

The Problem

The DoD invests resources in scientific and technical investigations because the Department anticipates a need for the findings of those investigations. The amount of money spent in advancing some area of science or technology should reflect the interest of the Department in that area. Similarly, the relative amounts spent in several areas should reflect the varying degrees of departmental interest among those areas.

Because total resources are limited -- and obviously will never be able to support all potentially useful investigations -- some prospects must be denied. No area of science or technology can be advanced as rapidly as its proponents might desire without affecting other areas. The problem of allocation -- or of achieving "balance" -- becomes a matter of determining how much an additional advance in one field is worth to the DoD, as opposed to an advance in some other field which might be bought with the same money.

TORQUE, in principle, proposes to clarify the matter of "balance" by requiring that the following questions be answered for each area of science or technology:

1. What achievements are desired?

2. What is the relative worth of each?

3. When are the achievements needed?

4. What will each cost?

As indicated previously, the planned feasibility test will consider these questions only in relation to the Exploratory Development (or Technology) category.

When available the answers to these questions will be combined into a quantitative measure of the usefulness of money spent in each area of technology.

This point is worth emphasizing. The method does not measure the importance of an area of science or technology on an all-or-none basis. Instead, it evaluates the relative expected return on investment (of each of several possible budget levels) for that area. Thus, the relative importance attached to a given budget change in one area, compared with the same budget change in another area, can be evaluated.

CONSTRUCTING A UTILITY MEASURE

The most important single feature of the method described in this report is the use of a quantitative evaluation of the importance of each of the various levels of funding in specific areas of science or technology. This importance will hereafter be referred to as the utility of a funding level. The central problem is to define a measure of utility which can be applied to all programs or projects which are in competition with each other for funding. In what follows, the description will be in terms of a utility measure for Exploratory Development efforts. The extension to Research appears to be possible following a similar procedure. In this case instead of Operational Capability Objectives, technology needs for new scientific information will be the starting point.

As a first step in constructing a utility measure each military Service must define a set of Operational Capability Objectives (OCO's). (Slide 3) These state what operational functions the Service thinks it will be required to carry out in each of several time frames. The Service must then assign a set of numerical weights to these Operational Capability Objectives for a given time frame. The numerical weights must reflect the relative importance of the Operational Capability Objectives with respect to each other. A standard procedure, the Churchman-Akoff method has been chosen for assigning weights to objectives. Weights assigned by this method preserve the order of priority and have the additivity property. The process involves a series of comparisons among the Operational Capability Objectives and tentative assignment of numerical weights, followed by consistency checks. The procedure is best illustrated by examples shown in Volume I of TORQUE.

The next step involves analysis of each of the Operational Capability Objectives by an Interdisciplinary Team of users, technologists, intelligence specialists and systems analysts. The task of this team is to determine ways in which the Operational Capability Objective can be carried out in a specific time frame. This will generally involve OCO/technology links such as a weapon system(s), communication system(s), etc. The team must take into account the world situation expected in the time period, and the capabilities the enemy is expected to have during that time. They must then state the level of technological capability required of each subsystem, component and technology required in the system to carry out the Operational Capability Objective. This may be a statement of the strength of a material, range of a radar, accuracy of a guidance system, etc. They must next assign a number representing the criticality of the technological capability to the Operational Capability Objective. (Slide 4) This may range from a low number representing a technological capability which contributes only minimally, to a high number which implies that the Operational Capability Objective cannot be attained without this technological achievement. Finally, the team must assign two dates to each level of technological capability. (Slide 5) The first is the earliest date needed. That is, present equipment, or equipment already scheduled into the inventory is expected to be adequate until that date. The "earliest" date may, of course, be the present. The second is the latest date by which the technological achievement can be available, and still be used with full effectiveness. This may represent a date by which the enemy is expected to have a crude countermeasure, or in some other way the achievement enters obsolescence. (Slide 6)

TIME AND COST

The next step involves collection of the technological capabilities sought, (previously specified by all the Interdisciplinary Teams examining all the Operational Capability Objectives) into packages representing single areas of technology. These packages will hereafter be referred to as technologies. The key points to putting several required achievements into a single technology are: (1) that they represent different Levels of Difficulty (LOD's) of the same technology; and that (2) it be necessary to achieve the easiest as a first step toward achieving the next most difficult. A team of specialists in a given technology is given the set of LOD's pertinent to their technology previously prepared by the Inter-disciplinary Team. The task of the Technology Team is now to put these LOD's in order of increasing difficulty, and estimate the cost of achieving each of the LOD's by the required date given for that LOD by the Inter-disciplinary Team (Slide 7).

BUDGET ALLOCATION

The data provided by the various teams described above is used to determine the utility of each of several budget levels, for the next fiscal year, in each technology area. All calculations are expected to be carried out by a computer. The procedure can be described briefly as follows.

Each LOD has associated with it an Operational Capability Objective weight and a criticality number. Basically, the worth of having achieved an LOD is the proportion of the Operational Capability Objective weight and its criticality. That is, the worth of an LOD is the product:

Weight X Criticality.

Each LOD has a "latest" year associated with it, when it is needed. If the technology leading to this LOD is funded at the level specified by the Technology Team, the LOD will be achieved when needed. However, if the budget is reduced, the achievement date will slip. Thus, the worth of an LOD is reduced, according to a timeliness function. (Slide 5)

Finally, with each LOD there is associated a total cost, including the cost of lower LOD's which have to be achieved first. The current year's budget represents a certain fraction of this total cost. Thus, the worth of an LOD is modified further by this budget fraction.

The utility of a budget level allocated to a technology is the sum of the worths of each of the LOD's in that technology. This utility can be computed separately for several possible budget levels for the current year.

The allocation process involves the comparison of the additional utility purchased by an allocation to one technology, with the additional utility which could be purchased by allocating the same money to some other technology. The computer program is designed to make allocations in such a way as to buy the maximum total utility. It should be noted again that the method described is not capable of being used directly for allocating money between the services or between research and exploratory development.

What we have described then is a brief overview of a potential system for resource allocation by the services. The sequence of actions can be summed up in the following slide (8) which are spelled out in greater detail in four separate volumes. Volume I from which much of the previous material has been taken is an overview of the Methodology. Volume II "Instructions for Deriving and Weighting Operational Capability Objectives" goes into much greater detail as to how this should be done. Similarly, for Volumes III and IV entitled "Instructions for Interdisciplinary Teams" and "Instructions for Technology Teams" respectively.

Like any systems which has bright spots - and we like to think TORQUE has bright spots - there are problem areas too. TORQUE is not a panacea. It does not answer all questions and it raises some. It is a probable step forward but we won't really know until the experimental evaluation is completed about nine months from now. We do know, however, that it does have general shortcomings which have been pointed out to DDR&E. These may be summarized as follows.

(a) The effects of non DOD research and development on the DOD R&D picture are not taken into account. Thus AEC, NSF, NIH, NASA etc. can make significant contributions to the state-of-the-art and this will not be reflected in the TORQUE technique.

(b) The relative cost of doing research and development in different areas of science and technology vary and are not recognized in TORQUE.

(c) The inability to work in some area of science or technology due to lack of qualified personnel or ceiling limitations is not accounted for, nor are:

(d) The problems of technical risk

(e) The problems of one service doing work of benefit to another.

(f) The need for allowing some proposition of the total funds for use in high risk, high-payoff efforts of low apparant relevance which may, however, lead to significantly improved military capability.

These then are some of the recognized shortcomings and we may find more as the experimental implementation proceeds and completes. This does not, of course, mean that the method necessarily has no merit. What it does mean is that we must strive to improve and come up with a really meaningful, useful tool.

In summary then the procedure described above attempts to allocate resources to technology areas on the basis of the importance of advances in each technology to operational capability objectives and at the times when the latter are needed. If this effort proves successful we will then extend the methodology to the science area and we will also obtain the following benefits:

(a) In future years budget we will be able to determine what advances can be had (but not necessarily achieve) for each > or < in the budget in specific areas and the mission or missions it will impact on.

(b) Tie 6.2 (technology) money directly to mission (OCO).

(c) If carried to the next step the experiment will tie 6.1 (science) funds to technology needs.

d) Congressional criticism will be placated.

I would like to again emphasize that TORQUE is not intended to supplant the manager but rather to supplement his intuition and judgment. It is basically, another working tool for management. I think this is most important and this in closing is the most important thought I would like to leave with you.

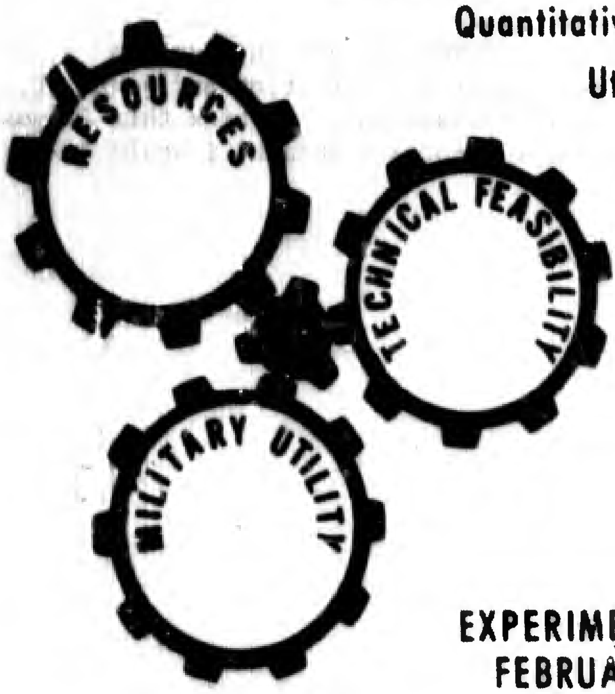
Thank you

Volume I

DISCUSSION OF PROCEDURE

TORQUE

Technology
or
Research
Quantitative
Utility
Evaluation



EXPERIMENTAL TEST
FEBRUARY, 1967

APPENDIX II

CRITICALITY OF A TECHNICAL EFFORT TO A DESIRED OPERATIONAL CAPABILITY OBJECTIVE

(The assumption is that the objective of the technical effort will be accomplished.)

Absolutely Essential

Failure to have this technology will absolutely prevent the attainment of the capability desired...1.0

Major Contribution

Failure to acquire this technology will result in a significant decrease in one or more of the major performance parameters needed to attain the capability desired. Such degradation probably would not prevent a favorable decision for development of equipment for the inventory.........0.7

Cost Reduction

Success in achieving this technology will provide a major reduction in the cost of achieving the capability desired...........................0.5

Substantial Contribution

Failure to achieve this technology will result in the loss of a highly desirable but not essential capability. Such degradation, while important, probably would not prevent a favorable decision on the development of equipment for the inventory to attain the capability desired..0.4

Refinement of Capability

Achievement of this technology will result in some refinement of the present capability. The desired capability, however, could be achieved without this effort...0.3

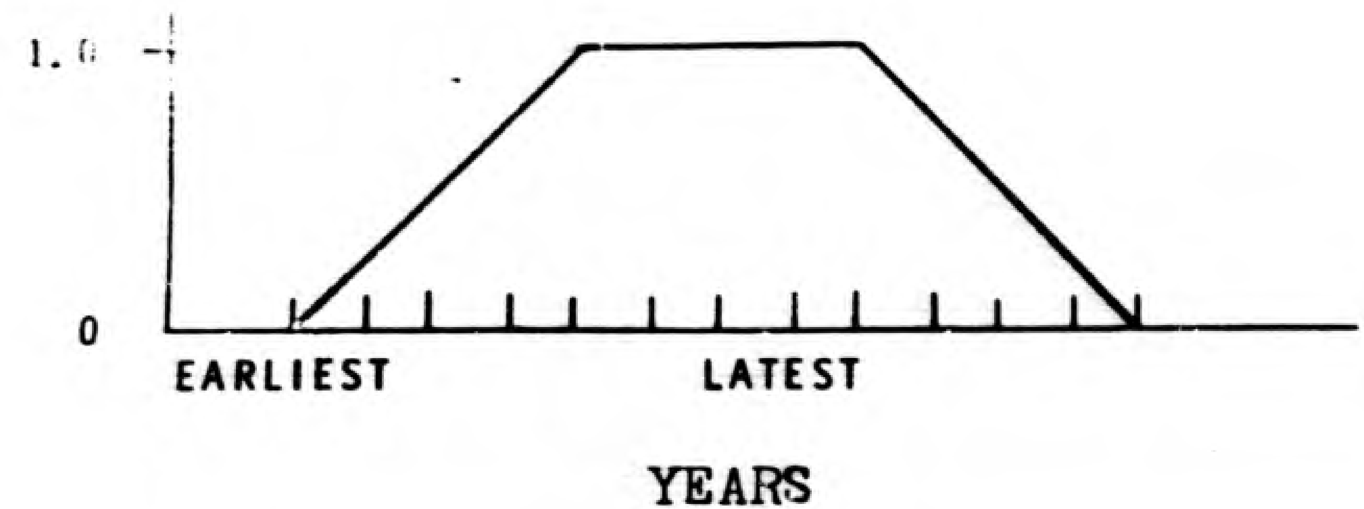
Indirect Contributions

Achievement of this technology will only be an indirect contribution to the capability desired..0.2

Remote Association

This effort has only a remote association with the capability desired.......0.1

No Contribution...0.0


1.0
0
EARLIEST
LATEST
YEARS

FOR 6.1 AND 6.2

TOTAL COST

BALANCE

TECHNOLOGICAL LEVELS OF DIFFICULTY

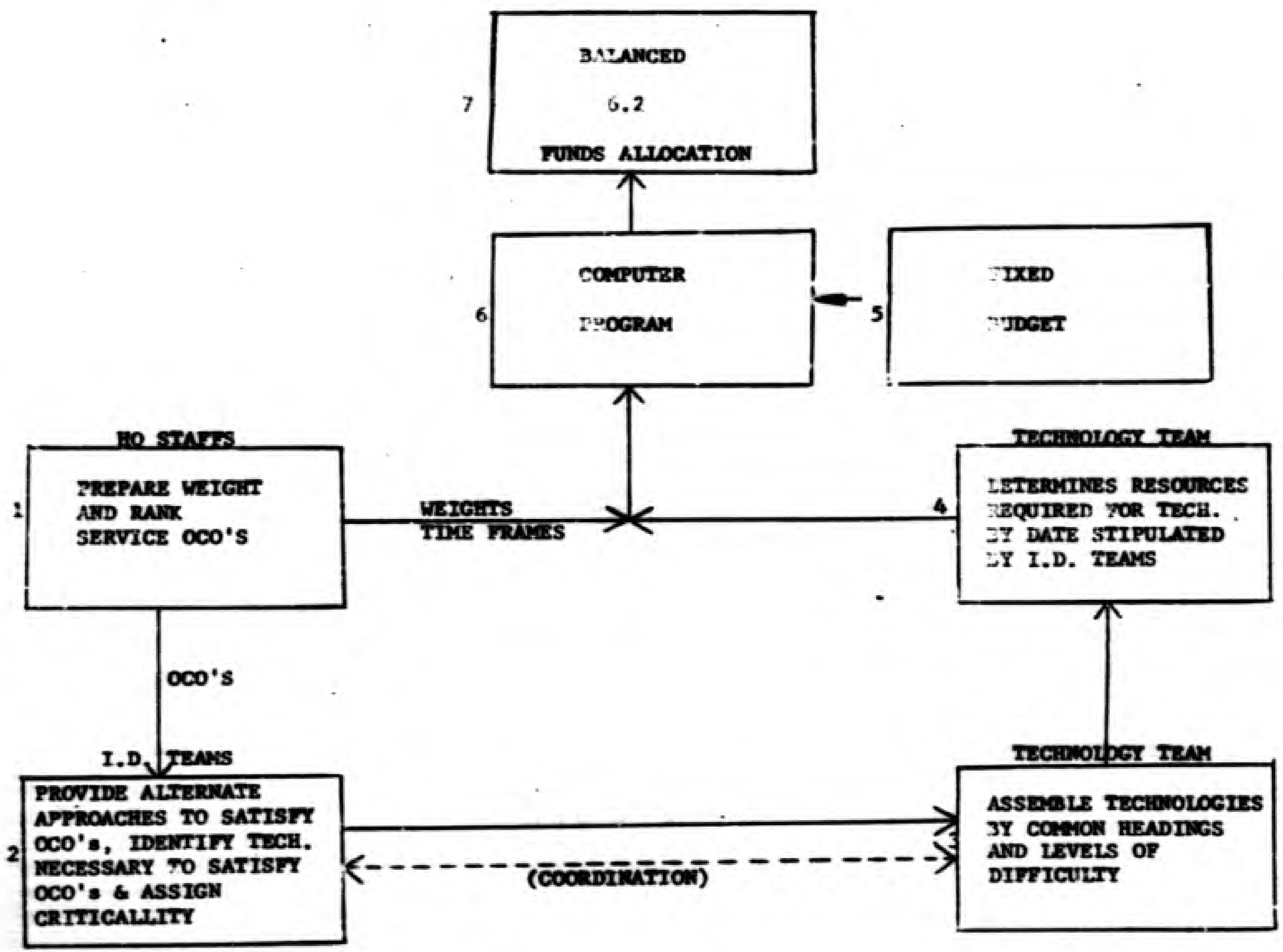
Position Fixing Radar with Accuracy of:	Needed in:
A. 1 mile	1970
B. 1/2 mile	1972
C. 1500 ft	1973
D. 500 ft	1977
E. 100 ft	1980
F. 10 ft	1982

FISCAL YEAR

LEVEL OF DIFFICULTY	1968	1969	1970	1971	1972	1973	1974	1975	ETC
A.	50	100	100						
B.		50	100	200	100				
C.				75	100	150			
D.						ETC			
E.									
F.									

TORQUE

SIMPLIFIED OPERATIONAL DIAGRAM



POSSIBLE OPERATIONAL CAPABILITY OBJECTIVES

(FICTIONAL TITLES)

WEAPONS ACCURACY AND EFFECTIVENESS

WEAPONS GROUND MOBILITY

AIR OPERATIONS IN LIMITED WEATHER

IMPROVED INTELLIGENCE GATHERING

BETTER CHEMICAL WARFARE

A LABORATORY PROCEDURE FOR SELECTING RESEARCH AND EXPLORATORY DEVELOPMENT PROJECTS

Mr. Bernard Sobin

Research Analysis Corporation

Cognizant Agency: US Army Materiel Command

In the next twenty minutes we must cover a considerable amount of ground: explanation of a model for optimization of a laboratory director's choice of research and exploratory development projects and description of an exercise in the use of the model at the Harry Diamond Laboratories.

THE MODEL IN BRIEF

The approach of the model is quite orthodox with respect to the general field of operations analysis, but unusual for research and development planning. It is assumed that Army laboratories exist to produce knowledge with values which are a function of contribution to future increases in military capability and reductions in cost. The laboratories have resources of money, facilities, and skilled manpower plus a wide variety of ways to combine these resources inproduction of knowledge. The problem is to choose a way of combining available resources so that the value of the knowledge expected to be produced is maximized.

The model developed with this approach has five major parts. The first two parts, which must be completed simultaneously, consist of a determination of expected resource availabilities and a definition of all project proposals in terms of what knowledge they may be expected to produce and what resources they may be expected to require if work is started on them (or continued if they have already been started). The two parts must be completed simultaneously because a single way of classifying resources must suit both sets of estimates. The third part of the model is a determination of relative values of the proposals as defined. The fourth part is a zero - one linear programming computation to determine which combination of project selections has the highest aggregate of relative values among all the combinations that are consistent with the resource availabilities.

The fifth part is a set of recyclings of the computations. It is an exploration of how computed answers would be changed by modification of some of the input . A technical director may wish to explore the increments in maximum attainable value associated with increments (positive or negative) in the availability of certain resources. In addition, the computed answers may appear to result from input errors or omissions that cannot be recognized until the implied answers are available. For example, the maximization of aggregate value with the menu of proposals as originally defined may involve leaving some resources idle. Use of otherwise idle resources is costless -- and may even have some positive value. Knowledge of availability of costless resources may generate ideas for augmentation of the original menu of proposals with others that make larger use of the costless resources in relation to other resources. Another reason for recycling may be a finding that, in maximizing the aggregate value of individual projects, the programming model has left major fields of technology without any project representation at all. The next cycle of computations could then include stipulations of minimum amounts of activity in such areas.

ADMINISTRATIVE HISTORY

The broad approach of the model was developed in the course of a year's work that was sponsored by the Army Materiel Command as a task under a Research Analysis Corporation contract with the Army Research Office. The task involved an analysis of the entire Army Materiel Command procedure for determining the content of its research and exploratory development programs. The final report included a recommendation that, to the extent that laboratories have any voice in determination of the work they do, they should use the approach described here.

Practical difficulties are bound to arise, however, in any application of a new procedure under realistic conditions. It seemed worthwhile to complement the theoretical recommendation of the first year with preparation of detailed procedures, trying out those procedures at Army laboratories, and modifying them (if necessary, even discarding them entirely) as realistic experience seemed to suggest.

Actually the first year's work had not been entirely theoretical. Staff members of a number of laboratories had participated in tests of the part of the model involving assignment of relative values to project proposals. These laboratory staff members were approached during the second year to see if they were interested in a full-scale exercise of the entire selection procedure. A number of expressions of interest were obtained in this way. Then, since considerable laboratory effort would be required for the kinds of exercises we had in mind, the Director of Laboratories of the Army Materiel Command was briefed on the exercise plans; and his permission was obtained formally for the interested laboratories to devote whatever resources they considered appropriate to experimentation with the model.

The exercise of largest scale was conducted at the Harry Diamond Laboratories. The exercise there was really two almost independent exercises. One was aimed at maximizing the effectiveness of the program of research and exploratory development in the Systems Research appropriation. Nearly all laboratories of the complex do some work under Systems Research; and every laboratory does work other than Systems Research. The second exercise covered all of the work in Laboratory 300, regardless of which appropriations might be involved. The major judgments for the first exercise were made by the Plans and Programs staff of the laboratory complex, headed by its director, Mr. James E. Spates. The judgments of the second exercise were made by the director of the laboratory concerned, Mr. Robert Hatcher.

The two exercises involved somewhat different kinds of problems. The exercise in which everything was Systems Research had more homogeneity of proposals, making value comparisons easier. Mr. Hatcher, on the other hand, had to make value comparisons for work in such diverse fields as fuzes for missiles and fluid amplifiers for artificial hearts. His task was eased, however, as compared with that of the Plans and Programs Staff, by his greater familiarity with the proposals evaluated. The exercise on Systems Research also had a relative disadvantage in lesser realism of any assumptions to define the manpower pools from which the selected projects could draw. Mr. Hatcher could reasonably assume that he was optimizing the use of all the skills in his laboratory; but in the other exercise, arbitrary assumptions had to be made for each skill class on how many of the Harry Diamond Laboratory personnel in that class should be considered as belonging to the pool that was to be available for Systems Research and Systems Research only.

Altogether, the two exercises at Harry Diamond Laboratories consumed more than 500 man-hours, though probably less than 600 man-hours.

SOME DETAILS OF THE MODEL AND ITS EXERCISE

The Time Horizon

Phrases like optimizing the selection of proposals subject to resource constraints can roll off a tongue quite easily; but, as soon as reduction to a mathematical model is considered, a problem of time horizon arises. If the task is to choose which of the newly proposed and already started projects should be worked on during some near-future period, it is clearly necessary to take into account the fact that the project values depend in many cases on further use of resources in later periods. Many investigations take three years or more. During the life of such a project, new proposals will appear; and resource availabilities will change in ways that cannot be predicted with any precision. Restricting the problem of maximizing ultimate value subject only to constraints to availability of resources in the near future would make the mathematical problem unambiguous, but a very poor reflection of the real decision problem. A proposal requiring a small amount of early work and a great deal of work in the future would look falsely cheap compared to one needing only a moderate amount of work right away.

The device used in the exercises was to have a judgmental constraint on the aggregate amount of present and future budget funds to be committed in the plan period. This was in addition to the constraint on the budget funds to be actually spent during the plan period. The limit on total commitment was supposed to be the product of an average year's budget and an average project turnover rate. In the Harry Diamond Laboratories exercises, the constraint was set at twice the current budget for one run and omitted for others to test the significance of the constraint.

No attempt was made to treat distant future resources other than money in a similar manner. Resources such as manpower skills are subject to changes in their mix if enough time is allowed. It was assumed in the exercise that, while the composition of the staff on hand and approved vacancies may be of decisive importance in determining the work that can be done during the immediately coming year, there is sufficient possibility of planned change during a year to permit the assumption that plans for periods beyond a year depend for their feasibility primarily on the availability of money.

Classification of Resources

The mathematical model assumes that all resources within a class are completely interchangeable. For example, if physical chemists is a resource class and if a particular project requires two physical chemists for a year, the computer model will assume that any personnel identified as belonging to the class of physical chemists are equally satisfactory for the job. If they actually are not equally satisfactory, the principle of the model requires a disaggregation of the class into sub-classes based on quality, but then requires the assumption that, within each sub-class as determined, there is perfect homogeneity.

In real life there are no two scientists or engineers at a laboratory who are identical in their capabilities. Resource classification for the model requires some error of homogeneity assumption. The problem is how to keep this error small. One device used in the exercise was to allow one person to be assigned to more than one class. A physical chemist who is also a physicist can be counted both in the physical chemists pool and in the physicists pool. All that is then necessary is to prevent the computer from assigning him simultaneously to two jobs. This is done by setting up a new resource class consisting of an aggregation of physical chemists and physicists. Any proposal that requires one of the components of the aggregate is listed as requiring both that component and the aggregate. For example, if there are six physical chemists and four physicists but only eight of the aggregate of physical chemists and physicists, restricting the aggregate of all projects to use of no more than eight physical chemists plus physicists is sufficient to ensure that nobody with both skills need therefore be called upon to fill two jobs.

Although another exercise, one conducted at Engineer Research and Development Laboratories, is not discussed here at length, the manpower classification there had some interesting features worth noting. Each of two broad classes of skill had three levels of capability. Every man in one of the higher skill levels was considered a member of the sub-classes at his level and at any lower levels. A requirement for a man at any level was accounted for as a requirement for the aggregate of all levels plus a requirement for all up to and including that level. Another interesting feature of the exercise there was the existence of a class that consisted of only one man. He was also in other classes, but he was the only one who could do certain kinds of work.

It is reasonable to expect that some kinds of work may be so specialized as to fit only one of the members of the staff. But where this becomes the usual situation, the problem of allocating resources changes. At one laboratory complex where an exercise was under consideration, each of the proposals considered for inclusion in the scope of the exercise had only a single investigator considered capable of doing the work. Moreover, each investigator was considered available for only one kind of work, work that he himself proposed. Under such circumstances, the only resource allocation question is how much financial support to give an investigator; and the model described in the present paper is not appropriate for that. The exercise there was abandoned.

Definition of Project Proposals

A project proposal as considered by the mathematical model is something to be either accepted in full or entirely rejected on the basis of whether the value achievable is greater or less than the value that would be achievable in the best alternative uses of the resources stated as required. This requires inputs of unambiguous resource requirements for each proposal and unambiguous values. The mathematical model cannot consider interactions among proposals nor suggest alternative ways of meeting the same knowledge goals by projects run more economically than the proposals as defined.

In the real world each definable piece of current work is related to other work going on simultaneously and derives much of its ultimate value as part of a combination of work efforts that include some not yet started, and perhaps not even definable until some time after completion of the current effort. Compromises are clearly necessary.

Here are rules that were used in the exercises to deal with such problems. To begin, although any relatively small-size project is likely to be virtually worthless if all of the rest of a laboratory's program is dropped, a unit of work is not too small to be included in the proposal menu as a separate proposal unless it is so complementary to detailed pieces of the program that it would not be worth considering except in combination with those other pieces. Frequently this level of aggregation will be found in units of work classified as tasks on Form 1498 reports to the Army Materiel Command, as appeared to be true in many cases at Harry Diamond Laboratories. Value interrelations may still remain, of course. The value of Proposal A by itself plus the value of proposal B by itself may be more or less than the value of A and B in combination. Where the independent sum is worth more than the combination, the proposals are at least partial substitutes; where the sum is worth less, the proposals are complementary. When such value interdependence is considered to exist, those defining proposals for the exercises must assume that each original proposal would be considered independently in the later evaluation work, but they must add a dummy proposal to the menu which would consist of the combination. Thus, if A and B are related, the values assigned in the next stage would be for each on the assumption that the other will not be accepted; but the contingency of acceptance of both should be allowed for as a rejection of both independent proposals and an acceptance of the dummy combination.

It may be seen that a principal problem of proposal definition was to arrive at a list, including dummy proposals, such that each proposal could be considered as having a value independent of the acceptance or rejection of any other single proposal on the list. A second problem was to make sure that all interesting variations of particular proposals were listed as separate proposals because the computer was not going to modify any proposal as defined. The computer would not say: "That is a very interesting and worthwhile proposal. It is accepted but subject to a reduction of 15 percent in the number of technical man-years from that proposed." The proposal as defined had to include the best judgment of what resources were likely to be required to achieve the stated objectives; and alternative proposals had to be defined to state what reductions in resources and associated modification of proposal objectives were worth considering. The computer would only accept or reject.

As is well known, present practice in research and exploratory development does include frequent reductions in resource availabilities without modification of proposal objectives. Logically, this can reflect either a disagreement with the proposer on what resources are required to reach stated knowledge objectives or simply a belief that whatever reductions in objectives may be made necessary by the resource reduction would not be sufficient to make acceptance of the revised proposal unwise. In principle, though, there is no reason that supervisors should not be able to squeeze the water out of resource requirement estimates before resource allocation decisions have to be made; and there is no reason why smaller-scale proposals with reduced objectives should not be capable of being defined explicitly. In any event, the procedure of the exercise removes some incentives to pad proposals in anticipation of arbitrary resource reductions; the padding may lead to a rejection instead of a mere trimming of the proposals.

Assignment of Relative Values

To a theoretician the assignment of relative values for the proposal as defined may appear to be the most difficult part of the model. Actually, the problems of definition of proposals and resource classes appeared to give more trouble in the exercises. The assignment of relative values was almost a routine application of procedures worked out and partially tested well before. A preliminary version of these procedures was described almost two years ago in a paper by Sobin and Proschan [1]. Complete details of the latest version of the procedure appear in a paper by Sobin and Gordon [2]. Only a few highlights will be given here.

The procedure has a slight similarity to the more widely known procedure of Churchman, Ackoff, and Arnoff [3]. The latter has the evaluator first rank all proposals and then guess at relative values of each of small groups of proposals in relation to an arbitrary value of a standard proposal. Then the evaluator must make a series of ordinal judgments within each group among combinations of elements of the group and the standard proposal. Each ordinal judgment establishes bounds to the relative value combinations that are permissible within the group. Enough ordinal judgments are made to establish what may frequently be rather narrow limits to the relative value possibilities; and any initial guesses that are outside those limits must be modified. After each group has been so processed to eliminate any discrepancies between ordinal judgments and relative values within the group, a second set of adjustments is necessary to eliminate any discrepancies between relative values and rankings across all groups.

The procedure used in the exercises here requires fewer and simpler kinds of ordinal judgments and makes up for the lesser judgmental effort by assumptions of statistical regularity of some unknown function defining the relationship between value rank and relative value. The only judgments that need be made are an initial ranking of all proposals and then a number of ordinal comparisons of the value of one proposal as compared with the value of two others.

As in the Churchman, Arnoff, and Ackoff procedure, the evaluator starts with an evaluation of all proposals. There is also a designation of one proposal as having an arbitrary value. But then the similarities stop. The proposal with an arbitrary value is one of the higher ranking ones, at about the 90th percentile. This proposal is plotted on a graph with a linear scale of order numbers (ranks) and a logarithmic scale of relative values. The next step is to find the two proposals separated by two order numbers (i.e., with only one other proposal having intermediate rank) having a sum of values that, in the judgment of the evaluator, is most nearly equal to the value of the base proposal (initially the one with the arbitrary value). It is then assumed that the proposal with value intermediate between those of the pair has one-half of the combined value of the pair and therefore one-half of the value of the base proposal.

The number of order numbers between the base proposal and the proposal with one-half of its value is one measure of the slope in that region of the curve that describes the relationship between order number and relative value. Other measures of the slope in the same region are made by starting with bases one order number higher and one order number lower than before; and the average slope is tentatively taken as the true slope. A new base point is plotted at a value one-half that of the old base point along the line with the calculated slope; and the slope to reach a value half that of the new base point is calculated. This procedure is continued to plotting of as long a chain of points as possible. Straight lines between the plotted points provide interpolations between the highest and lowest values plotted.

Additional curves may be drawn starting at new arbitrary points among the highest ranking proposals; and the relative values implied by the various curves may be averaged. In the exercises discussed here, three such curves were calculated in each case. Finally, any proposals with higher values than those plotted so far may be calculated as sums of values of any two proposals that seem nearly equal in combined value.

In the Laboratory 300 exercise, all the judgments were made by one man. In the Systems Research exercise, it may have been a committee. In neither case can I be sure of how confident the evaluators felt about their judgments. But they did go through the procedures and produced curves with general shapes similar to what had been produced in a number of tests of the evaluation procedure elsewhere; and the curves conformed in general shape to the theoretical expectation that had existed before the acquisition of any test data.

The Linear Programming Model

The linear programming problem has the following general form:

$$\text{Maximize} \quad \sum^{j} V_j \quad (j = 1, 2, \ldots, j, \ldots, n)$$

subject to

$$\sum^{j} a_{ij} \leq \bar{R}_i \quad (i = 1, 2, \ldots, i, \ldots, q)$$

$$\sum^{j} s_{kj} \leq 1 \quad (k = q+1, q+2, \ldots, k, \ldots, m)$$

$$X_j = 0 \text{ or } 1, \text{ where}$$

V_j is the estimated relative value of the j^{th} proposal; a_{ij} is its requirement of the i^{th} resource class if it is selected for the program; $\bar{R}_i$ is the aggregate amount of the i^{th} resource available for the program; a_{kj} is a constant that is one for all j in a set of substitutes for one another and zero for all j not in that particular set of substitutes; and X_j is a variable that is one if the j^{th} proposal is to be selected and zero if it is to be rejected.

Although there are a number of algorithms that can be proven to converge to a solution to this kind of problem in a finite number of iterations, that finite number can be impractically large. An examination of available literature for the RAC project disclosed no procedure that could be relied on to give the correct answers in a practical amount of computer time when the problem was of one of the sizes encountered in the tests of the RAC resource allocation methodology.

The US Air Force Flight Dynamics Laboratory has a linear problem similar in general form (but with only three resource classes to account for, compared with as many as 20 in the problem here); and it uses a proprietary computer routine that belongs to C-E-I-R, Inc., and is tailored for the IBM 7094 system [4]. For the purposes of the RAC project, it did not seem practical to use a proprietary program that could be run only on the owner's computer.

The algorithm finally chosen was a modification of one published in 1965 by Egon Balas [5]. The Balas procedure belongs to the class of algorithms that experiments with various combinations of X_j that will be assigned a value of <u>one</u>. Since the number of possible computations is 2^n, where n is the number of variables, any practical algorithm of this class must be able to provide a more efficient search procedure than to simply try all combinations.* The basic Balas procedure does much better than to test all possible combinations, but not well enough. The modification of the problem here took account of special characteristics of the problem to tighten Balas's more general search procedures and improve convergence.

The computer program is now considerably different from the way it was during the exercises. Weaknesses of the mathematics at that time made it impossible to prove that the best solution attained in each run was the best attainable. It was possible only to put lower bounds on the amount of further improvement that could be proven impossible. The program was also clumsy to use and contained a great deal of IBM 7040 machine language. Since then there have been improvements in the mathematics to make rapid convergence to an optimum possible, and there has been a substitution of Fortran for machine language as part of a plan to make the routine more useful to Army Laboratories.** The new program, when tried on two problems that previously had taken more than an hour of

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* Another approach uses linear programming with variables restricted initially to any $0 \leq X \leq 1$. Then, where any X_j is found to be significantly different from both extremes, the problem is rerun with additional constraints designed to promote integer solutions.

** Daniel Cowgill, who wrote the first version of the computer program, used machine language to minimize storage space at a time when it was believed that storage space would limit the number of iterations. The present version of the program, however, can have an unlimited number of iterations; and storage requirements depend only on the size of the matrix. The conversion to Fortran and other work to improve output formats and simplify operating procedures is work by John Kenworthy that has nearly all been completed.

IBM 7040 time to produce solutions which could not be proven optimal, completed both problems with proof that the previous answers had indeed been optimal, in less than nine minutes of IBM 7044 time.*

EXERCISE OUTPUTS

The recyclings of computations for proposal list and parameter modifications suggested by earlier computations were not included in either of the exercises at Harry Diamond Laboratories. However, the original computations included not only the basic problem in the Laboratory 300 exercise, but also the maximum value on assumptions of two arbitrary changes in resource availabilities. In both exercises, the computations show what resources have surpluses.

EVALUATION OF THE EXERCISES

The decision procedure discussed here can be evaluated from four points of view:

(1) Is it internally consistent?
(2) Does the structure of the model reasonably reflect relevant characteristics of the real world?
(3) Are there any characteristics of the procedure (time required, cost, administrative difficulties, etc.) that make it impractical? and
(4) Are the inputs that can be obtained sound enough to yield good outputs?

The first question can clearly be answered favorably.

The second question raises such issues as the degree to which scientific and engineering personnel can be classified into groups so that within a group differences in capability may be disregarded for planning purposes without significant error. It will be recalled that this was clearly not possible at one laboratory where the exercise was abandoned. Another instance of such an empirical question is the feasibility of defining a menu of project proposals in such a way that the decision problem can be reduced to determination of which proposals or discrete variations of proposals should be supported fully or not at all rather than to determination of a continuously variable degree of support that is conceivable for each proposal. Discussions with participants in the exercises do not suggest that errors introduced by such simplifications of reality were important at Harry Diamond Laboratories; but no definite statement has yet been obtained. Of course, whichever way the decision may go for Harry Diamond Laboratories, it can be the other way elsewhere.

The fourth question is most crucial. Any procedure for choosing research and exploratory development projects must rely heavily on human judgment. An objective procedure would have to depend on false assumptions about the nature of the problem.

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* The IBM 7044 system now used at RAC does a problem of this sort about two or three times as fast as the IBM 7040 system.

When the exercises were planned, it was believed that the judgments required by the procedure were in forms that maximized the likelihood that they would be relatively good judgments. Projects are judged only comparatively and with respect to their output value ranks. Sometimes it is necessary to compare output values of two projects with output values of one project; but there are arrangements for averaging out some of the errors in these more difficult judgments. Finally, the procedure avoids the use of any "black boxes" that convert judgments about details into major decisions in ways that cannot be followed by the author of the judgments. The implications of all judgments are obvious; and the judgments can be changed at any time where changes are suggested by the implications.

Despite such heuristic arguments in favor of the relative quality of judgments in the procedure exercised, a great deal of weight should be attached to the considered opinions of those who made the judgments in the exercises. If they have more confidence in decisions reached by judgments in the form required by this procedure rather than by judgments required in connection with alternate procedures, then the judgments are good enough. At this time, we do not yet have a formal statement from the participants. We hope to have such a statement included in our formal report to the Army Materiel Command.

REFERENCES

1. B. Sobin and A. Proschan, "Proposal Generation and Evaluation Methods in Research and Exploratory Development," in M. C. Yovits, et al (editors) Research Program Effectiveness, Gordon and Breach, Science Publishers, Inc., New York, 1966, pp. 319-369.

2. B. Sobin and J. B. Gordon, "Improvement of Army Methods of Determining Research and Exploratory Development Programs," T-482, Research Analysis Corporation, McLean, Virginia, June 1966.

3. C. W. Churchman, R. L. Ackoff, and E. L. Arnoff, Introduction to Operations Research, John Wiley and Sons, Inc., New York, 1957, Chapter 6.

4. A. B. Nutt (Air Force Flight Dynamics Laboratory), "An Approach to Research and Development Effectiveness," prepared for presentation at the 1965 National Aeronautics Conferences, Dayton, Ohio, 12 May 1965.

5. Egon Balas, "Linear Programming with Zero-One Variables," Operations Research July-August 1965, pp. 517-544.

EFFECTIVENESS OF THE ARMY TACTICAL AIRSPACE REGULATION SYSTEM (ATARS)

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The Army Tactical Airspace Regulation System (ATARS) is a weapons support system enabling the field commander to obtain maximum use of Army rotary wing aircraft. In the development of modern weapon and support systems such as ATARS, a level of complexity has been reached that makes it essential to conduct a broad system study in the concept formulation phase to insure the selection of the best system approach. Recognizing this need, the Avionics Laboratory of U. S. Army Electronics Command, Fort Monmouth, New Jersey has contracted for this study with Communication Systems Incorporated. At this juncture the study project is three-quarters completed and is entering the final selection and recommended design phase.

ATARS objectives start with the basic need to enable the field commander to obtain maximum use of Army rotary wing aircraft. Thus, the system is being designed to operate primarily for helicopters in all variety of tactical situations, with emphasis on low visibility flight conditions. It is intended to provide support to all aircraft in flight, in the performance of tactical missions. This includes providing safe and expeditious air traffic flow on a twenty-four hour all weather basis within the Army coordinating altitude.

This paper is concerned with the system effectiveness of ATARS, that is, how well does the system do what it is supposed to do. To determine this, we start with a discussion of the nature of the problem. This is followed by the performance required, system concepts, and the means of measuring performance effectiveness. In discussing the nature of the problem, recognition is given to the increasing need and use for helicopters in limited war, and the constraints placed upon both the pilot and the field commander in obtaining maximum utilization. Also, there are the limitations of the present manual system, and the multitude of problems introduced by interfacing with other military departments and civilian aviation.

Consideration is given to the performance requirements of the system needed to meet the objectives and hence to hopefully resolve the problems. This includes establishing performance criteria and system functions. In the usual operations research procedure, it was then necessary to perform the war gaming and modeling to obtain the range of quantitative performance requirements. System concepts were established based on assessing the technology to meet the requirements. These included establishing the subsystems, communications, navigation, etc., the alternative system approaches, and the technical trade-offs. Additional fundamental concepts were developed for such basic elements as collision avoidance, separation distances, and confidence limits on projected positions. Finally, the discussion of ATARS performance effectiveness explains that it is measured by means of statistical modeling which incorporates the appropriate queue models. The resulting measure of effectiveness includes such factors as flight density, conflict rate, composite system workload, and the system response time.

Nature of the Problem

Experience with the helicopter in Southeast Asia as a short range tactical weapon has established its increasing need and use in limited war. The advanced development of these rotary wing aircraft has provided a significant range of capability in the tactical theater of operations. As a result, the helicopter is replacing substantial ground transportation particularly over rough terrain and for amphibious operations such as unloading ships. It has proven its value in many military functions such as logistics, firepower, mobility, and command and control, through such factors as its immediate availability, freedom of utilization and economy of utilization. This increased utilization is accompanied by constraints on the pilots and field commander that restrict the optimum freedom of utilization. These constraints stem from limited visibility conditions and air traffic congestion. The problem of limited visibility may be caused by weather conditions or night time flying or both, and the difficulties resulting from air traffic congestion are encountered largely in the terminal areas.

In considering current air traffic control systems, there are several, the manual system presently in use by the Army, and other systems designed largely for high performance aircraft for civilian aviation and other military departments. While much can be learned from existing systems, they still have considerable limitations in their possible application to the ATARS problem. The Army air traffic system, as it exists today, is based upon airlanes, that is, air corridors between beacon points. While it has proven to be a workable system for the manual flight-strip technique currently employed, it has disadvantages of which perhaps the most important is the limited use of available airspace. In addition, the flight density that can be supported by the manual system within the control area is severely limited.

There can be no question that the nature of the flight conditions for rotary wing aircraft, such as nap of the earth flying, short range missions, undeveloped landing zones in the forward area, are all significantly different from those encountered in civil aviation and high performance military aviation. This is not to imply that high performance air traffic control techniques are entirely useless to the Army. Where techniques developed by the FAA or the Air Force can be used for helicopters in the tactical environment these are certainly considered. There are, however, many areas where entirely new techniques need to be developed.

Recognition must also be given to the need for interfacing with other military agencies and with civilian aviation for peace-time flights or transport through to tactical theaters. The overall Department of Defense objectives seek commonality of systems wherever feasible, the integration of communications, navigation, and regulation known as the CNIR concept, and at the very least, compatibility between different systems that interface. An example of this is the Air Force flight within the Army coordinating altitude.

This brief discussion has provided a birds-eye view of the nature of the problems to be considered in undertaking the broad scope of the ATARS study. Consider, next, the performance requirements established for the system.

Performance Requirements

To determine system effectiveness we first establish the performance requirements simply because system effectiveness is based on performance delivered against performance required. As a weapons support system, the objective of ATARS must be to enable the field commander to obtain maximum utilization of Army rotary wing aircraft. This means the system must provide support to all aircraft in flight, within the coordinating altitude, presumably in the performance of tactical missions.

The very nature of this support constitutes the performance criteria for ATARS. These criteria are shown in Table I, below.

TABLE I. PERFORMANCE CRITERIA

(1) Coordinate all airspace users including Air Force, Navy, Artillery, Air Defense, drone flights, etc.

(2) Maintain safety of aircraft by separation standards and monitoring air traffic.

(3) Facilitate flying under low visibility flight conditions through pilot guidance appropriate to limited visibility such as night flying and inclement weather.

(4) Provide for orderly traffic flow en route and within terminal areas to achieve efficient use of the airspace and minimize delays in queue.

(5) Facilitate search and rescue of downed pilots and aircraft by pin-pointing location and vectoring rescue aircraft.

(6) Display aircraft disposition to field commander to facilitate effective utilization.

ATARS may achieve the desired performance by means of several specific functions which may depend on either self-contained airborne avionics or ground based control systems. Most likely, a combination of the two will prove most effective. These functions are listed in Table 2 on the following page.

TABLE II. ATARS FUNCTIONS

(1) Flight plan processing to facilitate coordination of airspace users, terminal scheduling, and predictions along the intended path.

(2) IFR en route regulation to provide for safe and expeditious air traffic flow in low visibility.

(3) VFR flight following, a simplified en route activity to serve for coordination and rescue.

(4) Terminal control to encompass all air traffic regulation, take-off and landing operations in the terminal area.

(5) Coordination functions to provide for the interface with other military agencies and airspace users.

(6) Support functions to provide for rescue vectoring, other en route aids if needed, and aircraft disposition display to the field commander.

Having established the performance criteria and the ATARS functions, the next step is to determine the quantitative performance requirements which form the basis for system design specifications. This is accomplished with the aid of tactical mission scenarios also known as war games. The scenarios developed for ATARS are shown in Table III on the next page.

TABLE III. TACTICAL MISSION SCENARIOS

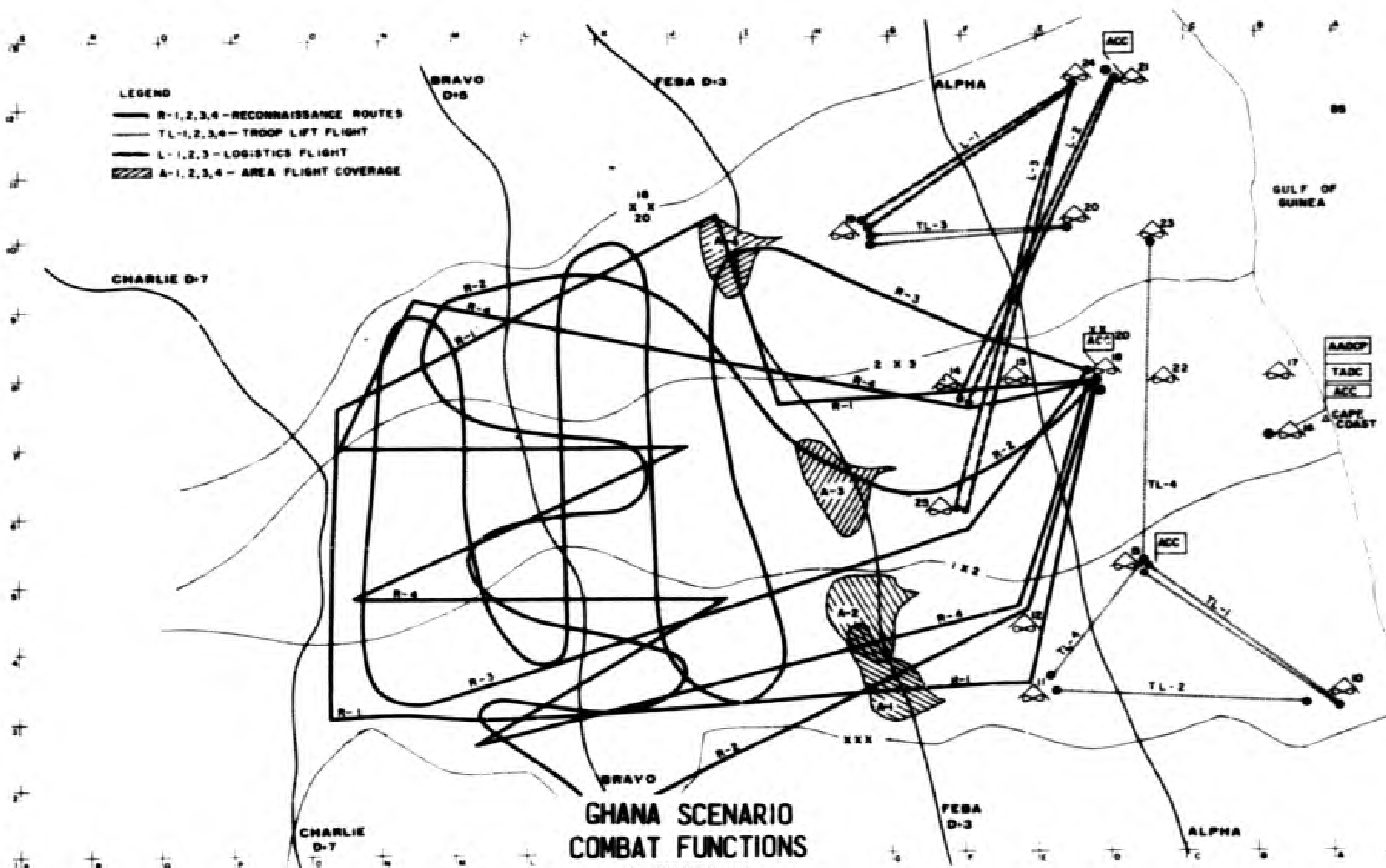
LOCATION	ACTIVITY	HELICOPTERS USED
(1) Ghana, West Africa	Independent corps conducting an amphibious operation. Two infantry divisions conduct the initial assault and penetration reinforced by a separate mechanized brigade. An airborne division is deployed in the final objective area.	360
(2) Morocco, Africa	An airborne division deployed in seizure of a critical objective. This is a typical example of brush-fire warfare.	170
(3) Western Europe	A six division Field Army engaged in wide frontal attack, deployed in considerable depth to portray extended mass and to establish high mobility requirements. Two air-mobile divisions were incorporated.	3400
(4) Vietnam	Three prime operational missions based on actual after action reports. These operations included an air assault division, an infantry division and an airborne brigade.	750

In the formulation of the tactical mission scenarios every effort was made to incorporate realism in the sequence of events. This realism is partially illustrated in Figure 1, an overlay of four combat functions in one phase of the Ghana scenario. As a further means of insuring realism a computer was programmed to introduce unexpected events such as enemy action, mishaps, or bad weather during the progress of the battle. Then, the completed scenarios were exercised on the Air Traffic Regulation (ATREG) simulator provided by Cornell Aeronautical Laboratories.

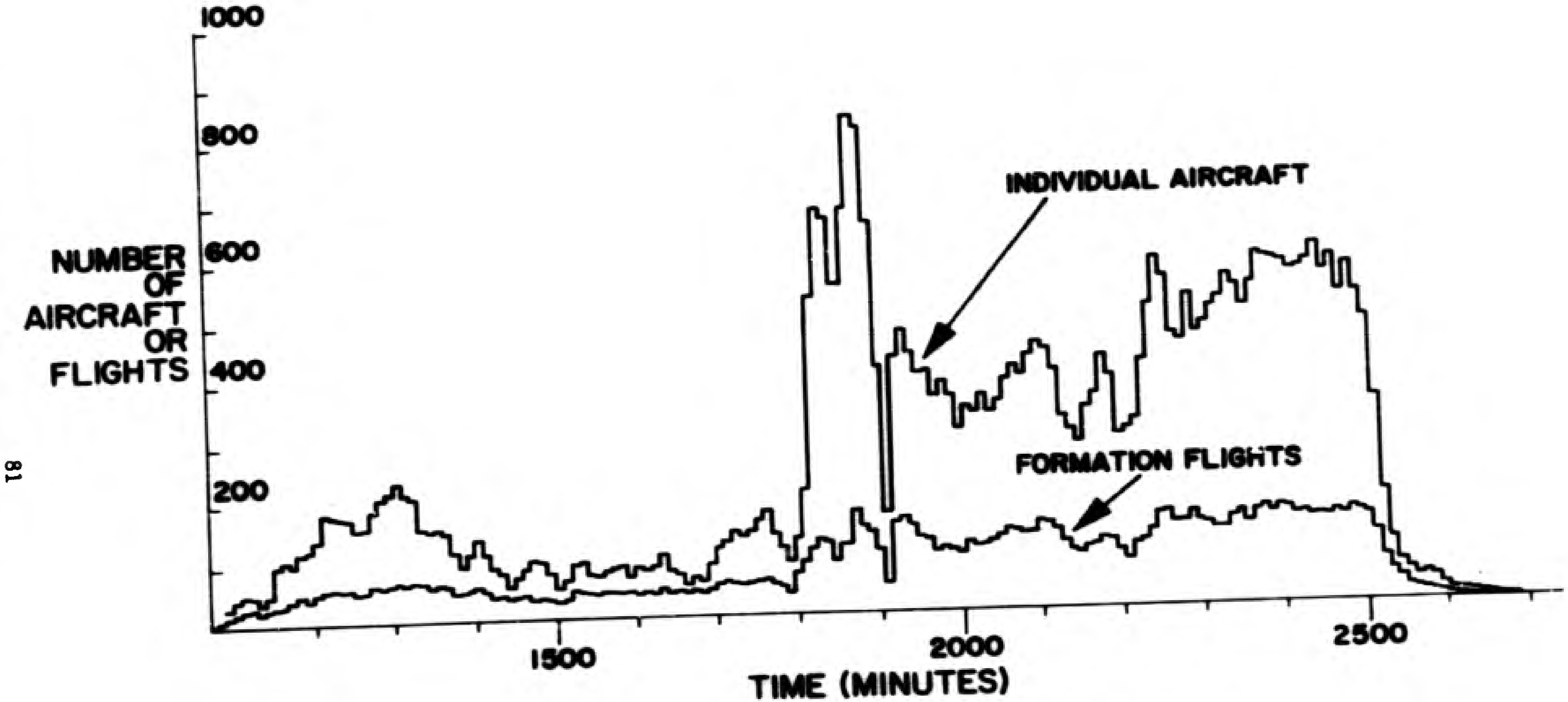
As an example of the results obtained from analysis of the scenario activities, Figure 2, shows the density distribution during a busy 24 hours. The upper curve represents the distribution for individual aircraft which reached a peak density in excess of 800 over the entire field army. The lower curve depicts the densities encountered for formation flights which averaged 5 aircraft per flight and reached a peak density of 175 flights. A summary of the quantitative performance requirements derived mostly from the analysis of the tactical mission scenarios is shown in Table IV, on the following page.

TABLE IV. RANGE OF REQUIREMENTS

PARAMETER	RANGE OR AVERAGE	DIMENSION
Flight Density	10 - 30	Flights Per Control Area 5,000 Square KM
Formation Size	5	Aircraft Per Flight
Velocity	200	NMPH Maximum Cruise
Radius of Formation	0.25	NM
Handovers	20 - 60	Two Per Flight
Flight Duration	30	Minutes
Terminal Operations 50% Load	100 - 300	Take-Offs and Landings Per Hour



GHANA SCENARIO
COMBAT FUNCTIONS
1 THRU 4
FIGURE 1



WESTERN EUROPE SCENARIO

FLIGHT AND AIRCRAFT DENSITY DISTRIBUTION

FIGURE 2

While analysis of the tactical mission scenarios provided important information about flight densities, formation size, and terminal operations in a realistic tactical environment, not all of the requirements could be determined by this war-game method. One set of design parameters needed is the empirical relationship between conflict rate, conflict volume, and the flight density. This information could not be determined from the realistic scenarios without elaborate techniques to play the games in real time with several military officers. So long as only one experienced officer prepared the flight plans, there were either no conflicts or very few. To circumvent this limitation, a flight profile generator was developed as a synthetic scenario. Its geographic configuration is shown in Figure 3. This scenario represents a control area 80 KM long and 72 KM wide in which the preponderance of air traffic flows both forward and to the rear with smaller components of cross traffic.

In the operation of the synthetic scenario a flight originates at either one of the two terminals. These are fictitious points because the flight profiles actually used are within the bounded area. Each of the three en route fix points is selected independently and at random from uniform distributions of five altitudes and ten width positions. The flight origination frequency is a Poisson distribution, and the flight density is increased in successive time intervals by reducing the average time between originating flights. The series of three-dimensional flight profiles are then exercised on the ATREG flight simulator to determine the conflict-density relationship.

FLIGHT PROFILE GENERATOR SYNTHETIC SCENARIO

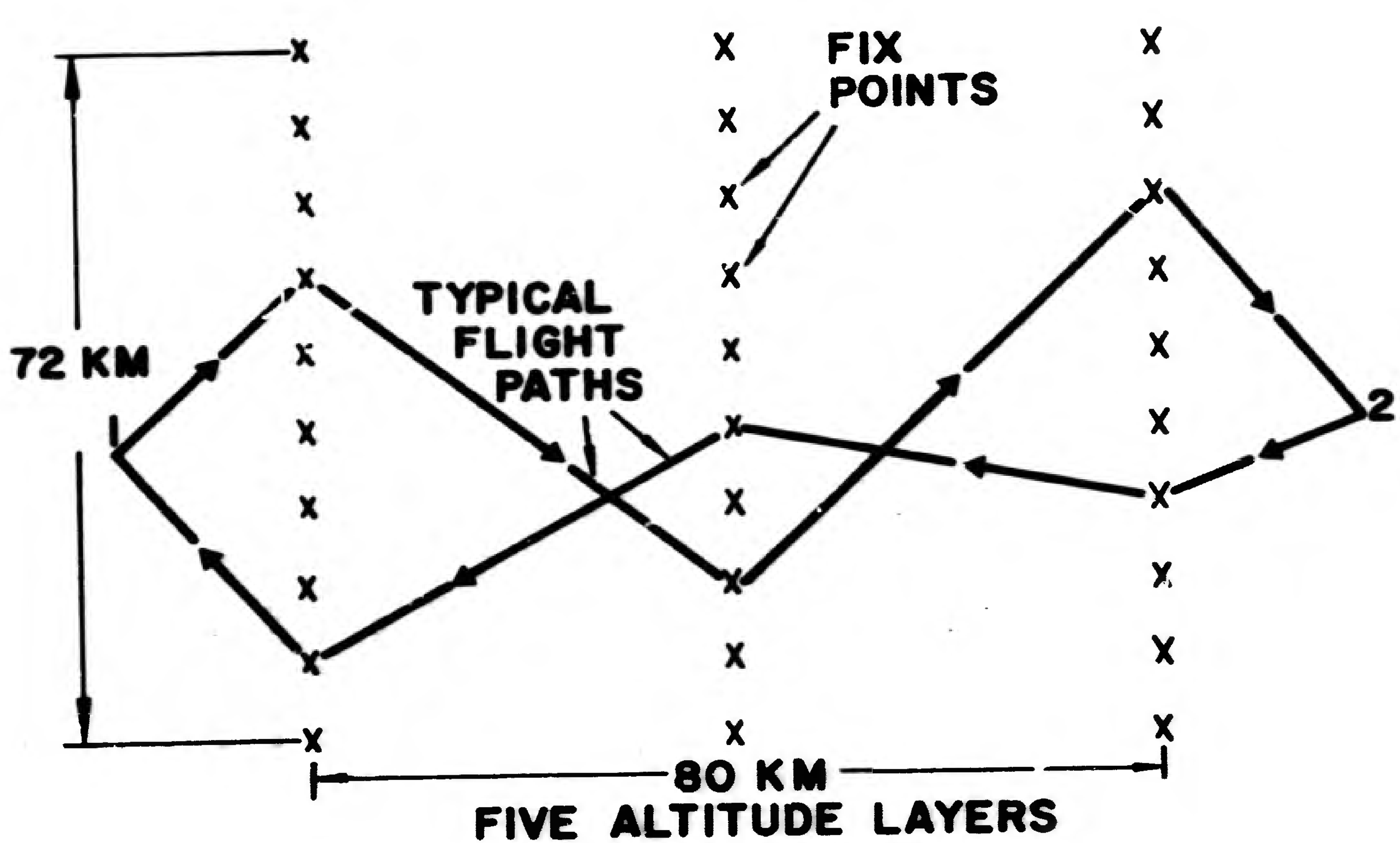
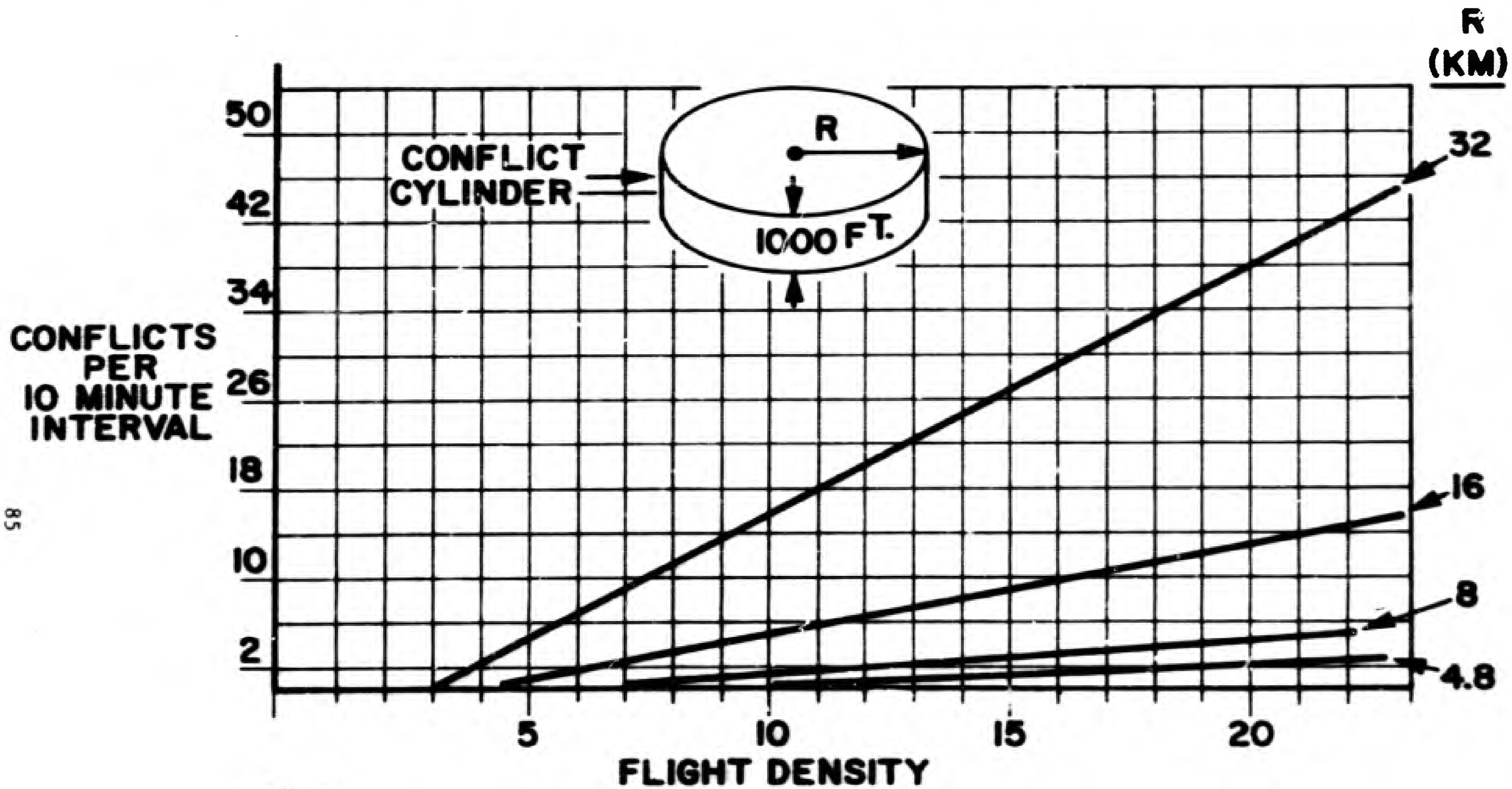


FIGURE 3

At the outset of this investigation into the conflict-density relationship, it was generally believed the number of conflicts would be proportional to the square of the flight density. This idea was based simply on the appearance of the squared term in combinations taken two at a time. Analysis of the empirical data, however, shows the best correlation is obtained for a linear relationship. We are obliged, therefore, to believe the flight densities encountered in the scenarios and the size of the conflict cylinders tested are very small when compared with the total volume of airspace under surveillance. The conflict rate versus flight density is shown in Figure 4, for several size conflict cylinders. The usefulness of these results is that conflict detection and resolution constitute the primary workload on the regulation system.

System Concepts

With the performance requirements determined the next phase of the study was to consider how the performance was to be achieved. A convenient starting point was to subdivide ATARS into the four subsystems usually defined for air traffic control systems. These comprise first, communications - ground-air-ground and point to point; second, navigation and landing which includes short range surveillance; third, the data subsystem encompassing data acquisition, processing and display; and finally the en route and terminal controllers. A comprehensive technology assessment was performed for each of these subsystems which can only be briefly mentioned in passing. Communication alternatives considered span the spectrum from HF ground wave to UHF line-of-sight with a variety of relay techniques. For the navigation and landing subsystem the choices included doppler, inertial, and radio position such as DECCA and LORAN, as



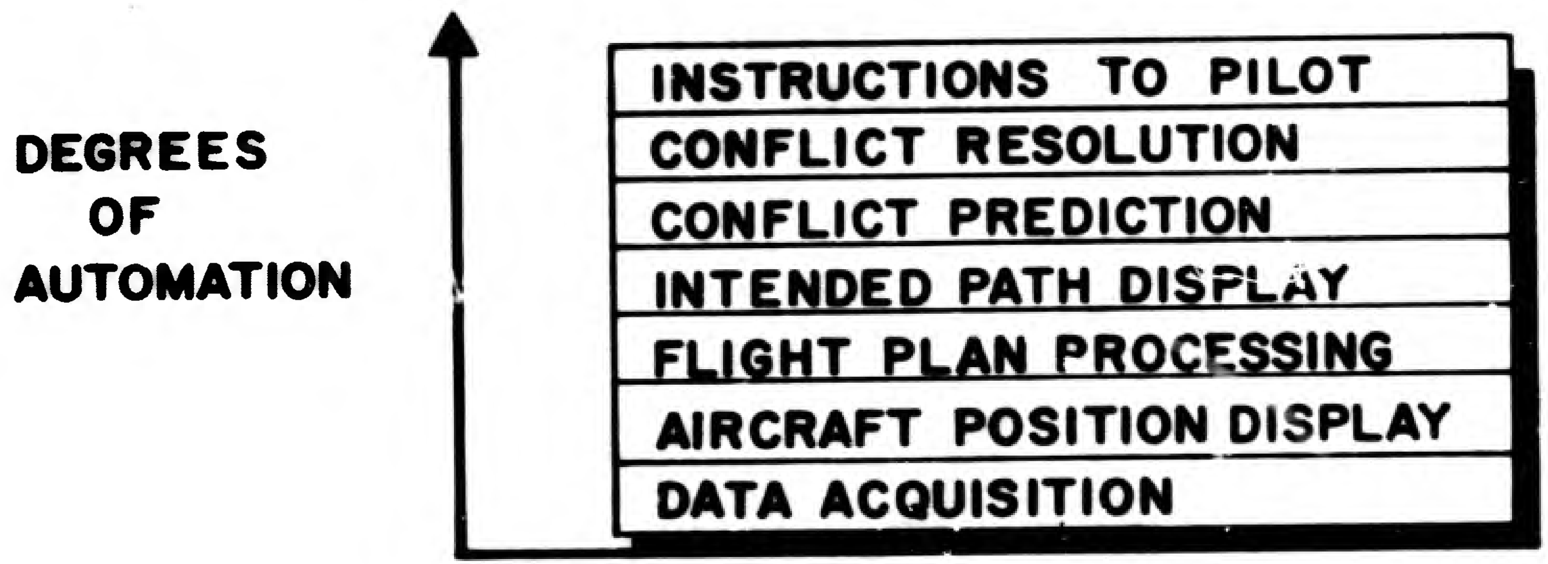
CONFLICT RATE VS. DENSITY

FIGURE 4

well as landing systems based on both ground guidance and airborne instrument navigation let-down. For data acquisition the alternatives included beacon transponders, primary and secondary radar, time synchronous systems and radio triangulation such as inverse LORAN.

Both the controller subsystem and the data processing and display subsystem involve the man-machine trade-off analysis. A fully manual system has limitations in capacity and speed of response, on the other hand, a fully automated system may not be justified or it may have too much complexity. The trade-off analysis being performed is to determine the desirable degree of automation. The choices are shown as building blocks from the bottom up in Figure 5.

In determining the underlying structure of ATARS we recognize that the regulation principles employed will determine the basic nature of the system, and will have a strongly projected impact on the degree of success to be achieved. Certainly, safe and expeditious air traffic flow depends most dramatically on ability to detect and resolve conflicts with ample leeway. The pilots ability to do this depends on visibility and air traffic. This ability diminishes, however, for limited visibility or in heavy air traffic such as in terminal areas. As a result, air traffic flow capability may be seen as a function of the constraints due to limited visibility or traffic congestion as illustrated in Figure 6. The pilots choice depends on his ability to see and the absence of congestion. ATARS support is needed when the constraints increase. Even under minimum constraint conditions, ATARS can contribute to safe and expeditious air traffic flow through coordination of airspace users, air defense, and restricted airspace.



MAN-MACHINE
TRADE OFF ALTERNATIVES

FIGURE 5

ATARS UTILITY

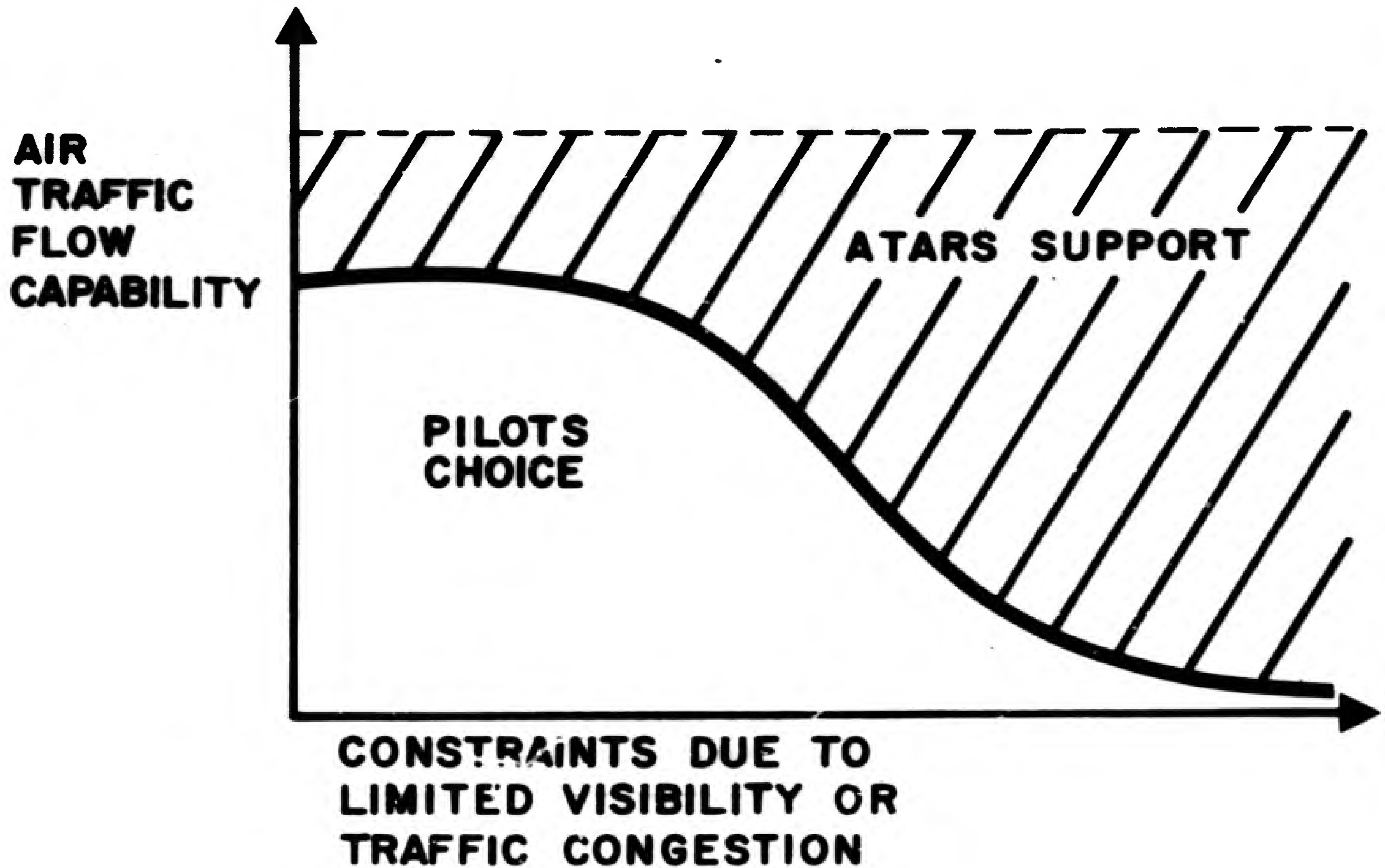


FIGURE 6

Previously we said two of the ATARS functions were IFR en route regulation and VFR flight following. Let's examine these two functions in the light of ATARS support versus the pilot's choice. From talking to some pilots it would seem their attitudes about IFR and VFR have taken on the emotional content of religion and politics. In clear weather, that free-as-a-bird feeling associated with VFR has become one of the pilot's inalienable rights. This attitude is not entirely surprising in view of the restrictions needed for IFR procedures as they exist today. What is really needed, we believe, is an entirely new approach. With the advanced technology available to air traffic regulation in the tactical environment, the carry-over from present techniques of two classes of flight, IFR and VFR, is entirely unnecessary. The question of visibility and the pilots choice to fly by instruments or visually should be of only minor concern to ATARS.

ATARS should be a completely permissive system which supports the pilots and the field commander without ham-stringing them. Whenever an airspace user is subjected to a restriction it should be imposed by the environment or conflict with other users, not by ATARS. Flight plans, for example, while desirable should not be mandatory. The information can be provided by voice communication after take-off if need be. Flight plan clearance takes on the nature of information to the pilot about safety along his intended path, but the decision to fly or not is always with the commander and the pilot, never with ATARS. When ATARS support is really needed such as for low visibility, we can trust the good judgment of the pilot to accept the guidance. At other times, ATARS serves as an extra pair of eyes that see further than the pilot can. Thus, the two functions mentioned previously merge into one, simply en route regulation.

In keeping with the concept of minimum restraint on the pilot we are also obliged to discard the air lane or air corridor technique. In its place we substitute the method of area control which means the pilot may fly in any direction he chooses. Level flight at defined altitude layers still appears desirable but this is not a serious restraint because the pilot flies at whatever altitude layer he chooses. The focus of concern is now collision avoidance. As illustrated in Figure 7, the function of collision avoidance may be accomplished by airborne avionics, or by ground based control, or possibly by a combination of both. The final recommendation will be based on the effectiveness of each method. Simply stated, collision avoidance is accomplished by predicting conflicts and resolving them with ample leeway. Whether this is done on the ground or in the air, the principles involved are essentially the same.

As a basis for analysis of conflict prediction and resolution, consider the distance between two flights shown in Figure 8. Flight (A) is the protected flight located at the origin of the coordinates, while (B) is the intruding flight, and all motion in space is considered relative to (A). As (B) approaches (A) it passes through five regions defined as follows:

(1) <u>Density Prediction</u>

The distance between flights is too great to make meaningful conflict predictions. No action is required unless the density prediction is greater than the system can handle.

(2) <u>Conflict Prediction</u>

Proximity is such that meaningful conflict predictions can be made. Projected and intended paths are examined

COLLISION AVOIDANCE

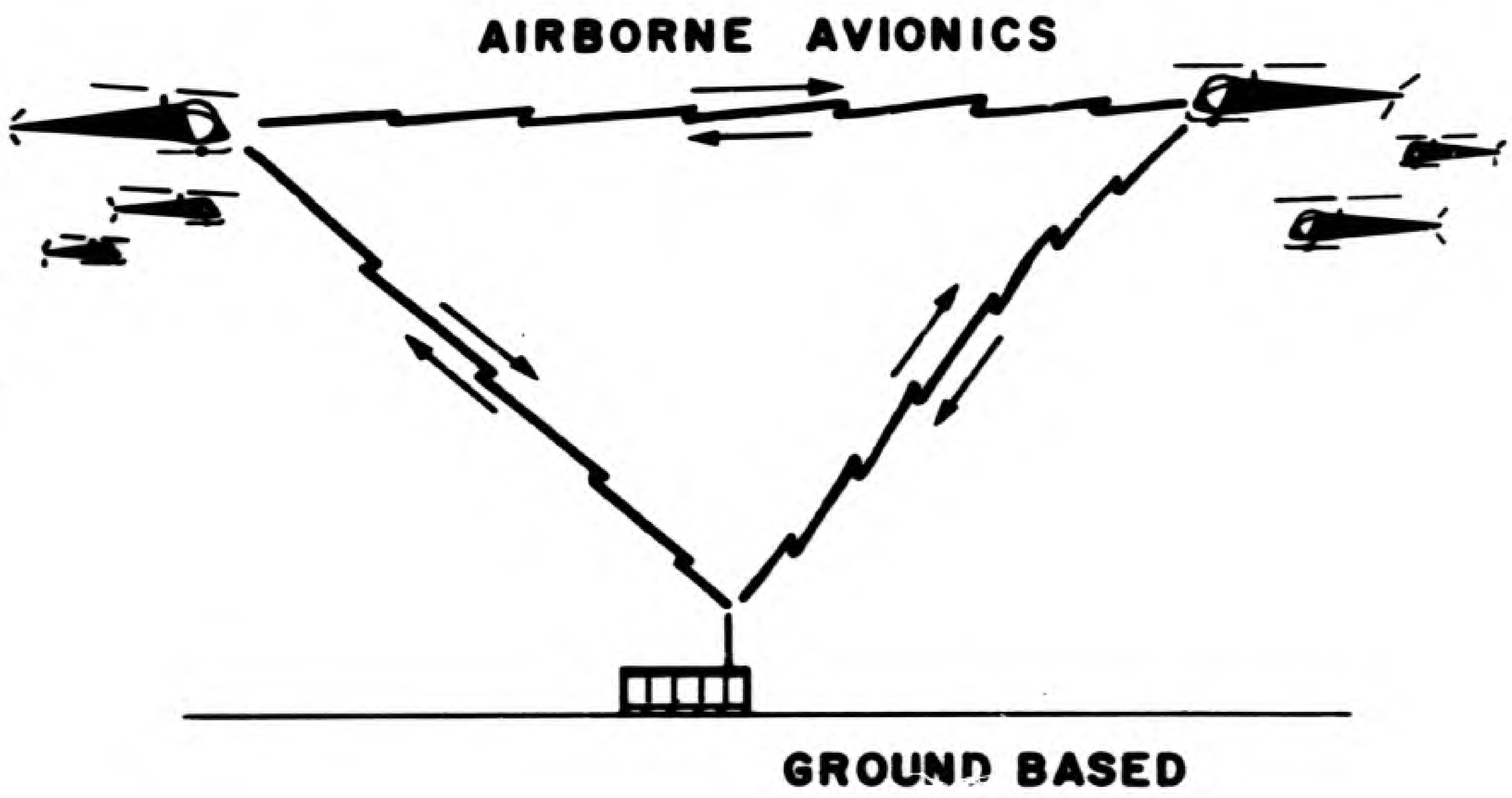
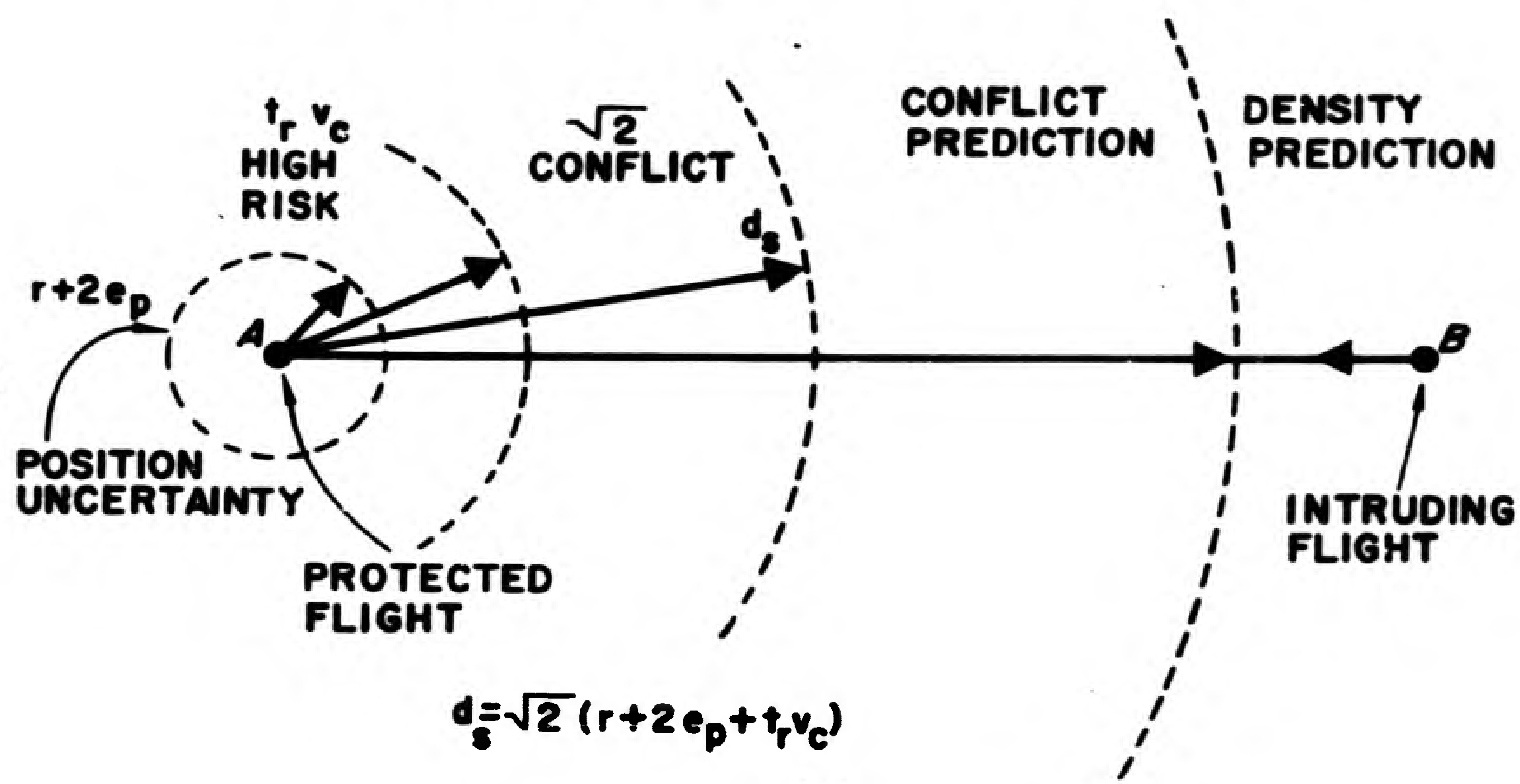


FIGURE 7

DISTANCE BETWEEN FLIGHTS



$$d_s = \sqrt{2}\,(r + 2e_p + t_r v_c)$$

FIGURE 8

for apprcaching conflicts. The controller may choose to act if the regression line intersects the position uncertainty circle and successive projections do not show an improvement.

(3) Conflict

At this distance (B) is in conflict with (A). Sufficient time exists to determine and execute an avoidance maneuver, but separation is not safe for unexpected maneuvers. The controller or system must make both pilots aware of the conflict and provide the necessary guidance for an avoidance maneuver if the projected path intersects the position uncertainty circle.

(4) High Risk

Inside this boundary there may not be sufficient time to determine and execute an avoidance maneuver. Hence, it may not be possible to assure the safety of the aircraft. If two flights get this close without prior detection, ATARS has failed statistically. Nevertheless, the controller will direct an emergency avoidance maneuver if the path violates the position uncertainty circle.

(5) Position Uncertainty

Inside this circle the controller cannot provide any guidance and the safety of the aircraft would depend upon local visibility if any, or airborne avionics.

We recognize that the radius of the position uncertainty circle is the minimum separation distance that should not be violated. This distance is $(r + 2e_p)$ the radius of the flight formation plus twice the position error. To obtain the high risk radius we add $(t_r v_c)$ the system response time multiplied by the relative closing velocity between the two aircraft. Finally, the conflict radius is $\sqrt{2}$ larger based on the assumption that an area larger than twice the high-risk area can support two flights safely. In summary, the conflict radius is obtained from the following expression:

$$d_s = \sqrt{2} \quad (r + 2e_p + t_r v_c)$$

We are presently solving for the radius of conflict prediction based on the confidence limits for the predicted position. This is illustrated in Figure 9, which is a representative plot of the upper and lower limits for the predicted position of distance traveled as a function of time. Assuming the segment of the flight path is linear the projected path is the regression line of several previous position reports. The prediction interval of width (w) about the estimated position will actually include the true position with reasonable confidence if:

$$w = 2\ t_p\ (K - 2)\ \sqrt{\hat{V}\ (x - s)} \quad *$$

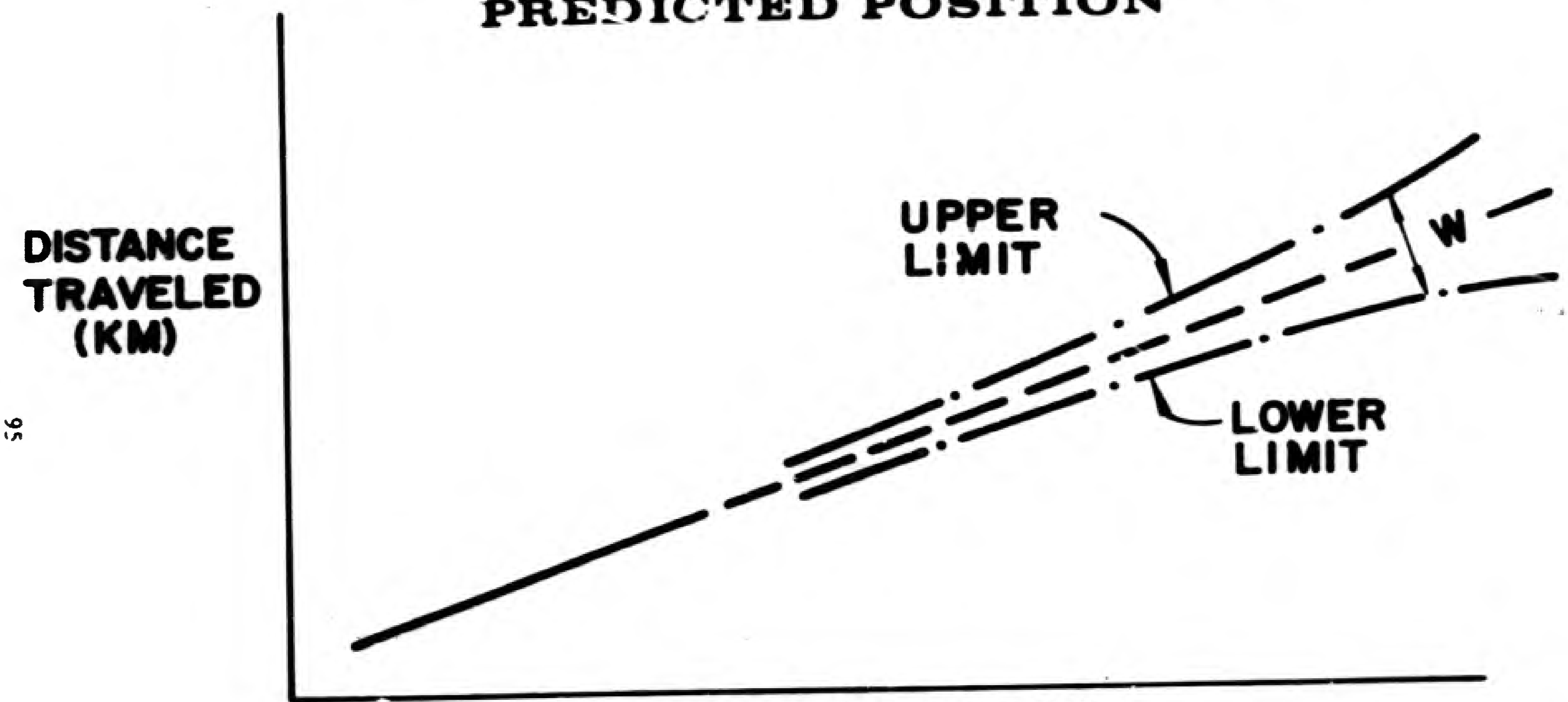
where t_p is the value of the Student (t) distribution for (K-2) degrees of freedom such that P is the probability of the event equal to or greater than t. K is the number of previous position reports serving as the basis for the prediction, and the confidence is 1-2P. $\hat{V}\ (x - s)$ is the estimated value of the variance of the deviation between the observed positions (x) and the estimated positions (s).

ATARS Performance Effectiveness

The focus of this discussion is the method of measuring ATARS performance effectiveness for proposed system configurations. This is being

*K. A. Brownlee, "Statistical Theory and Methodology in Science and Engineering." John Wiley & Sons, Inc.

CONFIDENCE LIMITS FOR PREDICTED POSITION



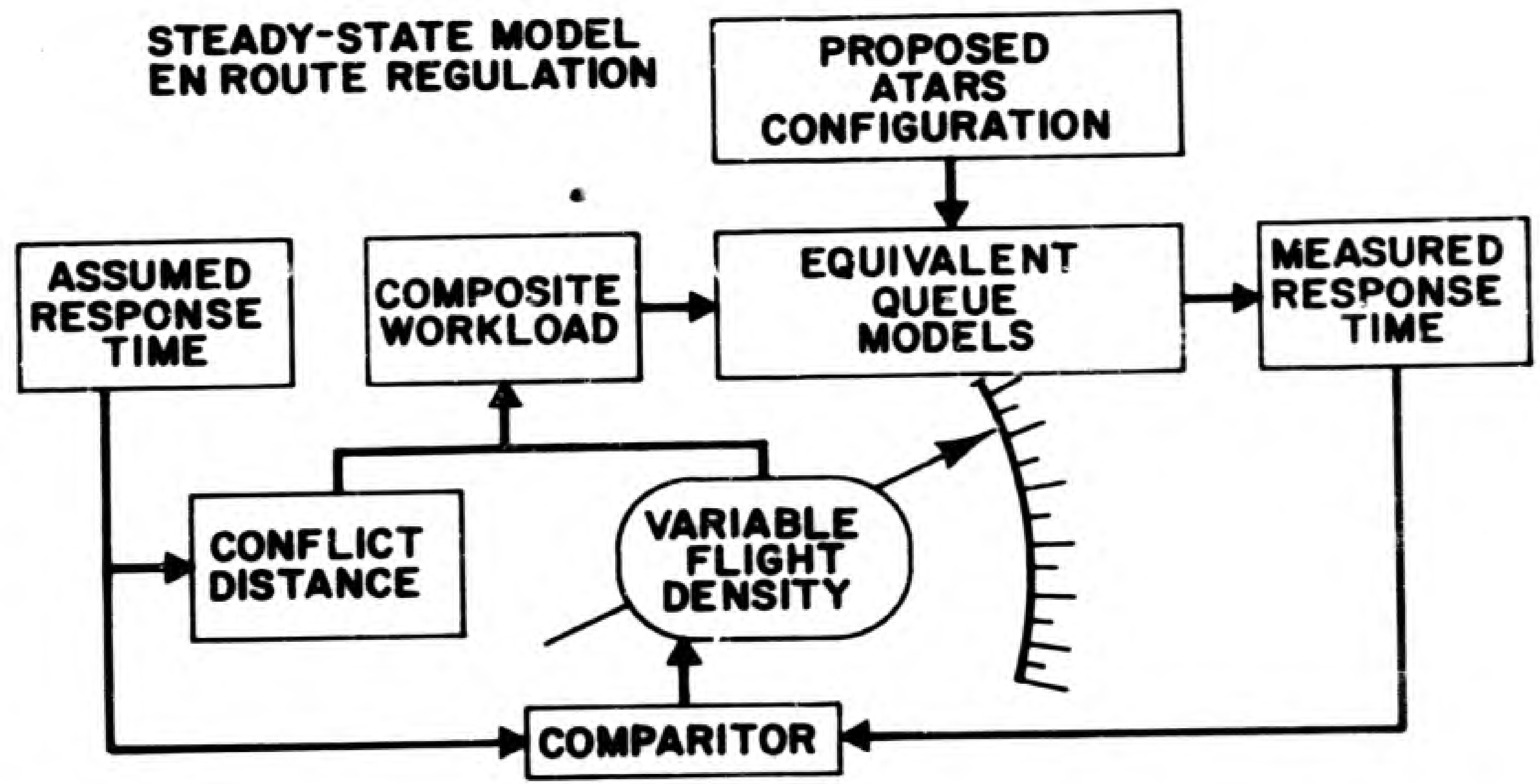
$$W = 2t_p (K-2) \sqrt{\hat{V}(x - S)}$$

FIGURE 9

done by means of statistical models which incorporate equivalent queue models of the proposed systems. The most important of these is the steady-state model encompassing en route regulation illustrated in Figure 10. This diagram represents a busy-hour model based on the assumption of statistical equilibrium which means time is removed from the variables. In the use of the model, the proposed ATARS configuration is inserted in terms of the equivalent queuing equations for the communication subsystem data processing, and the controller.

Response time is the total time in system including service time and expected delay of a conflict from the instant of the initial need for service until it is resolved. We start with an assumed response time and calculate the conflict distance from the equation shown previously in Figure 8. To proceed, the pointer on the variable flight density block is set to any arbitrary value. From the conflict distance and the flight density we determine the composite workload. This is based on the expected number of handovers, and the conflict rate versus flight density shown previously in Figure 4.

Now the composite workload represents the total demand for service. This is inserted in the queuing equations to obtain a measured response time which is compared with the original assumed value. If the measured time is greater, we reduce the density, if smaller we increase the density until the measured time is equal to the assumed response time. Then provided the numbers are practical, the flight density setting is the performance effectiveness for the conflict distance shown. The process is now repeated for a different assumed response time. In this way a curve is obtained for the proposed ATARS configuration that shows its performance effectiveness for en route regulation as a function of conflict distance.



ATARS PERFORMANCE EFFECTIVENESS

FIGURE 10

In conclusion it should be noted that many people have contributed to this ATARS study including Messrs: William Dobias and Gerson Scharf at CSI, Mr. Charles Grossman and Dr. Erwin Biser at U.S. Army ECOM, and the Project Engineers of both organizations. While not yet complete, the results of this study should prove to be a major step forward in Army airspace regulation. Certainly there are problems that remain to be solved but these can be made tractable.

Fortunately the workload requirements on the system remain within reasonable bounds for anticipated flight densities because the conflict rate increases linearly with density. Even so we can anticipate a significant need for automation while keeping the controller in the loop. A program for modular implementation will provide the needed flexibility for different theaters of operation, permitting a choice of manual or automatic ATARS.

Area surveillance is preferred to the more restrictive air corridor method and system effectiveness can be achieved with a minimum of restraint on the pilot and field commander. In addition, an adaptive system concept can be incorporated which adjusts automatically for different velocities, or navigational accuracies to maintain uniform efficiencies and safety factors through all modes of operation.

A WAR GAME ANALYSIS OF HELICOPTERS IN A COUNTERINSURGENCY ENVIRONMENT

E.P. Kerlin

This paper reports on the analysis of a counterinsurgency war game recently completed at the Research Analysis Corporation. The game was developed, played, and analyzed by RAC for the ARCSA II Study Group; (ARCSA meaning: Aircraft Requirements for the Combat Structure of the Army.)

The principal objective of the study was to evaluate the effect of varying levels of Army aircraft on the capability of an infantry division to perform a counterinsurgency mission. The Blue mission was to include search and destroy, search and clear, and security-type missions in the division's area of operations.

The war game, set in Vietnam in 1968, was played as a series of division level situations in which an infantry division, although faced with the same type mission, was faced with differing threats. Three special situations were created as shown on this slide. (Figure 1) They were termed PLEIKU, KONTUM, and DARLAC. Each situation was played three times with a different level of Army aircraft available for each play.

Because of limitations on time, each game was planned to simulate only five days of combat operations. In order to generate a sufficient number of combat missions to keep the division busy during that short period it was necessary for controllers to direct Red unit actions of various types that would logically evoke a response from the deployed US force. Had the games been completely "free" in the technical sense, that is had Red as well as Blue been permitted to plan all his own operations and tactics, it is conceivable that only a small fraction of the operations would have ensued.

The number of aircraft shown here represent a logical mix of LOH and fixed wing aircraft for intelligence purposes, the UH-1D and CH-47 type aircraft for troop lift, logistics resupply and artillery airlift and the UH-1B and Cobra-type gunships for aerial firepower. Sufficient aircraft were assigned to account for the necessary administrative and command and control type functions. By agreement the use of Air Force troop carriers was not played in the games, although it is recognized that for distances over 100 km, C-130 aircraft might be preferable to helicopter shuttles for moving sizeable numbers of troops and equipment. Also, at each level for each situation, 50 tactical aircraft sorties per day were allocated to the division for close air support.

It was intended that the games be designed to encompass a fairly wide range of variables so that the division's ground combat potential and its ability to deploy and support this potential by ground and/or by air means, over increasing distances, would be thoroughly exercised.

The aviation support levels as gamed proved to have a significant effect on the overall operations of the Blue force. Each increase in the support level provided greater capabilities to determine enemy locations, provided greater mobility for combat units and the associated artillery, and provided more effective helicopter firepower.

The duration of combat operations depicted in the games depended on five major factors.

1. The speed of reaction to the intelligence collected.
2. The number and type of forces available for commitment.
3. The ability of units to maneuver on the battlefield.
4. The amount of firepower brought to bear.
5. The tactics employed.

Results of the games indicate that Blue achieved considerable advantage under each of these areas as his airlift capability was increased.

For example, as the level of available aircraft incrased, Blue was able to commit his forces faster, more decisively and at greater distances from the original base area. This increased troop lift capability provided the means for combat units to be more maneuverable on the battlefield. Blue forces could now get behind and on the flanks of Red forces permitting Blue to better utilize his superior firepower.

After Red was located the tactics generally employed by Blue were to move forces into contact by the fastest means available, isolate Red by cutting off the escape routes which precluded Red from grouping into larger units, and then defeat him in detail. The use of these tactics was instrumental in reducing the length and increasing the effectiveness of the operation.

A good illustration of the length of operations can be given by showing (Figure 2) operations from the Kontum area. Certain of the operations shown indicate that not only was it possible to end a given operation in a shorter elapsed time, but it was also possible to begin an operation at an earlier time at the next aircraft level.

We spoke of these operations, in addition to being much faster, as being more decisive. This next slide (Figure 3) indicates, for the Kontum area, how the effectiveness of the Red force was degraded in each game as the aircraft support increased.

As a result of the increased mobility for maneuver units and artillery, plus the effective application of aerial firepower, the Red to Blue casualty ratio showed a favorable increase with increased aircraft support. However, as noted on this next slide (Figure 4) the ratio did not vary uniformly in all games. This variation is attributable mainly to the differences in tactical operations which were conducted and the degree of application of the assessment rules by the three control groups. These differences in application were permissible within the scope of the rules and are considered a logical outcome of games played by three different groups.

Throughout the analysis, attempts were made to compare the division's improved performance with the potential provided by the higher number of available aircraft. The objective was to find that the level of aircraft beyond which the increase in performance was smaller than the increase in potential. The next slide (Figure 5) shows the percentage of troop and artillery commitment and the percentage utilization of lift aircraft at each level. Although the commitment of combat elements tends to increase for each level of aircraft, the percentage utilization of UH-1D troop lift aircraft tends to decline beyond level 2. This decline however, may be attributable in whole or in part to factors other than a decrease in aircraft efficiency. All that can be said is that aircraft efficiency in the troop lift role does not increase beyond this point.

When we consider the percentage commitment of artillery units we note that maximum commitment occurs at level 3 aircraft. Likewise the percentage of maximum utilization for the CH-47 lift aircraft also occurs at this aircraft level.

If, based on other considerations such as cost and organizational control, it was decided that the division should go with the level 2 organization for aircraft, then one could infer from this second curve that more CH-47 type aircraft are needed to attain maximum utilization of the artillery units involved.

Thus far we have discussed overall game results and seen how increased mobility when applied to troop maneuver gave increased combat effectiveness. There are other areas such as intelligence, firepower, and logistics which were also studied in some depth.

As the strength of reconnaissance and surveillance aircraft increased the following results became evident.

The Pleiku area proved to be too small and in the five game days allowed, the Darlac area was too large to gain significant measurement of the effectiveness of various levels of intelligence aircraft. Only in the Kontum area where available equipment permitted an average of 80 percent of the area to be kept under surveillance did the results appear meaningful.

Detections of the enemy combat elements also varied widely throughout the games. The nine Red maneuver battalions present in the Pleiku area were all detected by the third day of each game. In Kontum, 15 battalions were detected by the end of the first game, whereas all 21 battalions were detected by Day 5 in the second game, and by Day 3 in the third game. The Darlac area only had a maximum of 20 battalions detected from the 39 actually present.

The fire support procedures employed during the games were patterned after those used by US division in Vietnam. Troop lifts, aerial resupply missions, and ground movement operations were normally escorted by armed helicopters. Preparation fires were usually delivered in landing zone areas by tactical aircraft, tube artillery, and the aerial rocket artillery in that order. Suppressive fires were then delivered by the escorting weapons helicopters immediately before the lift helicopters landed. The aerial rocket artillery which are heavily armed gunships proved to be an effective weapon when employed in roles of landing zone suppression and follow-on support of the ground operations.

The brevity of game play and the limited extent to which logistics was played prevented a detailed analysis of logistics support requirements. For example, the maximum resupply tonnage delivered by air in any one day was approximately 300 tons. In contrast to this amount, the total resupply tonnage requirements of this division at the level 3 aircraft is about 800 tons per day. Thus the retail delivery of supplies as gamed represented only a small portion of total division needs. However, these results should be viewed within the context of the additional support which was assumed to be furnished by US Air Force aircraft and by other means. The need for Army aircraft for logistical support as gamed is related directly to the maneuver capability of a unit and the extent to which this capability was employed.

In summary I will state some of the general findings of the study.

In the Pleiku area, the small size involved permitted free use of both ground and air vehicles so that the subsequent impact of aircraft was not as pronounced as elsewhere. It was true, however, that in the final game, the division combat potential was so fully exploited that the game play was essentially over in three days.

The Kontum game displayed most strikingly the importance of adequate reconnaissance and maneuver capability. At the lower aircraft levels, the Blue force had a substantial but not decisive capability. However, in the final game the increased lift capability permitted a change in Blue tactics which resulted in a decisive defeat of Red.

The principal finding from the Darlac area was that the size of the area and the threat so taxed the capabilities of the division's maneuver elements that the increased level of aircraft had a much less significant effect on degrading the effectiveness of the Red force.

FIGURE I

Characteristics of Game Operations

Game	Area Size (sq. km.)	Threat	Aircraft Available	
			Number	Lift Capability
PLEIKU				
1	5000	9 Bns.	91	1 Co
2			217	1 Bn (3 Cos)
3			495	2 Bns (6 Cos)
KONTUM				
2	15,000	21 Bns.	217	1 Bn (3 Cos)
3			495	2 Bns (6 Cos)
4			852	4 Bns (12 Cos)
DARLAC				
2	40,000	39 Bns.	217	1 Bn (3 Cos)
3			495	2 Bns (6 Cos)
4			852	4 Bns (12 Cos)

Figure 2. DURATION OF OPERATION: KONTUM

Operation	Level 2			Level 3			Level 4		
	Started	Ended	Total Hrs	Started	Ended	Total Hrs	Started	Ended	Total Hrs
MADISON-1	0715 Day 1	0930 Day 2	26.25	0645 Day 1	1500 Day 1	8.25	0615 Day 1	1440 Day 1	8.42
MADISON-2	0620 Day 2	1030 Day 5	76.017	0820 Day 1	1940 Day 3	59.33	0735 Day 1	1000 Day 3	50.25
SUPERIOR	1000 Day 1	1400 Day 5	100	0930 Day 1	0800 Day 4	72.50	0945 Day 1	0600 Day 3	44.25
OMAHA	0650 Day 5	Not completed		0210 Day 4	Not completed		0835 Day 3	Not completed	
DETROIT	0600 Day 5	Not completed		0010 Day 4	Not completed		1330 Day 1	Not completed a/	
FARGO	1200 Day 2	Not completed		0700 Day 1	Not completed		1330 Day 1	0600 Day 3	74.50
CHICAGO	Enemy known No operation			1450 Day 3	Not completed		0610 Day 3	Not completed a/	
SOUTH BEND	Enemy known No operation			1650 Day 3	Not completed		1045 Day 3	Not completed a/	

a/ Fighting continues, but enemy unable to attack and is attempting to withdraw.

Figure 3

PERCENT EFFECTIVENESS OF RED FORCE (BY DAY)

KONTUM: RED STRENGTH–30,550

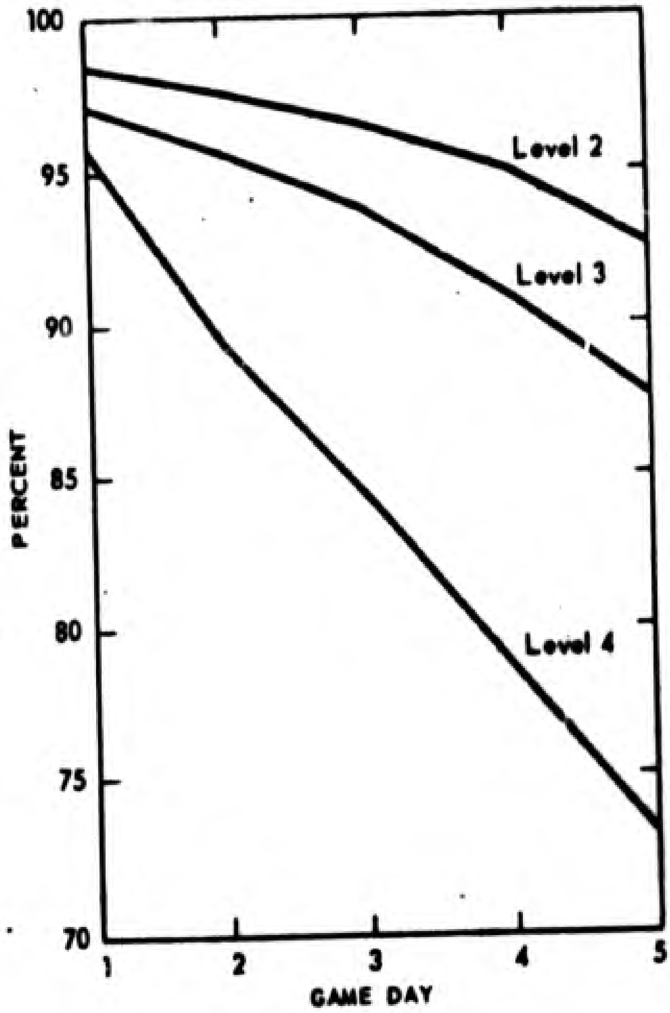


Figure 4.
OVERALL CASUALTY RESULTS (U)

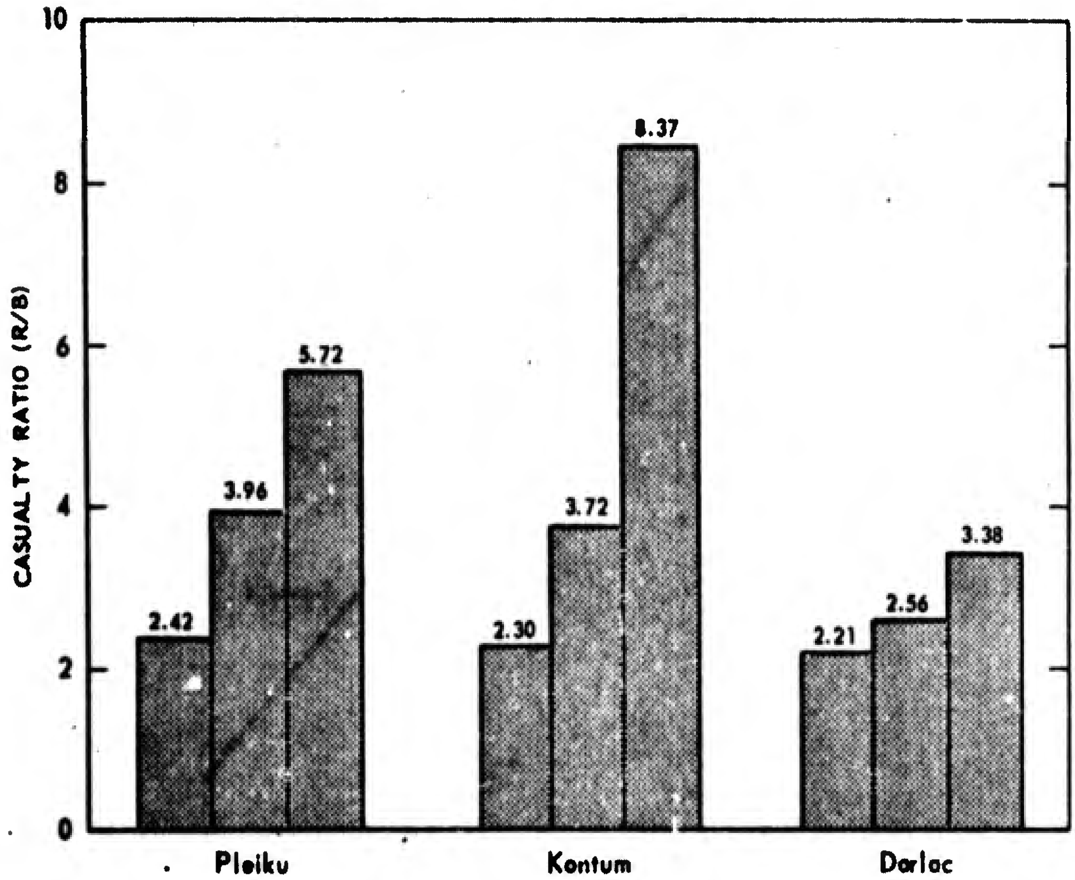
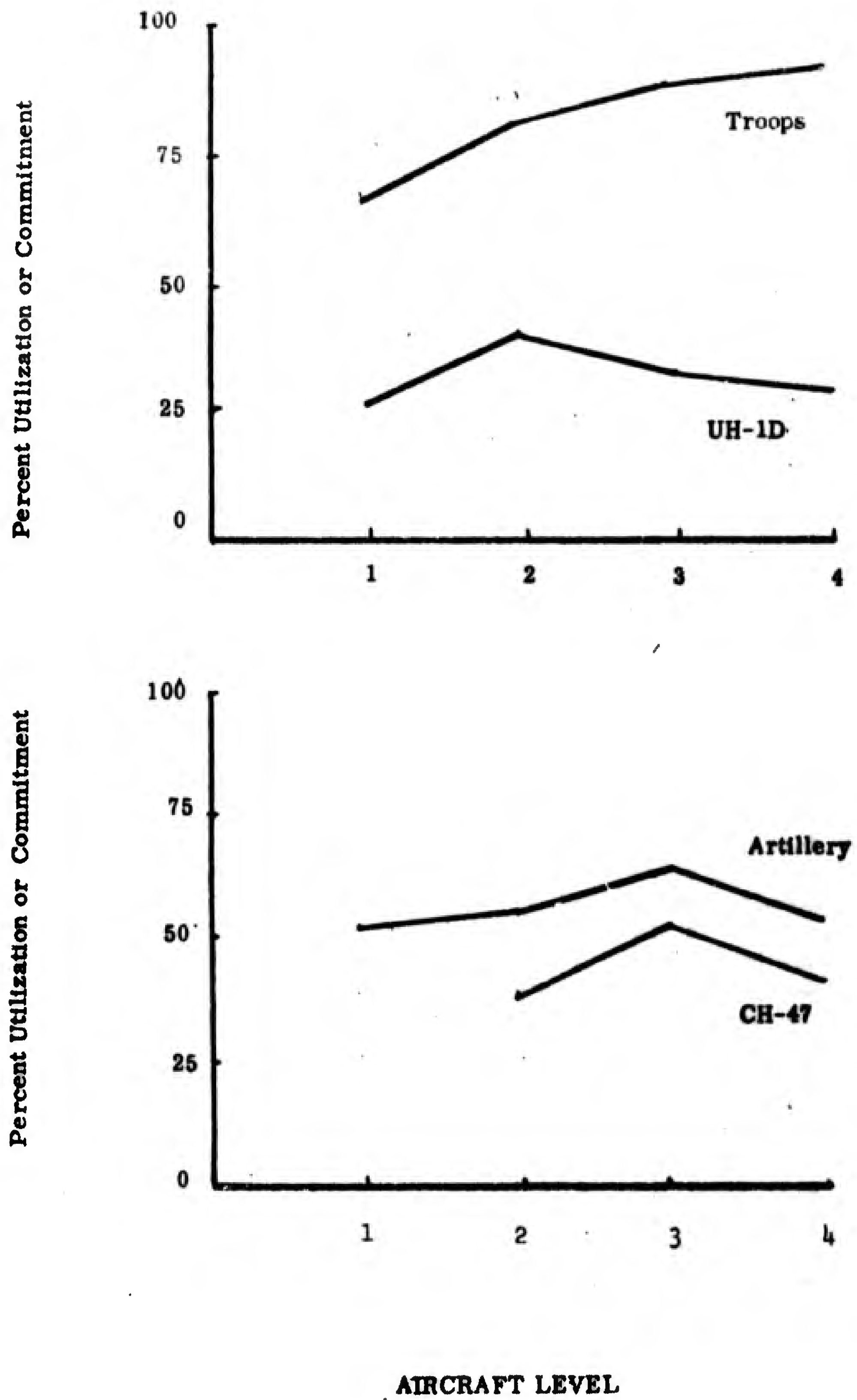


Figure 5.

Utilization of Lift Aircraft and Commitment of Troops and Artillery



ARMY STRATEGIC MOBILITY
PLANNING AND ANALYSIS PROBLEMS

CPT Gerald G. Wisz
Office of the Assistant Vice Chief of Staff, U.S. Army
Force Planning Analysis Directorate

GENERAL

(U) The present policy of the United States is to have a certain degree of strategic mobility, namely, strategic airlift, strategic sealift and prepositioning of materiel to meet world-wide contingencies. Our general strategic objectives are, first, to deter aggression, and second, to the extent that we cannot deter it completely, to limit it in form, locale and duration. The capability for early and rapid response by substantial forces serves both objectives. Studies by the Joint Chiefs of Staff and the Services have consistently concluded that such a capability could lead to avoidance of conflict or, in the event of conflict would lead in most of the situations examined to shorter wars, smaller total U.S. force commitment, fewer casualties to American and Allied soldiers, and less destruction to the threatened country and its inhabitants.

(U) What options are available to accomplish this mission of early and rapid response? We have a choice of a combination of transport systems and degrees of peacetime basing of combat units with their associated equipment and support. Considering the whole spectrum of possibilities, hypothetically, all our forces may be located overseas or they may all be retained in CONUS to be deployed when necessary. Or, more realistically a combination approach with some forces overseas and a strategic reserve in the United States with a capability to deploy rapidly may be followed. Materiel may be prepositioned overseas for marry-up with units stationed in CONUS upon their arrival in the theater of operations, or it may be moved in with the troops. Choices of the transport system must be made between quantities of air, sea, and ground capability and appropriate mixes within the type.

(U) The present and programmed improvement in U.S. airlift will significantly influence the rapid deployment posture of the Army. The major resources becoming available in the near future will be the heavy lift aircraft (C-5A) and hopefully fast deployment logistic (FDL) ships. In view of the recent Congressional testimony on the FDL program, it is apparent that further efforts are required to sell Congress on the program. From past and current studies, it is clear to the Army that the concept and acquisition of a fast surface logistic transport for the 1970-1980 period is required if the Army is to maintain a balanced and flexible response to support future contingencies. These new resources raise the question of what quantities should be procured and how can this improved mobility potential be effectively utilized by the Army.

OPTIMUM LIFT-MIX

(U) This improved capability requires detailed study to determine the optimum mix of C-5A aircraft, ships, and prepositioning of materiel to meet the U.S. Army strategic deployment and resupply requirements to support the rapid strategic deployment strategy as postulated by the Army planners. The problem is to develop an optimum strategic lift-mix for various contingencies in the 1970-1980 time frame. The strategic lift resource requirements in the optimum lift-mix would then be utilized by the Army planners in developing future strategies and capabilities and would provide Army requirements data to the Office of the Secretary of Defense for future budget decisions.

(U) The optimum lift-mix must be balanced in terms of types of resources so as to complete deployments in various parts of the world. A lift-mix system would not be effective if it was designed to accommodate only regional contingencies. The design of a transportation system to cope with single regional contingencies or to meet the requirements of the most demanding contingency in terms of speed of response could be accomplished but at the risk of an unbalanced and inflexible system. Such a system would not be adequately capable of responding to multiple conditional contingencies in various parts of the world. The Army planners are concerned with achieving a flexible system which could respond to a contingency in area A plus a contingency in area B or area C or area D. These contingencies could represent diverse missions of reinforcement or the fighting of a major non-nuclear war or the fighting of a minor war. For example, the Army may be required to reinforce area A, support a major non-nuclear war in area B or C or D and support a minor contingency in area E.

(U) The next step for the Army planner would be to develop detailed scenarios for the future postulated conflict areas. War gaming and/or simulation programs would now be used to develop a time phased deployment profile for the major tactical forces, supporting elements, and supplies required to achieve the Army's combat mission.

(U) Upon the determination of a deployment profile in terms of number and type of division force equivalents, the men and materiel in these divisions must be converted into commodities for movement. The conversion usually is made into short tons, and equipment outsize to specific transportation resources, that equipment which will not fit into a specific carrier, must be determined. The capabilities and characteristics of the various competing modes of transportation must also be ascertained.

(U) We now arrive at a difficult and complex analysis problem of selecting the least cost combination of transportation assets which will enable the Army to meet its specific deployment profiles. A world-wide transportation network must be adequately quantified to a degree of resolution which will provide meaningful solutions. This task would be infeasible to accomplish without the use of a computer model. Through mathematical techniques, a least cost transportation system must be developed to satisfy the Army's simultaneous deployment requirements. Once a least cost combination of transportation resources is determined, there may also exist the need to examine with more resolution the capabilities and delivery profiles of this or any other combination of resources with the objective of maximizing the flow of men and materiel through the transportation network and the effective use of a given set of resources.

(U) Now, if we consider a strategic mobility system as a complex network of nodes and arcs, the problems discussed so far were centered on the arcs of the system, the inter-theater movements. There are further problem areas on the nodes of the system which consist of CONUS and intra-theater constraints. The details of these nodes as well as the interrelationships between these nodes and their respective arcs must also be analyzed if the true potential of the major delivery systems is ever to be realized. A complete description of a strategic mobility system must contain a recognition of the total network including nodes and arcs. The funds allocated to a strategic mobility posture or program must be properly allocated among the competing uses of transport means, and improvement of CONUS and intra-theater constraints.

CONUS CONSTRAINTS

(U) Let us now turn to a consideration of some of the CONUS and intra-theater constraints. The units in CONUS have on hand varying levels of manpower and equipment and are in a certain state of training. The readiness capability of these units to assume combat is reflected in readiness indicators such as C1 and C2. The functions performed in CONUS, relate to the attainment of a deployment posture, staging, and CONUS movement. To attain a deployment posture, the following tasks must be accomplished:

1. Take action to obtain fillers and complete training.

2. Inspect, inventory, and repair equipment to accompany the troops.

3. Identify unserviceable individual and organizational equipment and requisition replacement equipment to accompany troops.

To accomplish the staging function the following tasks must be performed:

1. Personnel processing and receipt of fillers.

2. Receipt of supplies.

3. Inventory and turn-in of non-deploying supplies.

4. Installation clearance.

5. Packing and marking equipment.

6. Outloading deploying equipment and personnel.

   a. Transit times to port.

   b. Loading at home bases and ports.

(U) The functions of attaining a deployment posture and staging do introduce time delays in the strategic mobility system. These delays are eventually reflected in the delayed arrival of troops at a theater. Some of these delays may be capable of reduction through investment of funds and scheduling techniques. Other delays would be too costly to reduce and must be considered as inherent to the system. System trade-offs should be obtained between the CONUS systems and the availability and scheduling of inter-theater transport.

INTRA-THEATER CONSTRAINTS

(U) Turning to intra-theater constraints, the system delays due to the marry-up process should also be considered. The delays incurred in this process derive from the following tasks:

1. Transit requirements and times from airfields/ports to prepositioning sites (for equipment already prepositioned).

2. Activation of stored equipment to include required servicing and repairs.

3. Issue of the equipment.

4. Shakedown of equipment and orientation of troops.

5. Movement from equipment site to area of commitment.

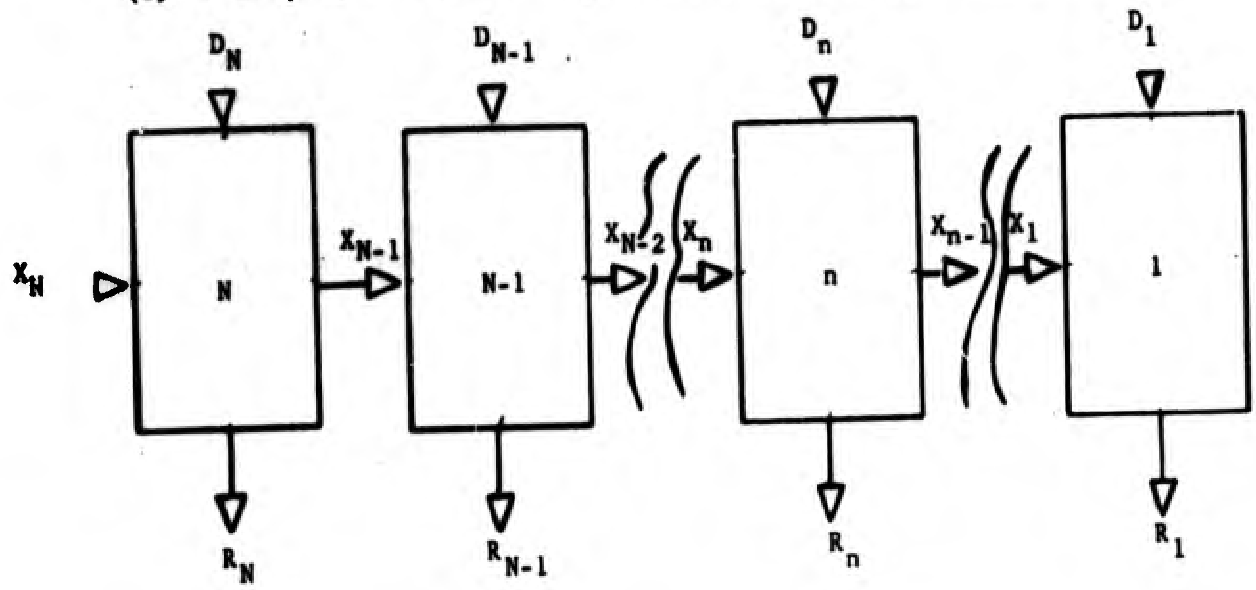
The throughput capacities of ports and airfields must also be considered as part of the delays in the marry-up process.

(U) The shakedown tasks will consist of activities such as: drawing and issuing of authorized levels of supplies, weapons firing and testing, and inspection of equipment. Again, through the investment of funds and use of such techniques as controlled humidity storage sites the time delays in the marry-up process could be reduced. System trade-offs should also be considered here between the marry-up process, LOC constraints and throughput constraints on ports and airfields.

<u>STRATEGIC MOBILITY SYSTEM</u>

(U) The problem of strategic mobility described in the preceding paragraphs may be viewed as a sequential multi-stage decision process. The strategic mobility system consists of a number of specified activities which are sequential in time. Decisions are made for each activity and the system effectiveness depends on the various decisions made over time.

(U) A diagram of a multi-stage process would be as follows:



(U) The input to a stage is characterized by a vector X_n (state vector) which provides all the relevant information about the input to the stage. The decision is characterized by the vector D_n which specifies the operating conditions for stage n. The output is given by a vector Y_n ($Y_n = X_{n-1}$) which contains all the relevant information about the output. The output of a stage is a function of the input to that stage, the decision or operating condition, and uncontrollable conditions at that stage. R_n is a scalar quantity which represents the stage return and which measures the effectiveness of the stage. The return R_n at stage n is a function of the input, decision, and stochastic variables of that particular stage. The objective is to maximize the returns over all stages and all decisions.

(U) It should be noted that the decisions made at each stage are interdependent, for the input to a stage depends on decisions made in the latter stages. Given the functions described above, the objective is to optimize some separable function of the stage returns, namely

$$\max \sum_{n=1}^{N} R_n (X_n, D_n)$$

(U) The strategic mobility system could be described in terms of the mathematical framework just developed. The stages in the process could represent the various activities as the following:

1. Attainment of a deployment posture.

2. Staging.

3. CONUS movement.

4. Loading at home bases and ports.

5. Inter-theater movement

6. Unloading at theater ports and airfields.

7. Marry-up functions.

8. Movement to the FEBA.

(U) The input vector (X_n) to each stage would consist of the number of personnel and quantity of equipment passing through the system at given intervals of time, for example, at D+5 a specific unit may have attained a deployment posture, may have completed its staging function and may be available for transit to port or airfield. The decision (D_n) at each stage would represent the amount of funds invested in a particular stage or activity, for example, for a given amount of investment certain ports may be improved or bases may be collocated with the ports so as to reduce the transit time in CONUS. The output (Y_n) from a stage would represent the flow of men and materiel at given time intervals upon completion of some activity.

The output of the inter-theater transportation stage could represent the flow of men and materiel to a theater, given the investment of funds in a certain level of transportation resources and given the time phased availability of men and materiel to utilize these resources. The flow of men and materiel from the ports and airfields of debarkation to the theater LOC would depend on the investment of funds in off-loading capabilities and the arrival of the inter-theater transports. The return (R_n) for each stage or activity would be the cost incurred at that stage. Cost may consist of an investment of funds or a degradation in the flow of men and materiel at a stage due to lack of sufficient funding for a specific activity. The objective would be to find a decision rule which determines what to invest at any given stage to minimize expected costs in the long run.

(U) Moreover, since the theater commander has as his objective function, a specific profile of delivery of men and materiel over time, an optimal decision process may regard this profile as a constraint on the system which must be satisfied, or an optimal decision may minimize costs and the expected deviation between the theater commander's profile and the actual profile.

(U) By considering the strategic mobility system as an interrelated process and by obtaining decisions which optimize the system, it would be possible to arrive at a balance between the inter-theater and intra-theater aspects of the process. The intra-theater transportation system affects and is affected by the inter-theater system. The preferred inter-theater system might be one which contained a large number of planes and very little sealift. This in turn would lead to an intra-theater system designed to handle many aircraft able to operate close to the combat zone, whereas if the inter-theater system was heavy in sealift it would be necessary to provide support and maintain LOC's from the ports to the combat operations occurring inland.

ROLE OF MODELS

(U) The magnitude and complexity of the major systems associated with the inter-theater, intra-theater, and CONUS processes and consideration of the realistic constraints contained therein, almost eliminate the possibility of using a single model to arrive at meaningful solutions to the problems posed by a strategic mobility system. An approach would be to develop sub-models to study each major system. These sub-models should be cast in a single system environment, with appropriate routines to allow for as much compatibility as possible and as a minimum that all these models operate off the same data base. The use and analysis of these models should reflect the multi-stage process of the strategic mobility system and deal with such factors as origins in CONUS, unit readiness dates, speed of deployment, port, and airfield throughput capacities and other activities in the system. The relevant role of various sub-models in the strategic mobility process could then be addressed by extensive operational experience with these models.

CONCLUSION

(U) In conclusion the following points may be made:

1. In planning to meet its commitments in the 1970-1980 time frame, the Army is planning and participating with the Defense community in developing a balanced inter-theater, CONUS, and intra-theater transportation program, consisting of transportation resources and various levels of prepositioning.

2. The capabilities of the current and planned transportation resources are being continually analyzed by the Army to insure that the goals of rapid and flexible response can be achieved.

3. The strategic mobility system is properly viewed as a dynamic interrelated multi-stage process the optimization of which consists in making valid investment decisions on the CONUS, inter-theater and intra-theater aspects of the system.

Colonel Allen P. Blade
Army Research Office-Durham
Session IV-B
"What Are You Doing?"

As a result of a symposium held here several years ago, it was recommended and approved by the Director of Army Research that we undertake the preparation of an Operations Research text. The idea at that time was to develop a text which would have general application in the Army, but be particularly useful to the service academies in their advanced courses and to the military service schools. A Project Advisory Group was appointed which included representatives from the Institute for Advanced Studies at Carlisle Barracks, Pennsylvania, the Military Academies, Post Graduate service schools, Combat Developments Command, CONARC, and scientists of some major commands. One of the principal colleagues of the symposium at that time, Dr. Herbert Gallihur, prepared the first draft. It had as its original goal to illustrate the mathematical techniques of quantitative analysis, to foster an appreciation of recently established studies and use of technical terminology within the area, and to develop the reader's intuitive capability to recognize and exploit applications of Operations Research in the Army.

As a result of difficulty the author experienced in acquiring specific information, together with the remarks and advice of the Project Advisory Group, the project became modified somewhat to the way it stands today. I would like to read to you some of the chapter headings. Those of you who have not seen the text may recognize the type of approach, and may wish to ask us questions about the content a little bit later. The chapter headings in this draft are: Operational Uses of Vectors, Matrices, Graphs, and Networks, Military Uses of Probability, Poisson and Related Random Processes, Markov, State and Renewal Processes, Activity: Forms, Patterns, Structures, Constrained Optimization, Programming Linear Activity, the Simplest Military Games, Systems, Stochastic Service Systems, System Reliability, Supply Systems, and Combat. The title of the volume is Mathematics of Military Actions in Operations Systems. This is a second draft which has been distributed for review and reflects the comments on the first draft, which was distributed only to individuals on the Project Advisory Group. We realize that a text of this sort cannot satisfy everybody. Some say it is still pitched at too high a level, and lacks detail and examples. That criticism of some time ago is less emphasized in current review comments, when it is recognized that the text cannot do more than serve as a basis or reference for many specialized service uses, such as student needs at the various CONARC branch schools.

Presently, we are seeking comments from all of you to provide examples for us so that we can come up with a publication that is all it should be, i.e., a mathematical military guide for use of Operations Research. Some of the local members of the Project Group, in addition to myself, are here to answer questions. COL Entwhistle acts as prime contractor to ARO-D. Dr. Marion Bryson, Professor of Statistics, provides technical help in editing. Dr. George Nicholson, Chairman of Statistics at the University of North Carolina, also helps us on content decisions.

In looking over the list of attendees at this meeting, it appears that a number of you, who have not been solicited for comments, should have copies of the draft for review. If you will ask or write to us here at ARO-D we will be pleased to provide copies for review. In turn, we will appreciate your comments as soon as possible in order that we can seek publication for more general distribution within the military by September of this year.

I might take a moment here to read one review. This review, which we have received from the Advanced Studies Institute, we think pretty well expresses what the purpose of this text should be, i.e.,

"1. The text is a useful reference work for the reader who is extremely well versed in the fields of mathematical statistics, decision theory, systems reliability and effectiveness, determination of optimal strategies, probability, and operations research.

2. The subject matter of the text is quite comprehensive and appears to include the vast majority of problems or types of problems that the Army has.

3. A good technical terminology has been developed and good definitions are given for many of the terms within the text.

4. The references cited in the volume are reasonably current and unnecessary depth is avoided in the large number of techniques displayed.

5. For the technical and mathematical user the text is well suited as a handbook where there is no doubt about the applicability of the theory. It also, generally, serves well as a guide for the development of solutions where practical need arises.

6. Though not designed specifically for the non-technical. non-mathematical user, the text provides many well written sections that readily serve as explanations of some of the problems of the non-technical military user.

7. The text does provide methods and references to methods for most standard problems and, therefore, provides a jumping off point for unsolved or similar problems. However, since many of the presentations are quite abstract, the non-technical military user will be lost and even the more senior technical people would need to go to the references for more information if they had not used the technique before. The text in its present form seems best suited for a somewhat select, specialized user."

Do we have reactions from the service schools on the value of the text? Yes. Frankly, that is probably the most difficult remaining problem in connection with the purpose of the text, i.e., its use by all schools in the Army. It will provide some instruction on Operations Research, but it is quite basic. This poses a very difficult problem to people like CONARC, who have some 26 schools and need student texts. Fine officers go to the schools, but often they don't possess what is generally considered to be two years of college mathematics required to use the text. We do feel that we can accomplish the designed purpose for the Army if we can incorporate examples and recommendations from people like yourselves. However, we do have a better report on progress of the project at this time than we did for your symposium last year. As time progresses, we think the total objectives of the OR text are seriously hampered because we've lost so much time. We need all the help we can get. So again, those of you who do not have copies of the draft text and are willing to assist with constructive comments, please ask us at ARO-D for copies to review. We will appreciate your in-put.

Mr. Cecil D. Johnson
US Army Behavioral Science Research Laboratory
Session IV-B
"What Are You Doing?"

The Behavioral Science Research Laboratory has a number of tasks in the area of Operations Research. However, I am just going to mention a couple that straddle human factors and OR and then center on a particular research project that is definitely in the Operations Research area.

To begin with, our laboratory has a CDC 3200 computer with 32K memory with discs, and has a battlefield surveillance research laboratory on-line with this computer system. It has random access slide projectors, CRT's, special consoles, etc. The research accomplished in the on-line surveillance research laboratory is a mixture of OR and human factors research.

For the remainder of my time I am going to talk about our Operations Research mission in the statistics division of BESRL. (Vugraph #1) Our approach to the Optimization Models Task is to first analyze particular personnel sub-systems. We focus on a particular function in an area where management has asked us to minimize or optimize some particular outcome that becomes our objective function -- it may be the number that has to be reassigned or it may be predicted performance on the job. At any rate, we focus our attention on one particular point in the total system. We formulate the problem and develop algorithms, then place these on our computer, and finally we evaluate them. The method of evaluation might well be, in the future, the SIMPO type model which I'm going to talk about as the main part of this discussion.

I will mention later a number of personnel functional categories in which our laboratory and DCSPER are particularly interested. (Vugraph #2) In the past few years, we have developed a number of simulation models of different types; in which we have studied, simulated, and evaluated personnel policies within one or two of these personnel functional areas with the intent that the model should show the interactions or trade-offs either within or across only two or three of these functions when a personnel policy is changed. The change may have particularly strong impact on one of these functions, but in general there are certain kinds of trade-offs with respect to the rest of them. The capability of studying these effects across more of these functions is a strongly felt need in both OPO and DCSPER.

Our laboratory has developed a number of more specific models in response to the needs of the Under Secretary's Office, ACSFOR, the Programs and Plans Office of the Office of Personnel Operations, and the Chief of Staff's Office. These models could be strung together in a rather crude way. However, when we look at the ambitious desires of the customer, we feel that rather than trying to string together the various specific models, we should first do a complete personnel policies and operations concept analysis.

The first four sub-tasks of SIMPO (Vugraph #3) will essentially be developed simultaneously; we will work on all of these at the same time. We will have to do a special kind of operational analysis of the personnel sub-system - with special orientation for the kind of modeling we intend to do. We must catalog and do a certain amount of re-working with existing models in order to make them compatible - for inclusion in a library. We must talk further with management in order to develop the concepts we need, in order to lead to appropriate measures of system effectiveness. We must then proceed to develop our models and go through our design and computer programming phases, then evaluation of the simulation models, and finally the development of a problem-oriented language for management.

Tomorrow, Dr. Sorenson will be presenting a paper on a generalized model here at Durham. This model has quite a bit of capability for simulating selection, allocation, and assignment policies in procurement and distribution functional systems.

A couple of years ago at one of these conferences, Dr. Sorenson presented a paper on a flow model which determined the feasibility of certain policies in regard to rotation policies, e.g., with regard to determining whether a particular rotation base would sustain the manpower requirements, say, in Vietnam. This has been converted into a dynamic model with considerable capacity which will permit us to designate four major kinds of tour categories and as many as 30 or 40 different kinds of tours. The connection between these tours can be indicated at the time of execution. We then project this through time to determine the effects of the particular policies being modeled - whether the policy set is feasible, and what the effect is on other system variables. Both of these approaches, the one reported previously and the one being reported tomorrow, will be used in SIMPO.

The concept of SIMPO I am about to present in a flow chart form is still very tentative; the final product may look very much different. What I will show in the next three Vugraphs is essentially a vertical slice - beginning with a computer generated sample from an input population. (Vugraph #4) The first chart shows the procurement and allocation functions.

From a training model (Vugraph #5) we can depict training policies and effects with respect to the quality of personnel that are going to result from training policies. We can also depict on-the-job training. We will have a distribution model that will show world wide requirements, then the program providing the sequential continuity will be able to go into a rotation-promotion model which will be essentially like the dynamic flow model that I mentioned before (Vugraph #6). We have in presently existing versions of this latter model provision for stochastic kinds of inputs and outputs to show things like casualty rates in Vietnam.

The user of SIMPO will generally be concerned with certain policies for which many of the modules are not critical, and thus we will want to be able to by-pass certain parts of the model at our discretion

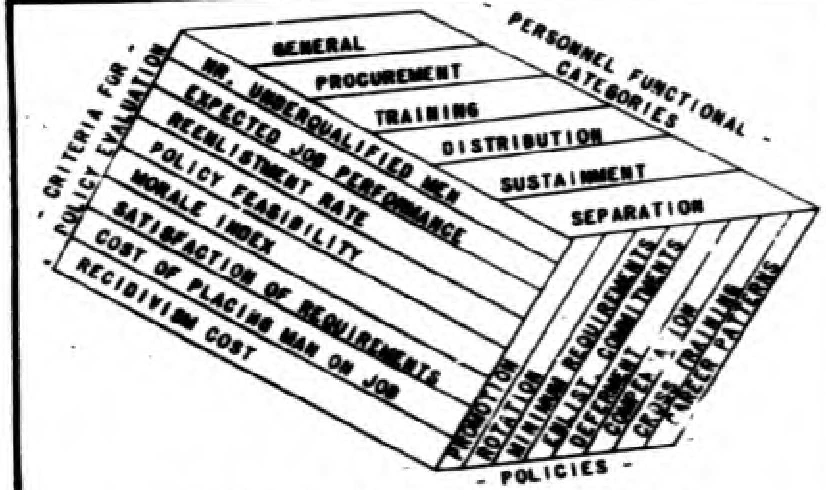
In the development of SIMPO during the next two years, we will be conducting operational analysis, designing models, testing of models for sensitivity and fidelity, and aiding in the implementation of the system as a management tool (writing manuals for both management and the ADP centers that provide computer support to management).

OPTIMIZATION MODELS TASK

Methods of Approach

1. Analysis of particular personnel systems
2. Development and adaptation of optimization algorithms
3. Use of computer models to evaluate alternative procedures and policies
4. Consult regarding application of quantitative techniques for management

VUGRAPH #1



RESEARCH CUBE FOR PERSONNEL OPERATIONS

VUGRAPH #2

SIMPO

RESEARCH SUB-TASKS

a. Operational Analysis of Personnel Sub-System

b. Cataloguing and Integration of Existing Manpower M.dels

c. Development of Me.sures of System Effectiveness

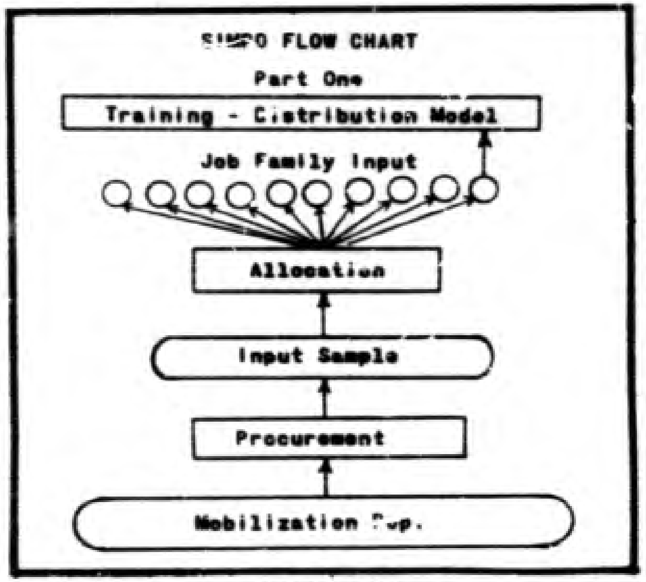
d. Development of Modeling Techniques

e. Design and Programming of SIMPO

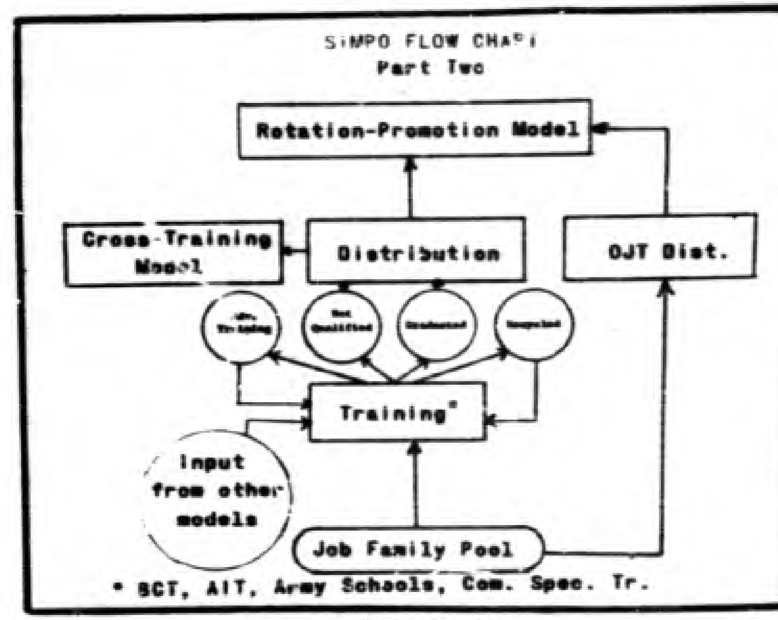
f. Evaluation of Computerized Models

g. Problem Oriented Language for Management

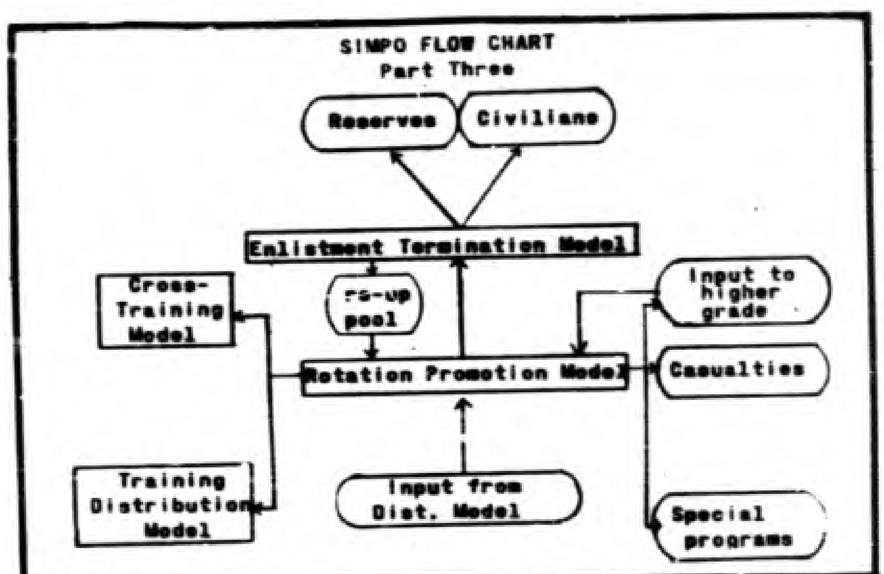
VUGRAPH #3



VUGRAPH #4



VUGRAPH #5



VUGRAPH #6

Major Herbert C. Puscheck
United States Military Academy
Session IV-B
"What Are You Doing?"

I. INTRODUCTION:

Operations Research and Systems Analysis have as many definitions as there are analysts. For our purposes during the next fifteen minutes, we shall mean that electic, pragmatic approach normally called "The Scientific Method." Specifically, we mean this quantitative approach as it is applied to operational problems. I shall take no notice of any difference between Operations Research and Systems Analysis. Any difference would be more apparent than real and quite unimportant when applied to undergraduate education.

All of you are, directly or indirectly, associated with military Operations Research, for the military is still the biggest user of OR skills. It is self-evident, I believe, that Operations Research at the Military Academy will eventually and inevitably affect the men in uniform with whom you work.

I shall discuss OR/SA at the US Military Academy today. First we will place this instruction in proper perspective and then take a quick look at typical problems which are discussed in Operations Research oriented courses. Certainly we will break no new ground - no great advances - in this area.

II. PERSPECTIVE:

The United States Military Academy is an undergraduate institution now finishing its 165th year. Educational programs are broad in order to support the Academy in its mission of developing those qualities and attributes essential for each graduate to continue his career development in the US Army. Each cadet takes a minimum total of 158 credit hours, of which 10 credit hours, or four courses, are electives. Cadets may restrict their electives to an area of interest. There is no majors program, however. In 1961-1962, following the recommendation of leading educators, the Dean of the Academic Board ordered a study to determine the extent to which Operations Research should be added to the curriculum. Incidentally, General Westmoreland was then superindendent of the Military Academy, and took an active interest in this new subject area. Slide 1 shows electives currently taught which have an Operations Research slant. My own bias is for the two courses (Management Engineering and Operations Research) with which I am associated. These are the courses which focus on quantitative approaches - more pragmatic than rigorous, concentrating on useable methods. The courses are quite popular, as you can see. More on this in a moment. The mathematics with which all cadets are equipped during their first two years, a minimum of 23 credit hours, is summarized in Slide 2.

I might add that in addition to cadet courses, a one night per week semester course on "Systems Analysis and Computer Assisted Decision Making" is available for interested personnel - both military and civilian.

III. SCOPE OF COVERAGE:

It is our purpose in OR to instill a grasp, understanding, and appreciation for the philosophy of Operations Research: to quantify those aspects of a problem which can be quantified; to take maximum advantage of experience and data. In this we are not alone. We are unique, however, in our desire to illustrate various concepts with military examples. To date, it has been difficult to develop adequate military examples which are simple enough to handle in a classroom, yet somewhat realistic. I should emphasize one point: we do not attempt to develop OR analysts. However, we feel we do bring science to the battlefield.

In addition to classroom lectures, the cadets work with the 3 GE 225 computers and 15 remote terminals scattered around the Academy. They work on individual and group projects in Management Engineering, present short discussions of selected articles in Operations Research, study and critique a Systems Analysis study in Defense Economics, and hear a number of noted lecturers. The past few months have seen Dr. Martin Brossman of RAC lecture on "Wargaming;" LTC Robert Gard, Special Assistant to the Secretary of Defense, discuss "Decision Making in the Department of Defense;" Major Carl Hess, OCRD, lecture on a particular problem, the problem of target coverage with multiple volleys; and Dr. Laurence Lynn, the Director of Strategic Mobility and Transportation Division, Office of the Assistant Secretary of Defense (Systems Analysis), lead a televised panel discussion of Systems Analysis in the Department of Defense.

With this brief background, let us look at a few of the problems which are attacked by cadets in their various OR oriented elective courses.

IV. SPECIFIC PROBLEMS:

A. Jacket Problem: (1 Slide)

This rather simple example presents the problem of how to allocate excess inventories to optimize a criterion function. Needless to say, a first guess is almost always to use the mean as a basis of distribution. A hand approach using simulation illustrates one method of solution. This approach is then expanded to include computer simulation and more complex problems. You may enjoy toying with a pure analytical solution to this problem.

B. Optimization Search: (2 Slides)

An engineering design problem is presented by the Department of Civil Engineering. This slide shows an example developed and used last year by COL C.H. Schilling, the head of the Department. The sketch shows an area within which one must locate a rocket site. The cadet must select values for three variables, X, Y, and Z which correspond to the X and Y coordinates and the elevation of the rocket pad. The measure of effectiveness is dollar cost. The costs naturally vary with the terrain since different drainage requirements must be met. The elevation affects cost of concrete which increases with increasing Z and with drainage for which the cost decreases with increasing Z. The problem was approached gradually. First the cadets picked X and Y and tried by hand to find an acceptable Z. Later the computer provided the value of optimum Z and the saving in cost. Finally a computer program was used to find the optimum X, Y, and Z using the gradient-search technique. This slide shows the isocost curves, which were plotted by the computer, superimposed upon the layout sketch.

C. Base Stockage Problem: (1 Slide)

Our Operations Research Course (OE 487) uses the publications shown on this slide as the basis for a study and and critique of an inventory policy which is now being tested by the Air Force on selected high cost, low demand, essential items. This study could well have important effects on future Army supply policies.

D. Linear Programming: A Case Study: (1 Slide)

This semester the elective on computer science fundamentals is using a battalion level war game in lieu of a final exam. Opposing forces, Red and Blue, are engaged in a portion of West Germany. The time frame is based on five minute intervals. Terrain is classified by five different designators on kilometer square sections. Incidentally, this is the first time that a war game such as this has been used at West Point. The game is open-ended and is in actuality a large scale simulation. Cadets will likely add to the basic program: such variables as weather, air strikes, etc. could be added. The game was developed by Major J.R. Parker at Arizona State and offers a great deal of promise. It might be used in various tactics and military history courses in the future.

V. PROBLEM AREAS:

Naturally we have a numbers of difficulties in our program. Briefly I would list:

1. Measure of Effectiveness: How do we measure the effectiveness of a single course or group of courses? There is a possibility of using the graduate record exam to compare selected results of those who take certain courses with those who do not. This is not done now.

2. Time: Certainly one never has enough time. This is particularly true with electives which are themselves a two-edged sword. As a course becomes more compact and hence difficult, the enrollment drops. The instructor is himself confronted with an Operations Research type of problem - a most unfortunate development.

3. Approach: But time also affects approach. How can we give a proper grasp of the Operations Research approach without discussing techniques? And how can one teach techniques without underemphasizing the most important "Systems Viewpoint?" Our solution is satisfactory, but not ideal.

4. Coordination: It is always difficult to closely coordinate all work in an area which must, of necessity, be taught by many departments. This is a problem we hope to live with rather than "solve."

5. Military Slant: Few texts offer sufficient usable examples with a military slant. Those texts which are available are almost always directed at an audience with a totally different background.

VI. SUMMARY:

In summary, we are proud of our accomplishments in the last few years. We feel that all cadets, but particularly those in the OR electives, have a good appreciation of the OR discipline. Most, nearly 3/4, will later take graduate study. Many will then study OR in greater depth.

USMA ELECTIVES

INVOLVING

OPERATIONS RESEARCH/SYSTEMS ANALYSIS

PRINCIPAL COURSES

	Course	No. of Cadets Enrolled 66-67	67-68
MA 481	Linear Algebra and Linear Programming	44	5
MA 486	Numerical Analysis with Digital Computation	21	24
SS 482	Applied Economic Theory	30	43
SS 483	National Security Seminar	98	223
OE 385	Management Engineering	225	184
OE 487	Operations Research	17	27
EF 382	Computer Science Fundamentals	129	83

ASSOCIATED COURSES

PL 431	Managerial Psychology	120	160
EL 483	Digital Computers	22	19
EL 484	Information Transmission	7	7
EL 487	Automatic Control Systems	5	5
MA 482	Abstract Algebra	10	7
CE 484	Individual Engineering Project	6	10
OE 482	Individual Ordnance Project	21	5

TYPICAL ELECTIVE SEQUENCES

IN SYSTEMS ANALYSIS/OPERATIONS RESEARCH

"Management Science" Emphasis

OE 385	Management Engineering
EF 382	Computer Science Fundamentals
SS 482	Applied Economic Theory
OE 487	Operations Research

"Systems Analysis" Emphasis

OE 385	Management Engineering
EF 382	Computer Science Fundamentals
MA 481	Linear Algebra & Linear Programming
SS 483	National Security Seminar

"Operations Research" Emphasis

OE 385	Management Engineering
EF 382	Computer Science Fundamentals
MA 486	Numerical Analysis
OE 487	Operations Research

USMA COURSES

IN

MATHEMATICS

(Standard and Advanced)

MA 101	Calculus and Analysis
MA 102	Calculus and Analysis
MA 104	Linear Algebra
MA 109	Basic Analysis
MA 154	Advanced Linear Algebra
MA 156	Advanced Calculus and Analysis
MA 157	Advanced Calculus and Analysis
MA 158	Advanced Calculus and Analysis
MA 159	Advanced Calculus, Analysis and Linear Algebra
MA 201	Calculus
MA 202	Differential Equations
MA 204	Probability Theory and Statistical Inference

OE 385 MANAGEMENT ENGINEERING

JACKET PROBLEM

The manager of the Cadet Store stocks five (5) sizes of a given type of jacket. He must fit 100 incoming cadets whose sizes are unknown. The manager knows that, in the past, sizes were distributed as follows:

Size	Relative Frequency (%)
1	10
2	10
3	20
4	50
5	10

The manager can stock 20 extra jackets (Total: 120). How should he distribute this extra inventory in order to minimize the expected number of cadets who cannot be fitted?

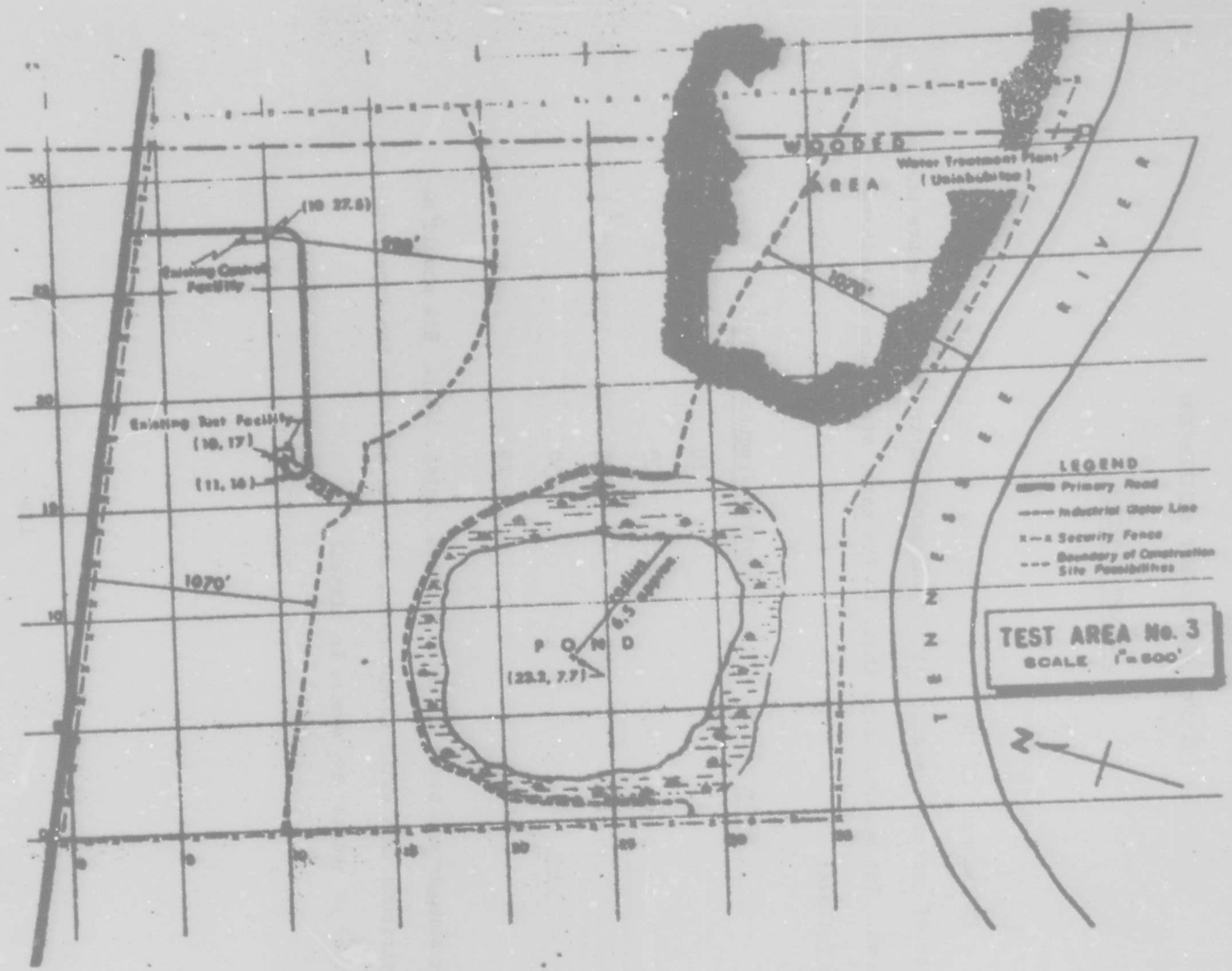


Figure 1: Plan of the Existing Test Facility.

OE 487 OPERATIONS RESEARCH

INVENTORY CONTROL

Ref.	
P-3345 (May 1966)	A Systems Approach to Base Stockage... Its Development and Test (Campbell & Jones)
RM-4362-P2 (March 1966)	An Objective Bayes Approach for Inventory Decisions (Feeney & Sherbrooke)
RM-4176-1-PR (March 1966)	The (s-1, s) Inventory Policy Under Compound Poisson Demand: A Theory Of Recoverable Item Stockage (Feeney & Sherbrooke)
RM-3644-PR (June 1963)	An Aggregate Base Stockage Policy For Recoverable Spare Parts (Feeney, Petersen, & Sherbrooke)

LINEAR PROGRAMMING

Ref.

RAC-P-17 (March 1966)	Programming The Procurement Of Airlift And Sealift Forces: A Linear Programming Model For Analysis Of The Least-Cost Mix Of Strategic Deployment Systems. Fitzpatrick, et al
RAC-P-19 (July 1966)	A Programming Model For Determining The Least-Cost Mix Of Air And Sealift Forces For Rapid Deployment. Fitzpatrick & Whiton

Mr. Henry G. Alley
Combat Service Support Group
Session IV-B
"What Are You Doing?"

My presentation this afternoon will be in three parts. First, background on Combat Developments Command as a whole, second, the Combat Service Support Group, with which I work, and third, an important problem to the Combat Developments Command at this time.

The first part, background on Combat Developments, will relate in part to papers presented by representatives of the Combat Developments Command later at this Symposium. The Combat Developments Command was established on 20 April 1962 as a major Army field command. This was a result of a 1962 re-organization of the Army, which was basic and far-reaching. The purpose of organizing CDC as a separate command was to centralize all of the functions and activities of Army Combat Developments in one command. CDC is a command responsible for providing the answers to three questions: how the Army should fight, how it should be equipped, and how it should be organized. First, Combat Developments is a process, not a random search. Next, its purpose is to improve the combat developments and the effectiveness of the Army in the field as a realistic force, properly supported by cost effectiveness studies. Third, Combat Developments follows an orderly sequence; and last, the basic commodities of Combat Developments are new and improved doctrine, materiel requirements, and organizations. We can all recall from the history of the Civil War the tactics, the weapons, and the organization of the forces. This served as a basis for much debate as to how certain battles might have been different had these factors been altered in various ways. In World War I, the tank made its appearance; however, tactical doctrine for its use had not been developed. As a result, you can see that the tank was misused. In World War II, we recall that the German Blitzkrieg was a spendid display of integrated doctrine, organization, and materiel. Also in retrospect, in the early days of the airplane, we needed a doctrine on its usage. This had to be developed before optimum tactical and strategic results were obtained. Intimately associated with the doctrine and organization were the capabilities that could be and should be provided with the manufactured item itself; be it a rifle, tank, airplane or what have you. Therefore, we come to the Army concept programs, whereby these factors (new or improved doctrine, materiel and organization) are integrated into the Army in the field.

Let us focus your attention on the groups, the Combined Arms Group, Combat Support Group, and Combat Service Support Group. CSSG commands its assigned agencies, as do the other two groups, and serve essentially as mid-managers of the agencies' mission work using approved concepts now developed by the Institute of Advanced Studies, to be developed, as General Betts told you, by the Institute of Land Combat and doctrine studies developed by the Institute of Combined Arms and Support as a basis.

We manage the development of studies by assigned agencies, to insure timely completion of each Army concept program. As you would expect, the concept is very broadly stated. The doctrine studies develop the concept in detail, while derivative studies go into further detail for smaller sized units and specific functions, such as Petroleum Supply System. The organizations which are required are developed and necessary field manuals prepared. Materiel requirements are identified, and on approval of a materiel requirements document, the development of the item or system is monitored through research and development, type classification, and issued to the Army in the field, terminating only on removal from the Army inventory.

And now, for the third part of my presentation, I wish to turn your attention to a subject of particularly important concern to the Combat Service Support Group, in fact, all of the Combat Developments Command at this time. This is total military worth evaluation of Army materiel. While this subject has always been with us, it was recently pointed up and emphasized in the decision of the Chief of Staff, Department of the Army, which said that this is a periodic evaluation; that it extends throughout the life cycle; is made in broad context. We at this time are planning the best way for the decision and guidance of the Chief of Staff to be carried out. A minimum of one formal military evaluation will be made prior to type classification and initial production of Army equipment and additional evaluations will be made as required throughout the life cycle of the materiel, from the requirement proposal until it is removed from Army inventory for disposal. Each military evaluation will determine the utility or value of the materiel in terms of a practical assessment to include: performance, endurance, (that is, its service life), reliability, and maintainability, and, as stated before, this evaluation will be made in the broad context of personnel, tactics, organization, training, operations, logistics capability, and other equipment which comprise the Army. Each military worth evaluation will utilize to the extent practicable, data from all available sources, to include but not be limited to, the results of all reports of tests, service test evaluation, technological forecast, Army concept and doctrine studies, information made available from other DOD services, international standardization agencies, industry, field trip reports, and the like. To carry out the express desires of the Chief of Staff and the Army will require expansion and systematization of a program that will insure an adequate evaluation of the military worth of each item. Such a program presents a number of problems or questions, one of which is, "How best can we accomplish this?" Some of the questions to be resolved are qualitative, e.g., what types of personnel would be best for this work. Some are quantitative, e.g., how many of each should be employed in the various facets of the work. Next, what information on an item or system should be collected? How collected, and how to sift and refine to collate and form a data bank to analyze and evaluate and ultimately reach a decision for action?

In addition to the task of obtaining required data, a system will be necessary for rapidly retrieving and processing the mass of data collected and must permit intensified management of the literally thousands of items of materiel that are essential to the accomplishment of the US Army mission. Bear in mind that the data will be used for decisions to improve or revise, not only materiel, but also to improve US Army doctrine and organization.

What methods should we employ in these evaluations? What operations research methods would produce fast correlation and evaluation in total perspective for the Army, now and in the future? It is apparent that we must systematize data collection, simplify analysis and evaluation of data, enhance our supervision and decision making process, and establish more positive control over the life cycle of each item or system, must disclose quantitative and qualitative adequacy of present materiel to determine if the present combat development objectives are adequate; if not, we must ascertain what additional combat developments actions are required and when they should be initiated. We at CSSG and throughout CDC are endeavoring to determine the best management methodology to employ. Your thoughts and constructive suggestions as to how further military worth evaluations should be accomplished would be appreciated.

In summary, I would like to say that CDC was created to answer three questions: how the Army should fight, how it should be equipped, and how it should be organized, now and in the future. The organization with which I work, Combat Service Support Group, located at Fort Lee, Virginia, is vitally interested in all the functional areas of combat service support of the Army in the field. The evaluation of each item or system of Army materiel will be expanded in scope and systematized to insure adequate life cycle evaluation for total military worth and this is now being studied to determine how best to accomplish it.

A CURSORY REVIEW OF OPERATIONS RESEARCH STUDIES AT THE U. S. ARMY HUMAN ENGINEERING LABORATORIES

By

Michael Famiglietti

The Human Engineering Laboratories (HEL) recently formed an Operations Research Office (HEL-ORO). The mission of the new office is to coordinate the formulation and development of mathematical models and improved methodologies and procedures, for use in analyses and evaluations of human factors aspects of new conceptual Army materiel systems.

The range of problems encountered by the office and the techniques employed for their solution span the gambit from deceptively simple and coarse to complex and sophisticated.

Illustrative of the former is a problem which involved the determination of the composition of the crew in a two-man vehicle.

Decision on the crew composition for a given two-man Army vehicle early in the system development cycle is often made without the benefit of an analytical treatment of the problem. Consequently, the specified crew's effectiveness can be predicted only in nebulous, qualitative terms, which are useless in deterministic studies of system cost effectiveness. Thus when the crew's effectiveness is not quantified, it is impossible to trade off crew composition with training needs and any requirements for duplicate displays and controls. A method for quantitatively estimating the utility of the composition of the crew in a two-man vehicle was recently developed.

For illustration the method is applied to a low-altitude, high-speed (LAHS) surveillance and target acquisition, conceptual aerial vehicle.

The methodology is based on the assumption that crew composition depends predominantly on the man-assigned tasks to be performed. Therefore, we began by dichotomizing the entire workload into two disjoint sets, p and q, where:

p = piloting tasks, i.e., all the sensing, data processing, and actions required for maneuvering the aircraft effectively through a given mission, and

q = non-piloting tasks.

A crew member, then, may be defined in terms of the tasks he can perform. Let:

P = a man capable of performing all p

Q = a man capable of performing all q

$\hat{P}$ = a man capable of performing all p, and some but not all q

$\hat{Q}$ = a man capable of performing all q, and some but not all p

P_Q = a man capable of performing all p and q

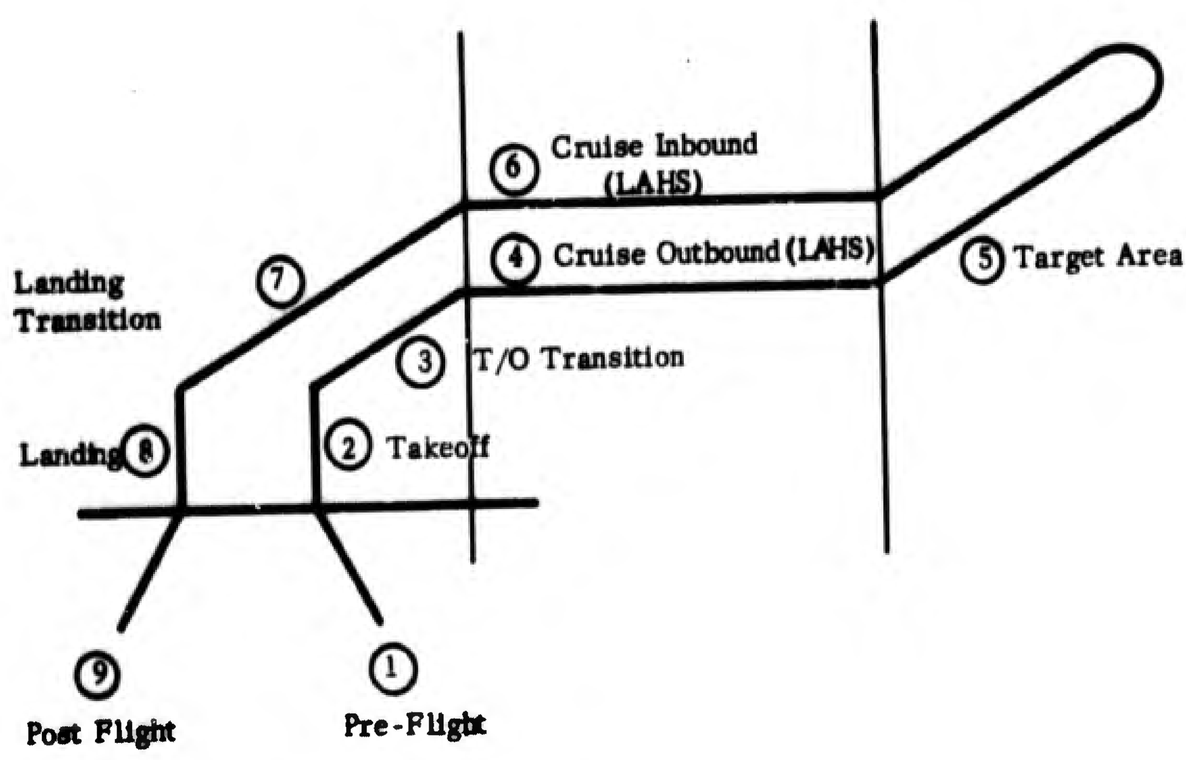
Some of the boundary conditions imposed are:

H1. Sets p and q are non null for each mission segment of a typical mission profile.

H2. A crew consists of two men, one trained at least for p, and the other trained at least for q.

H3. Crew composition depends on task-backup requirements which may be imposed to anticipate potential overloadings of either crew member, etc. The methodology involves the performance of some elementary manipulations, which will not be detailed here, and which utilize the following input data:

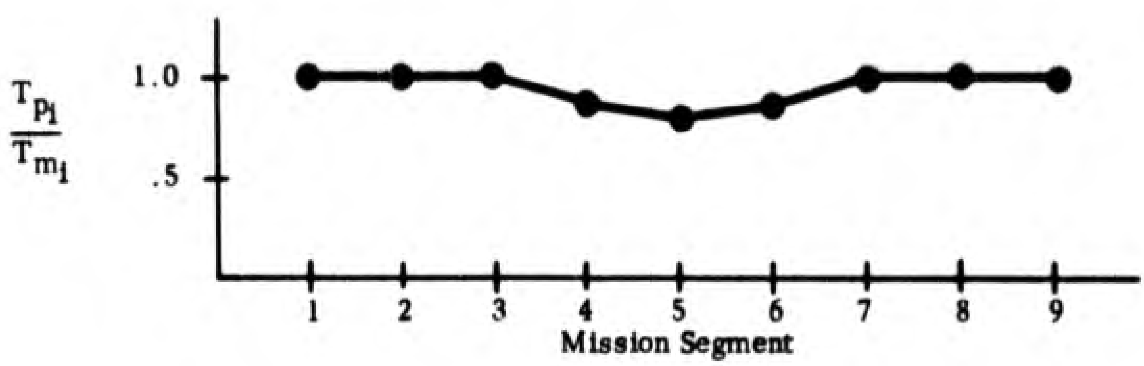
a. A typical mission profile, divided into flight segments:

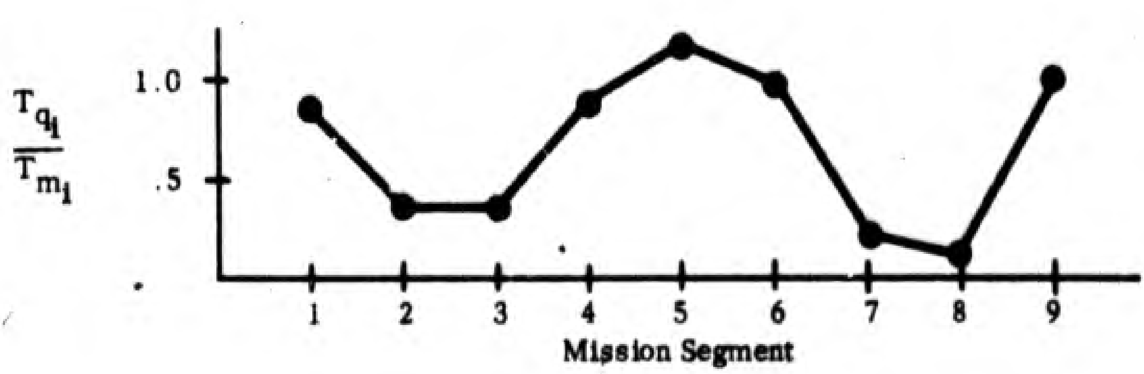


MISSION PROFILE

b. Coarse time estimates for each segment's total workload, dichotomized according to the tasks each crew member must perform.

RATIOS OF REQUIRED TASK TIME TO AVAILABLE TIME





c. Assigning priorities to selected tasks within each mission segment.

Task Priorities

	Mission Segment								
	1	2	3	4	5	6	7	8	9
Task Priorities	$p \gg q$	$p \gg q$	$p \gg q$	$p = q$	$q \gg p$	$p = q$	$p \gg q$	$p \gg q$	$p = q$

And finally, to complete the input data, each mission segment is weighted to determine its contribution to completing the mission successfully.

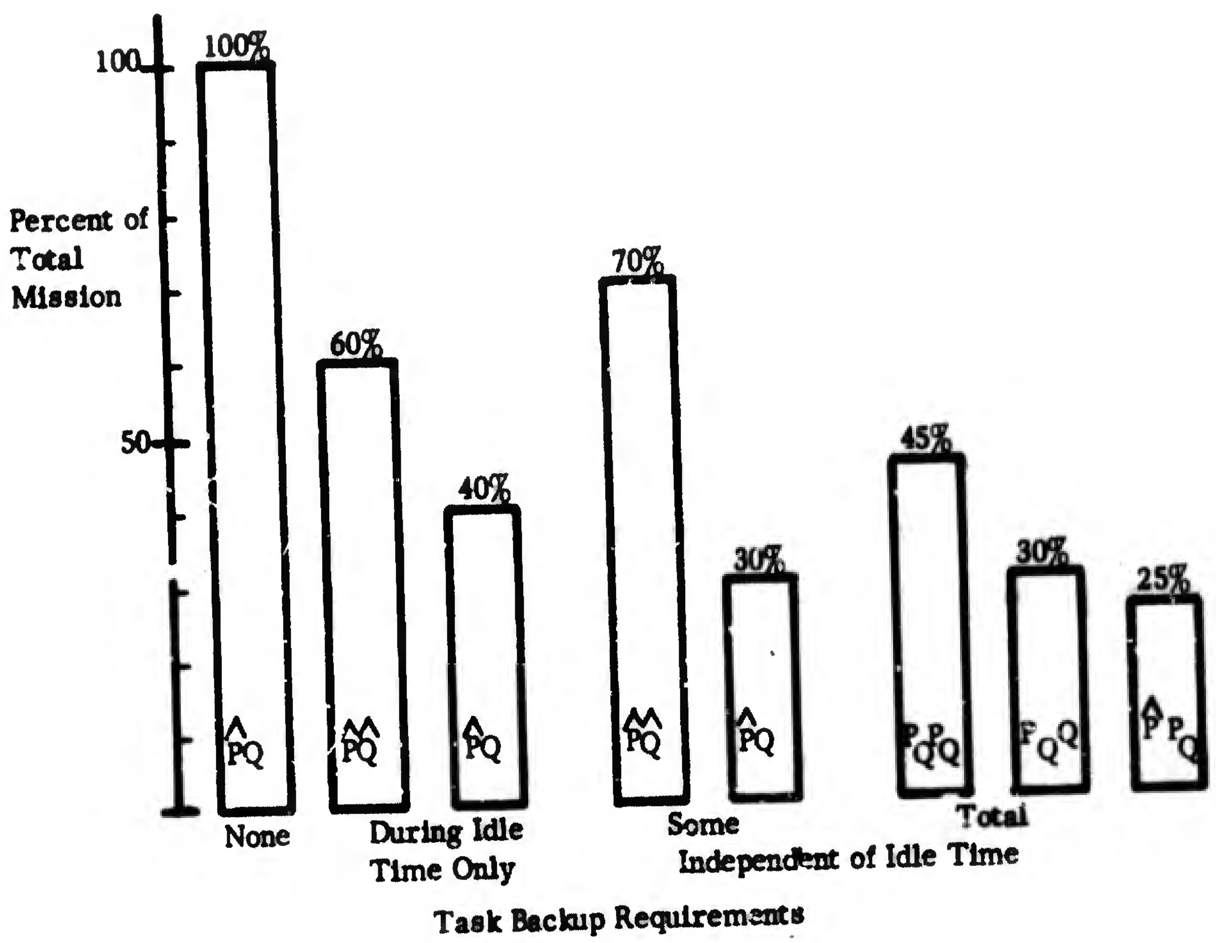
Mission-Segment Weights

	Mission Segment								
	1	2	3	4	5	6	7	8	9
Weight	.05	.05	.05	.15	.30	.20	.05	.05	.10

The mission-segment weighting factors reflect each segment's relative importance to the overall success of the mission, in accordance with some pre-selected criterion.

The result of applying the developed methodology is a frequency-of-use histogram. The histogram depicts gross quantitative estimates of how crew composition depends on backup requirements.

CREW COMPOSITION UTILIZATION



This frequency-of-use histogram makes it clear that, even with the most stringent requirement for task backup, using crews of two men who are completely cross-trained (P_Q P_Q) may be undesirable in terms of cost effectiveness, because of the expense of training and duplicating displays and controls.

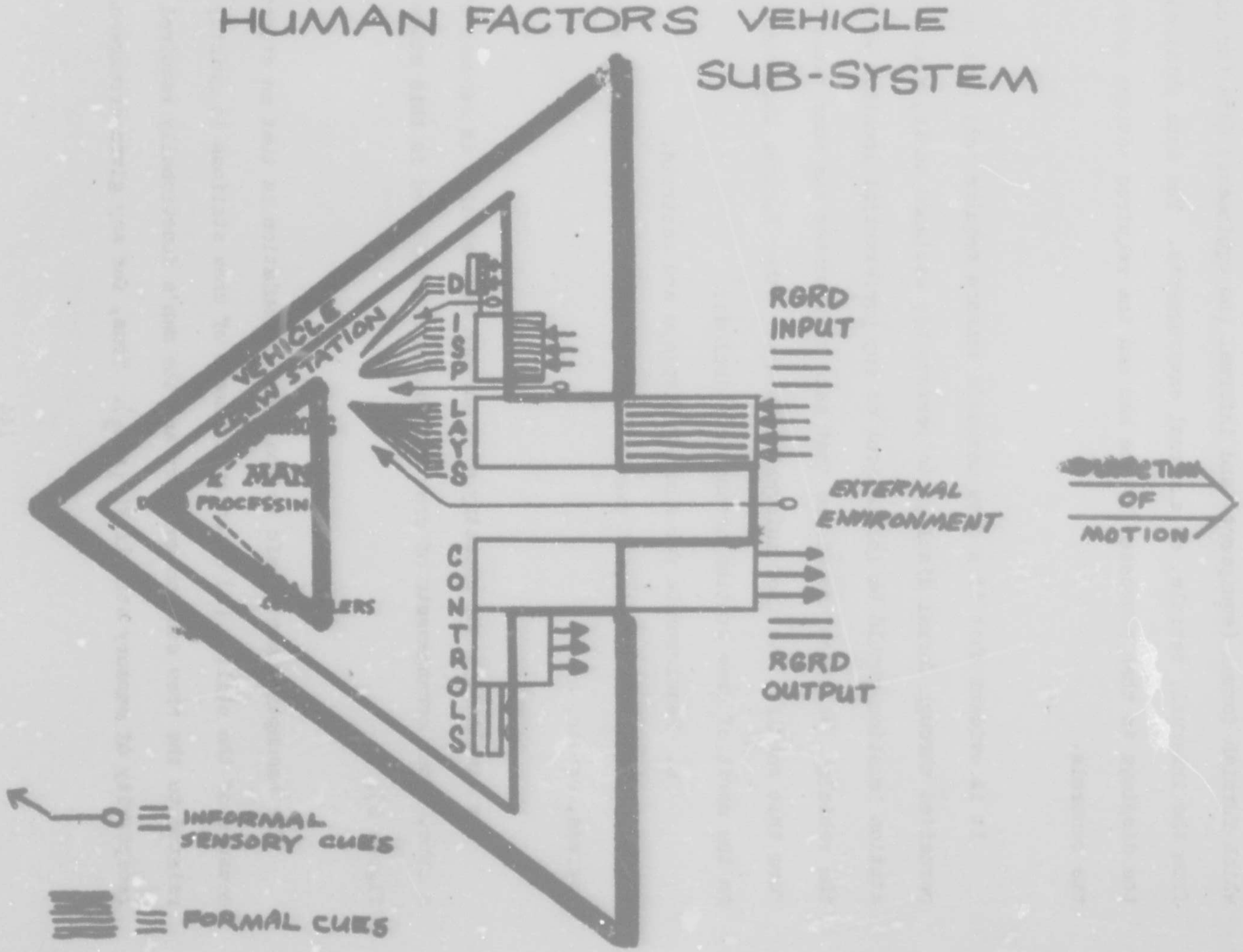
It is also clear that one man in the two-man crew must be trained for at least all piloting tasks and some but not all non-piloting tasks (P). The analysis further suggests that the mission segments which give this indication should have a thorough definitive task analysis.

Another problem we are currently considering may be stated as follows: Given a two-man vehicle, develop a mathematical model for predicting the relative merit of the arrangements of the two crew stations. A crew station is defined as the location where an individual crew member performs his assigned tasks. It is assumed that the composition of the two-man crew has been previously determined.

Initially, the basic elements that constitute the vehicle subsystem and the pertinent interfaces were distilled (see figure 1).

The crew station in essence is assumed to consist of a man, displays, controls, and the crew station environment. The man is considered to be a

Figure 1


HUMAN FACTORS VEHICLE
SUB-SYSTEM
VEHICLE
CREW STATION
DISPLAYS
CONTROLS
RGRD INPUT
RGRD OUTPUT
EXTERNAL ENVIRONMENT
OF
MOTION
INFORMAL SENSORY CUES
FORMAL CUES

sensor-processor-controller. The man's sensors interrogate the displays, which furnish formal (equipment) and informal (no equipment) data (or cues) from the internal, vehicle, or external environments. The data obtained from the displays is then processed by the man and the required actions taken via the controls.

It is evident that if a crew member's sensors require only that data perceived through formal displays to perform his assigned tasks, then his crew station location should be independent of any preferential location within the vehicle. We therefore assume that each crew member has some tasks to perform that require data from informal displays. Other factors that contribute to the merit of crew station arrangement include:

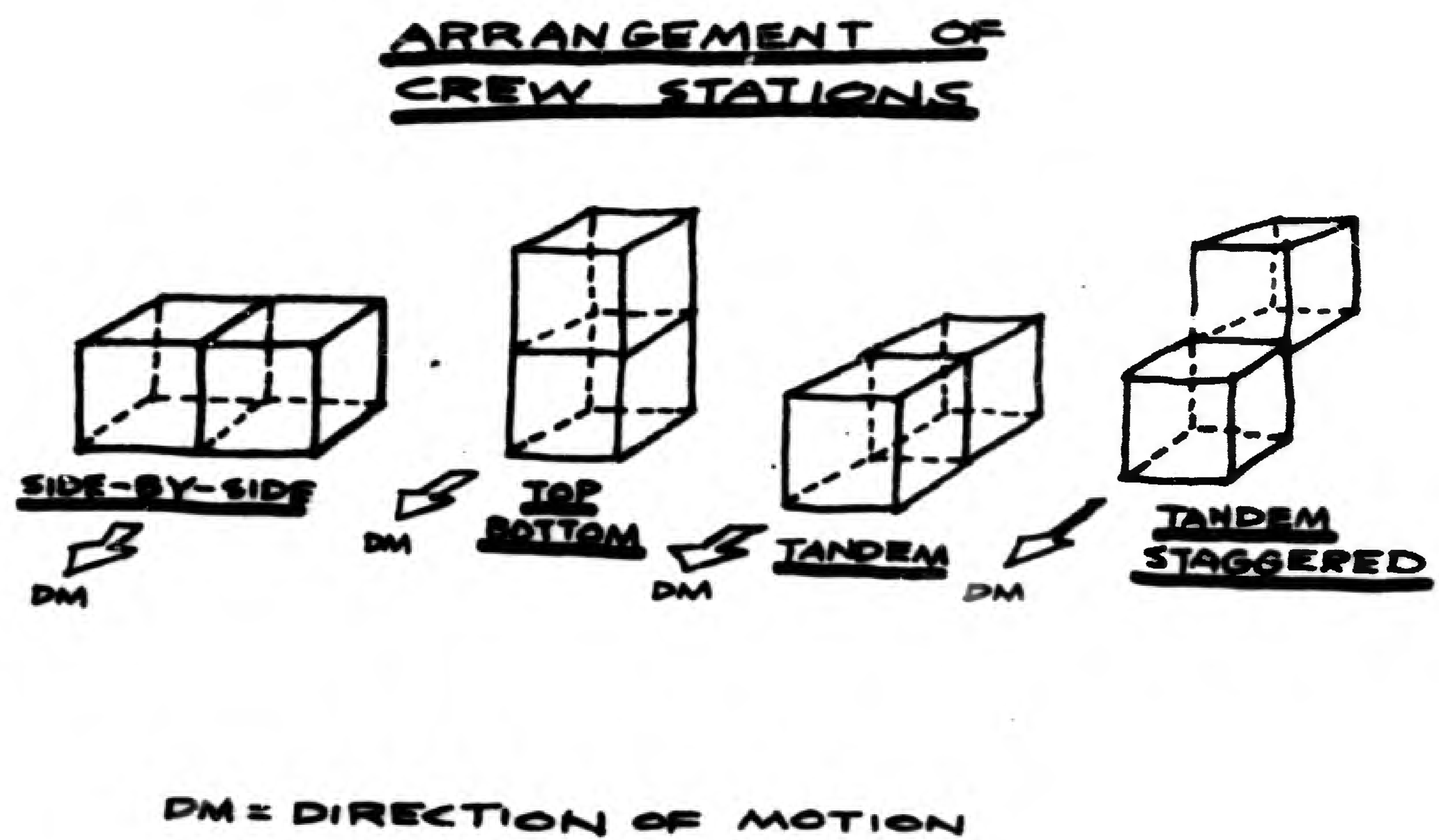
a. Requirements for sharing displays and controls.

b. Vulnerability of crew station positions, psychological stress, ingress, egress, etc.

For simplicity, the geometry of a one-man crew station is assumed to be a cube. Four arrangements of crew stations are considered in this study (see figure 2).

The assumption most basic to the model formulation is that an effective measure of the utility (U) of an arrangement of crew stations is jointly related to the crew station geometry and the man's functionally required receptivity of sensory stimuli $F(x_1x_2x_3)$. Thus, for any given arrangement of

Figure 2


ARRANGEMENT OF
CREW STATIONS
SIDE-BY-SIDE
DM
DM
TOP
BOTTOM
DM
TANDEM
DM
TANDEM
STAGGERED
DM = DIRECTION OF MOTION

of two crew stations,

$$U = K \iint F(x_1 x_2 x_3)\ dx_i dx_j$$

where K is a constant of proportionality.

Man's five primary sensor faculties (vision, audition, tactile, olfaction, gustation) along with kinesthesis (the sensation of bodily movement), cutaneous (combination of the temperature and pain senses), and vestibular (relating falling and rectlinear movement and rotation), are considered in the model.

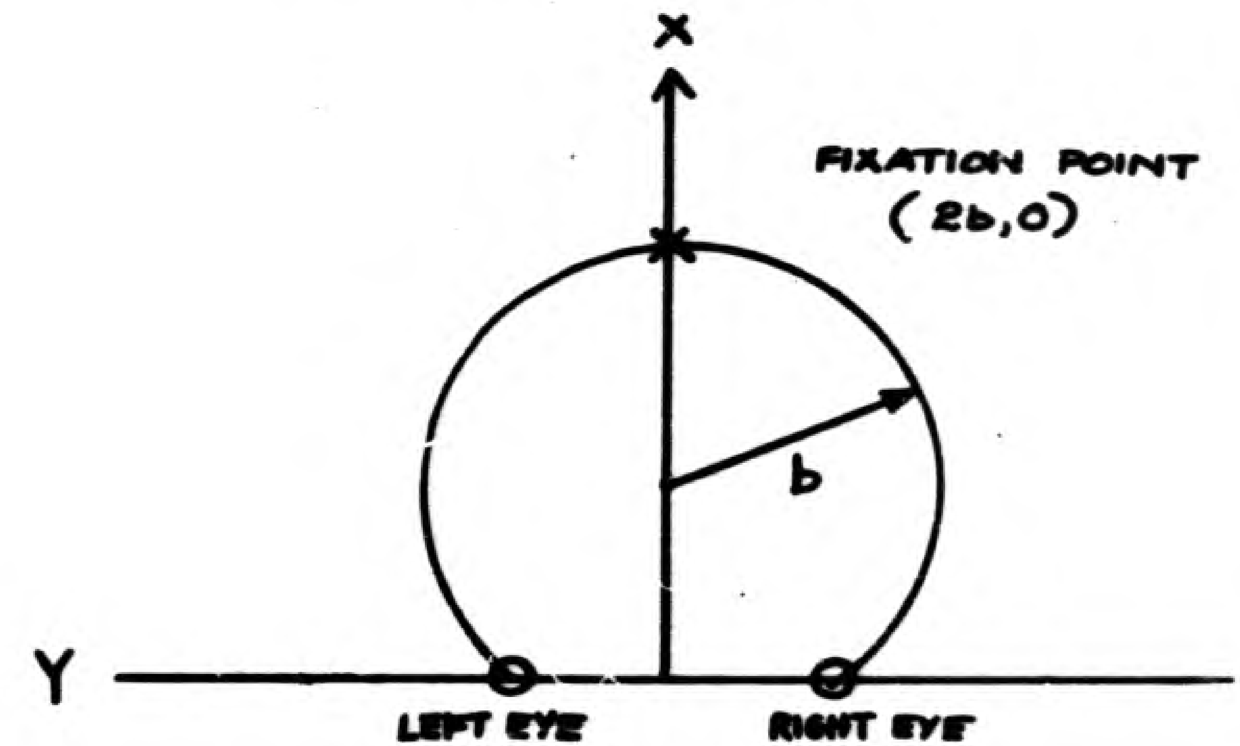
The most difficult aspect in the formulation of this crew arrangement model is the generation and/or formulation of a single acceptable function to represent explicitly the receptivity of sensor stimuli.

To illustrate: For vision, by assuming that the eyes are facing in the direction of motion and fixed on a certain point in space, the locus of points in external space whose images are formed on corresponding elements of the retinas and which are seen singly, lie on a graph called the Vieth-Muller circle. Rotation about the x-axis produces a tolerable and satisfactory receptivity function for vision required in the model, figure 3.

For audition, however, the receptivity of directionalized auditory stimuli was first crudely assumed to be a prolate spheroid with man as a mass point in its geometric center. However, the non-elementary transformations required in attempts to get a closed-form solution yielded elliptic integrals of the first and second kind whose integrations relied heavily on

Figure 3

RECEPTIVITY OF VISUAL STIMULI
(VIETH - MULLER CIRCLE)



$$(x-b)^2 + Y^2 + Z^2 = b^2$$

approximations, and the total contributions to errors in the measure of the utility of an arrangement were difficult to bound. Fortunately, however, a modification of the audition function was able to be made, which subsequently integrated nicely in the desired closed form.

Despite the noted dearth of mathematical representations of man's receptivity of sensory stimuli, both in the open and classified literature, a methodology has been formulated which will indeed yield quantitative estimates, although crude, of the relative merits of crew station arrangement. For illustration, the methodology is being applied to a conceptual airborne vehicle. Currently, a bit of tidying up needs to be done before drafting a final paper.

We are also in the process of developing a model which will describe head dynamics as a function of physical loadings (weights) placed in pre-assigned positions on the head. The objective of the study is the determination of helmet-weight limits and distributions which may be acceptable to an active individual, without deterioration of normal locomotion or equilibrium and without sensory or somesthetic disturbances, under conditions of acceleration and vibration.

To initiate the study, a commercially produced skullcap shell is being considered with the initial objective of determining the effects on its center of gravity when given elemental weights are placed on pre-assigned surface locations. A mathematical representation of the skullcap shell has been formulated.

Projected perimeters and template tracings in the longitudinal and lateral planes of the skullcap shell suggested that significant sections of the shell lend themselves to the mathematical approximations shown in figure 4.

To determine the goodness of fit of the mathematical model with the physical shell, the average weight and thickness of the shell, and the average density of the material composing the shell were experimentally determined. Treating thickness and weight as independent variables and density or volume as a measure of the goodness of fit, the errors tabulated below were determined:

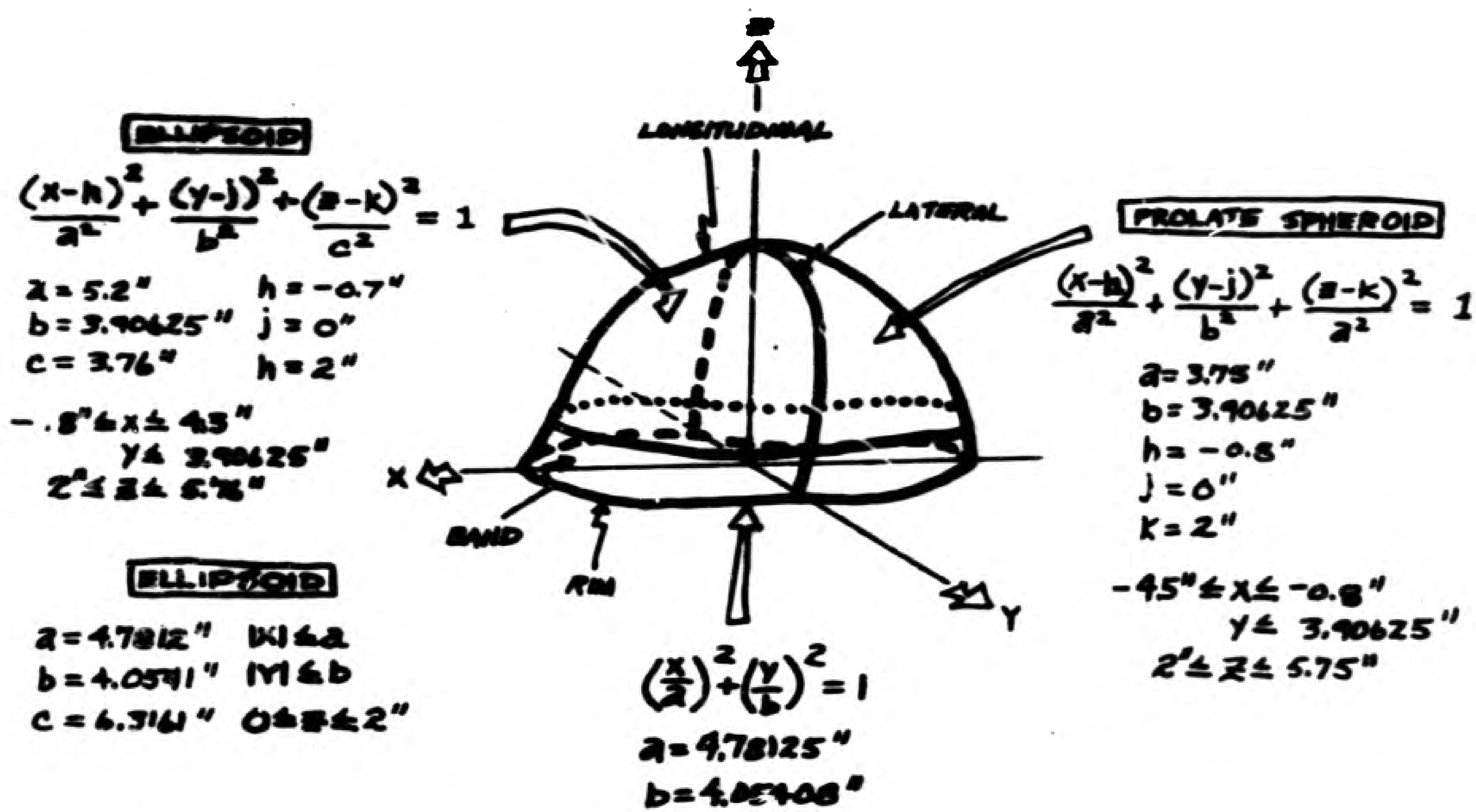
	Shell Measurements	Model Predictions	Percent Error
Weight (gm)	368.665	(A) 368.665	----
Density (gm/cm^3)	1.4958	1.4950	.053
Volume (cm^3)	246.4668	246.5951	.053
Thickness (cm)	.1069	(A) .1000	----

(A) = values assigned to independent variables.

These errors are deemed acceptable.

The model was most recently augmented by consideration of the suspension retention system (SRS) which consists of padding, webbing, and chin straps,

Figure 4



LONGITUDINAL
LATERAL
BAND
RIM
X
Y
$$\frac{(x-h)^2}{a^2}+\frac{(y-j)^2}{b^2}+\frac{(z-k)^2}{c^2}=1$$
a = 5.2"
b = 3.90625"
c = 3.76"
h = -0.7"
j = 0"
h = 2"
-.8" ≤ x ≤ 4.5"
y ≤ 3.90625"
ELLIPSOID
a = 4.7812"
b = 4.0591"
c = 6.3161"
|x| ≤ a
|y| ≤ b
0 ≤ z ≤ 2"
$$\left(\frac{x}{a}\right)^2+\left(\frac{y}{b}\right)^2=1$$
a = 4.78125"
PROLATE SPHEROID
$$\frac{(x-h)^2}{a^2}+\frac{(y-j)^2}{b^2}+\frac{(z-k)^2}{a^2}=1$$
a = 3.75"
b = 3.90625"
h = -0.8"
j = 0"
K = 2"
-4.5" ≤ x ≤ -0.8"
y ≤ 3.90625"
2" ≤ z ≤ 5.75"

corresponding to medium, large, and extra large helmet sizes.

Currently, we are attempting to formulate a mathematical model of the head and neck dynamics to compliment the model of the helmet.

We are also in the early stages of developing a model which will predict the performance of a man-pistol system as a function of pistol physical design parameters and parameters affecting the spatial position and bio-mechanics of the human upper limb. The equations necessary for a complete description of the system in three dimensions are presently being formulated.

25 May 1967

OPERATIONS RESEARCH IN R&D TO ACHIEVE ANTI-AIRCRAFT EFFECTIVENESS

Mr. Doyle E. Pickens
Mr. James L. Edmondson
U. S. Army Missile Command

OUTLINE

I. INTRODUCTION

II. LIFE CYCLE OF A WEAPON SYSTEM

- Concept Formulation Phase
- Contract Definition Phase
- Engineering Development Phase
- Production Phase
- Operational Phase
- Disposal Phase

III. OPERATIONS RESEARCH IN THE LIFE CYCLE

IV. HOW MICOM IS ORGANIZED TO PERFORM OPERATIONS RESEARCH

V. ANALYTICAL MODELS USED AT MICOM

- Close Support Weapons Simulation
- General Support Weapons Simulation
- Air Defense Weapons Simulation
- Cost

VI. TYPES OF STUDIES PERFORMED BY MICOM

VII. SUMMARY

OPERATIONS RESEARCH IN R&D TO ACHIEVE ANTI-AIRCRAFT EFFECTIVENESS

Mr. Doyle E. Pickens
Mr. James L. Edmondson
U. S. Army Missile Command

I. INTRODUCTION

The three speakers in this session will discuss the operations research/system analysis activity associated with the overall development, production, and deployment phases of the materiel life cycle. Although these phases are closely associated and interrelated, I will attempt to confine my remarks to the Research and Development Cycle, up to the contract definition phase, so there will be no duplication of the following presentations. Additionally, I will not present a hypothetical problem and a specific model application for solution, but rather a philosophical approach to the development of the requirement and to the application of Operations Research/Systems Analysis in the research and development of effective anti-aircraft air defense weapons systems.

SLIDE 1

I will address five major topics: (1) the life cycle of a weapon system; (2) operations research in the life cycle; (3) how the U. S. Army Missile Command (MICOM) is organized to perform operations research; (4) analytical models used at MICOM; and (5) types of studies performed by MICOM.

II. LIFE CYCLE OF A WEAPON SYSTEM

SLIDE 2

There are six distinct phases in the life cycle of a weapon system. Of particular importance are the types of technical activity involved and the agencies of prime responsibility. It is obvious that a vital interrelationship exists between intelligence community, the user, the developer, and industry.

I will discuss the first two phases of the life cycle. The other four phases will be discussed by the following speakers.

"Concept Formulation", as used here, encompasses the Research and Development activities (Exploratory and Advanced Development) preceding a decision to enter the contract definition phase; that is, the R&D and analytic process by which the Army determines what materiel should be developed.

The concept formulation phase consists of many steps which may be repeated many times before progressing to the next step. Typical major steps which are performed by ACSI, CDC, and AMC agencies working together are:

- Develop Potential Military Threat
- Develop Requirements for Weapons to Defeat Threat
- Postulate Technical Concepts to Meet Military Requirements
- Evaluate Technical Design Concepts
- Perform Exploratory or Advanced Development
- Postulate Weapon System for each Threat
- Evaluate Weapon System in Combat Environment
- Postulate Force Structure to Counter Worldwide Threat
- Evaluate Force Structure in Combat Environment

There are six prerequisite conditions which must be accomplished in the Concept Formulation Phase prior to the approval of a request to initiate work in the engineering/operational systems development:

1. Technology is in hand. Only engineering is required - not experimentation.

2. Mission and performance envelopes have been defined.

3. Best technical approaches have been selected.

4. Thorough trade-off analyses have been performed.

5. The cost effectiveness of the proposed item has been determined favorable in relation to competing systems throughout the Department of Defense.

6. Cost and schedule estimates are credible and acceptable.

SLIDE 3

The typical materiel life cycle extends about thirty years from the time research is conducted, the products of research are incorporated into weapon systems or equipment, the system is developed, produced, fielded, and then finally discarded as obsolete. This is not to say that we have the same system in the Army inventory for thirty years before a new one is developed. In fact, a new item is usually developed and produced about every nine years. It must be emphasized that not all systems will follow all phases. Individual items may be initiated at any point in time. Delays of any type, such as programming, budgeting, type classification, establishing requirements, production decisions, and development and production difficulties will prolong the operational and disposal phases.

This chart is based on a four-year development cycle, an eight-year procurement plan, and a system service life of ten years (some vary from six to thirty-four years or more). One can readily see that different actions may be going on in each phase at any one point in time. For instance, while disposal actions are underway on an obsolete system (System A), a replacement system (System B) is being produced and fielded. At the same time, much work is being done to define and develop a new modern system (System C), and extensive research is being performed to evolve future concepts of combat and requirements.

Within this thirty-year cycle, how is the worth of a system determined? Basically, through its performance. Performance requires technology and organization, and both require money to buy and to operate. Before a weapon system can be developed, purchased, and used, it must be justified to DA and DOD. This justification includes a description of the need, a rationale for its choice over other alternatives which address the same need, or its priority over other systems which address the same need, or its priority over other systems which address different needs - all competing for the same dollar. The needs (requirements) come to the developer in several different forms.

SLIDE 4

Basic Research Programs generally address the requirement set forth in the:

1. Army Research Plan (ARP)
2. Army Force Development Plan (AFDP)
3. Army Research & Development Plan (ARDP)
4. Combat Development Objectives Guide (CDOG)

Exploratory Development responds to the:

1. Qualitative Materiel Development Objectives (QMDO)
2. ARP
3. Research and Development Long Range Plan (RDLRP)
4. AMC Objectives for Technology.

Advanced Development responds to the:

1. Advanced Development Objectives (ADO)
2. QMDO
3. Qualitative Materiel Requirement (QMR)
4. Small Development Requirement (SDR)

Engineering Development responds to the QMR and SDR

Requirements in the production and operational phases are quantitative, and are really a numbers game to compute to the quantity of an item needed to equip the army in the field. New systems concepts, addressing these requirements, are conceived during the concept formulation phase of R&D which encompasses all phases through Advanced Development.

SLIDE 5

A typical concept formulation time-phase plan consists of twelve major milestones over a period of years, during which time systems studies, system designs, and subsystem development are performed. Operations research is performed during the attainment of nearly all milestones.

III. OPERATIONS RESEARCH IN THE LIFE CYCLE

SLIDE 6

Generally, the terms "Operations Research"and "Systems Analysis" are used indiscriminately; by combining the two we have "Operations Analysis" which will be defined by Mr. Porter of Raytheon, the next speaker in this session. Suffice it to say that the definition holds for this discussion. Why, when and to what level does Operations Research occur in the materiel life cycle? The application of Operations Research/Systems Analysis has become known as THE technical discipline for providing the decision-makers with the professional guidance necessary for the development of the total planning for, and the implementation of, the development of today's highly complex, high-cost materiel. This technique of total resources evaluation is a systematic way of comparing old/current systems and their possible improvements with new and advanced ways of accomplishing the total job. Further, it provides the basic for rational choices between the alternatives that are available. There are four main components of such analyses: (1) Requirement - What do we need to do?; (2) Alternatives - What are the different ways of doing it?; (3) Evaluation - How well do the alternatives perform?; (4) Choice - How do we choose the best alternative? Operations Research is undertaken with various specific resultant requirements (very often concurrently) and performed in each of the six phases of the materiel life cycle discussed earlier.

Let us examine an Air Defense Program which emanates from a suggestion that certain systems studies should be performed to develop several technical alternatives for a family of advanced air defense systems, including the development of a broad technological data base to assist the user in the preparation of system requirements (QMDO's, QDO's, SDR's, etc). This procedure follows a familiar pattern. The first step is the possession of knowledge - An Operations Research Evaluation of the technical threat and a projection of that threat into the appropriate time frame, and operations research evaluation of the operational capabilities currently available, and a summation of the state of technology. This knowledge - perhaps information resulting from the work of others - is stored in the same reservoir that originates ideas. Certainly the ideas must flow freely (usually the result of a team effort, supported by the spectrum of technical disciplines) and have reasonable feasibility implications (technical forecasting, based upon applicable exploratory and advanced development results). Such ideas result in the alternative generic systems concepts (missiles, guns, rockets, other).

The second step is the massaging (iteration) of the generic concepts and the summation of technology with the technical threat via the performance of the systems concept studies. It is the results of these studies which provide the sense of direction to the overall program (i.e., the early redirection of the exploratory and advanced development programs oriented to attain feasibility demonstrations of the component technological alternatives). Initial OR/SA studies (one system versus one target) are performed to determine the technical capability of the systems concepts using the projected attainable technology characteristics. As results of the redirected hardware programs are attained, these studies are upgraded to narrow the broad base search and come to grips with specific parametric designs and parametric analysis thereof. Obviously, during this phase there is a great deal of experimentation accomplished and latitudes enjoyed in the R&D community, and, of course, the User is cordially invited to participate also since we have a common, but difficult, goal: total cost/effective weapon systems feasibility demonstration for each of the weapon system alternative concepts that are technically supplementary/complementary in an Operations Research Optimum-family-mix force structure analysis. Assuming the attainment of a favorable climax, the next step should go one of two ways - contract development phase and subsequent engineering development, production, and deployment; or redirected for additional advanced component development and a rerun at total C/E Weapons Systems Feasibility demonstration. When the weapon system is able to stand on its own feet independent of R&D or begins to show signs of obsolescenee, we begin to look for fresh, new ideas to pursue.

SLIDE 7

The Operations Research/Systems Analysis Interface with the R&D activity will be discussed briefly. I consider the development of an appropriate matrix-of-analysis and the accomplishment of the defined analyses the most important aspect of any well-planned and directed program of air defense since no weapon system can now stand alone, but must be considered as a composite part of the cohesive whole of the total air defense posture.

What do I mean by the matrix-of-analysis? I mean the documentary evidence of the application of every technical/functional/operational characteristic of each defined/designed candidate system entering the worldwide combat force structure simulation and C/E analyses. You say - today's Operations Research Community doesn't have the capacity to accomplish the total scope within the time usually allocated. I agree; however, I am convinced that total detailed analysis is achievable by proper early program planning for the operations research/system analysis function. How? Simply by iteration of the analytic output/input requirement of the various levels of analysis, the elimination of the duplication of simulation/analysis efforts, and the placement of prime responsibility for the model/simulation development within the appropriate technical organizational entity. The very detailed component/sub-system (e.g., Infrared Seekers - 3 to 5 and 8 to 14 micron, Ultraviolet, Optical Contrast, Radio Frequency) simulations must be performed on a cost/effectiveness basis in the Component Technology Laboratories to provide the technological basis for sub-system component selection in the Parametric System Design Cost/Effectiveness studies.

The outputs of such studies could and should be initiated with the Advanced Concepts Laboratories so that they provide direct inputs into the Systems Design Analyses. The output of the Concept Laboratories PDCE Analyses directly inputs to the Development Agencies Operations Research Combat Environmental Simulations and C/E Studies. The output of the Development Agencies Operations Research Analyses directly input into the users worldwide force structure simulations and C/E analyses. The inclusion of a new weapon in the optimum force structure is used as a basis for entering engineering development.

I hope I have conveyed the message that Systems Simulation/Analysis and/or Operations Research is an integral part of every important facet of any Research and Development Program; and that it is most important that we develop the prime levels of analytic capability in order to provide the smooth transfer of technical knowledge via the output - direct-input interface.

IV. HOW MICOM IS ORGANIZED TO PERFORM OPERATIONS RESEARCH

SLIDE 8

MICOM has recently formalized by regulation standard procedures for performance of operations research studies. Once the problem has been defined, the requirements, operational characteristics, and threat data are obtained from CDC and the threat community, respectively.

The technical characteristics to be studied for possible fulfillment of the requirements are obtained from R&D. The subsystem concepts are generated by the seven R&D laboratories, with the system concepts being generated by the Advanced Systems Laboratory. The subsystem detailed technical simulations are performed by the seven R&D laboratories with the system detailed technical simulations being performed by the Advanced Systems Laboratory.

Individual system concepts and/or family concepts are simulated in the tactical environment by the Operations Research Branch to determine the best alternative of those proposed. This simulation shows the interaction between the operational characteristics and the technical characteristics for a given cost.

The study must also include the production plan, deployments, and a life cycle support plan for each concept simulated. The Quality and Reliability Management Office furnishes availability and reliability data for use in studies. The Comptroller and Director of Programs, based upon the study outline presented by Operations Research Branch, obtains and validates the appropriate cost to be used in the study from the respective directorates and project managers.

It should be noted that the interaction between the subsystem concepts, system concept, and individual weapon and/or family of weapons being simulated in the operational environment will undergo many simulations in order to arrive at the best of the alternatives proposed. This type of simulation also enables MICOM to validate for the user those requirements which can be met, those which require further technical development, and those he may desire to modify.

V. ANALYTICAL MODELS USED AT MICOM

SLIDE 9

MICOM, with contractor support, has developed analytical models in each of the major areas of missile development. These models are computerized simulations of a complete family mix of weapons (tube artillery, rockets, missiles, and aircraft) in a realistic combat environment to determine the effectiveness of a candidate weapon in the family mix. All of these computer programs are presently programmed for the MICOM IBM 7094 computer. Modifications to these models now in development will require a larger computer.

SLIDE 10

The MICOM Close Support Model is a modification of the DYNTACS model developed by the CDC Armor Agency at Fort Knox and Ohio State University. The DYNTACS model is essentially a tank - anti-tank engagement. We are modifying this model to include infantry and close support artillery weapons and tactics. The simulation includes terrain in a specific geographical environment; realistic scenarios for acquisition and assignment of targets; dynamic simulation of the movement of both friendly and enemy forces until the objective has been accomplished.

This model is an effectiveness model which requires costs to be developed separately.

SLIDE 11

The Dynamic Effectiveness Model is a dynamic simulation of General Support weapon family mixes during a period of combat which includes a delay phase, a defense phase, and an attack phase. Three geographical environments are being programmed into this model.

A matrix of operational parameters and a matrix of weapon system characteristics are inputs to the computer simulation. The computer then follows the scenarios to account for time of battle, movement of weapons and targets, and damage assessment. Typical outputs are attrition in personnel and equipment to both RED and BLUE forces, ammunition required to defeat the targets, and the time that each weapon was used to defeat each of its assigned targets.

This model is primarily an effectiveness model to be complemented with a cost model. However, costs can be added to the last subroutine to automatically calculate up to thirty measures of effectiveness, which may include cost effectiveness.

SLIDE 12

Another general support combat simulation model has been developed to investigate the need for, and cost effectiveness of, various penetration aids for long range missiles. The usual operational and technical parameters are inputs. In addition, this model includes a cost analysis routine to complement the effectiveness routine and to yield direct comparisons of cost effectiveness of each of the postulated penetration aids.

SLIDE 13

The MICOM Air Defense Simulation model is also a geographically oriented dynamic combat simulation model. The inclusion of detailed terrain is a major improvement in this air defense model.

The summary of output information includes all functions from detection through site suppression. Site suppression is defined here as the destruction of the air defense radar site by the attacking aircraft. However, we hope that the output of "number of missile launched" and of "intercept kills" will negate the site suppression output.

This model is an effectiveness model which requires costs to be developed separately.

SLIDE 14

The MICOM System-Oriented Cost Model was developed to furnish the many types of dollar costs required to complement the effectiveness calculated by all the effectiveness models previously discussed. The development, investment, and operating costs are considered for up to twenty-five weapon systems in the family mix. The cost output can be time phased if desired in six different formats.

Each of these simulation models would require hours to present in detail. However, we will be glad to furnish any additional information to any government agency upon request to the Operations Research Branch at MICOM.

VI. TYPES OF STUDIES PERFORMED BY MICOM

SLIDE 15

In the twelve years of existence, the Operations Research group at MICOM has performed many studies of three general types. Examples of Quantitative Analysis are the cost effectiveness studies of proposed missile systems or improvements to current missile systems.

Examples of Qualitative Analysis are the logistic and manpower utilization studies of competing missile systems.

Examples of State-of-the-Art Analysis are surveys of the Free World's Missile Threat, and transportation capabilities.

VII. SUMMARY

SLIDE 16

In summary, I would like to re-emphasize four important factors to be considered in the performance of operations research to increase air defense effectiveness.

1. The entire life cycle of a weapon system must be planned and documented during the first phase of life.

2. Each step in the life cycle must be proven and approved before the next step is funded.

3. Increasingly close coordination among Intelligence, CDC, AMC, and Combat Arms Agencies is required to optimize worldwide force structures.

4. Within AMC, Operations Research techniques and simulation models are necessary and valuable tools in the technical design of weapon systems.

OPERATIONS RESEARCH IN R&D TO ACHIEVE ANTIAIRCRAFT EFFECTIVENESS
OUTLINE

I. INTRODUCTION

II LIFE CYCLE OF A WEAPON SYSTEM

- CONCEPT FORMULATION PHASE
- CONTRACT DEFINITION PHASE
- ENGINEERING DEVELOPMENT PHASE
- PRODUCTION PHASE
- OPERATIONAL PHASE
- DISPOSAL PHASE

III OPERATIONS RESEARCH IN THE LIFE CYCLE

IV HOW MICOM IS ORGANIZED TO PERFORM OPERATIONS RESEARCH

V ANALYTICAL MODELS USED AT MICOM

- CLOSE SUPPORT WEAPONS SIMULATION
- GENERAL SUPPORT WEAPONS SIMULATION
- AIR DEFENSE WEAPONS SIMULATION
- COST

VI TYPES OF STUDIES PERFORMED BY MICOM

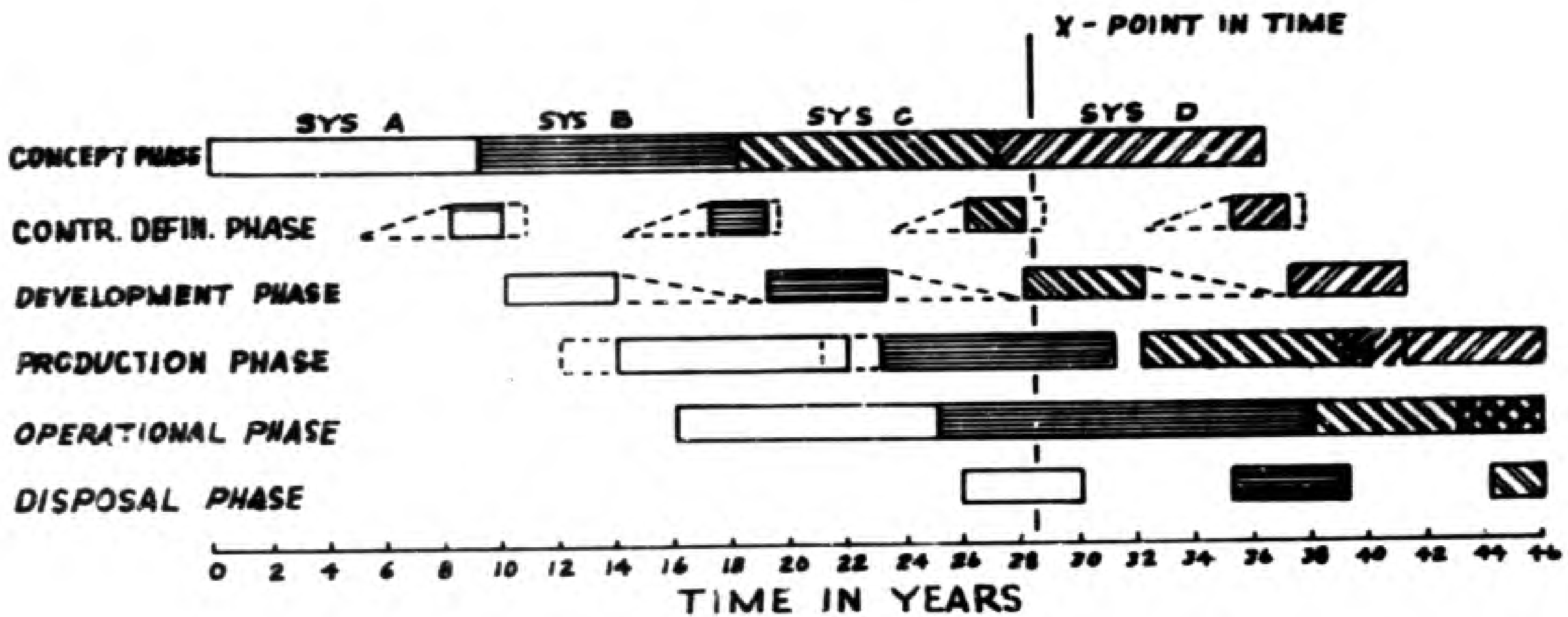
SLIDE 1

LIFE CYCLE OF A WEAPON SYSTEM

	U.S. ARMY
A. CONCEPT FORMULATION PHASE	
• DEVELOP POTENTIAL MILITARY THREAT	ACSI
• DEVELOP REQUIREMENTS FOR WEAPONS TO DEFEAT THREAT	CDC
• POSTULATE TECHNICAL CONCEPTS TO MEET MILITARY REQUIREMENTS	AMC
• EVALUATE TECHNICAL DESIGN CONCEPTS	AMC
• PERFORM EXPLORATORY OR ADVANCED DEVELOPMENT	AMC
• POSTULATE WEAPON SYSTEM FOR EACH THREAT	AMC
• EVALUATE WEAPON SYSTEM IN COMBAT ENVIRONMENT	AMC
• POSTULATE FORCE STRUCTURE TO COUNTER WORLDWIDE THREAT • EVALUATE FORCE STRUCTURE IN COMBAT ENVIRONMENT	CDC AMC ACSI
B. CONTRACT DEFINITION PHASE	AMC CONTRACTOR
C. ENGINEERING DEVELOPMENT PHASE	AMC CONTRACTOR
D. PRODUCTION PHASE	AMC CONTRACTOR COMBAT ARMS
E. OPERATION PHASE	AMC COMBAT ARMS
F. DISPOSAL PHASE	AMC

SLIDE 2

LIFE CYCLE SPECTRUM



4 YR. DEVELOPMENT CYCLE
8 YR. PRODUCTION BUY
10 YR. SERVICE LIFE

SLIDE 3

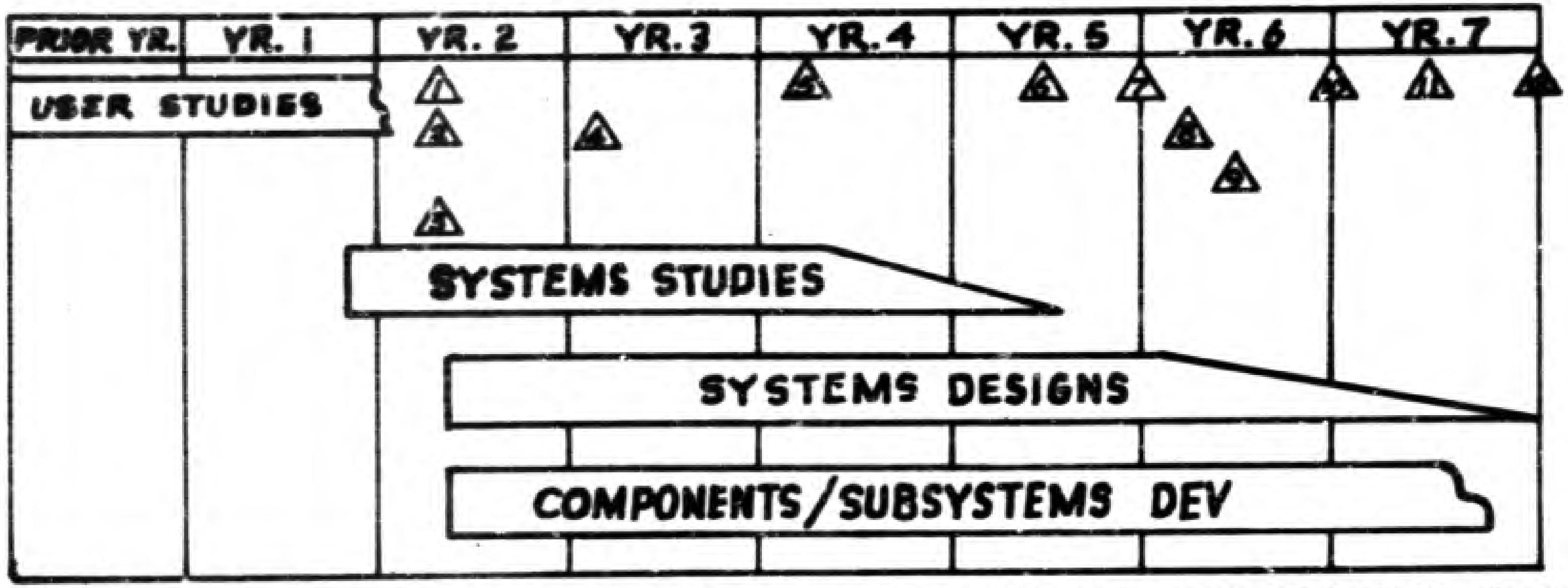
REQUIREMENTS-R&D RELATIONSHIPS

- RESEARCH – ARP, AFDP, ARDP, CDOG
- EXPLORATORY DEVELOPMENT – QMDO, ARP, RDLRP & AMC's OBJECTIVES FOR TECHNOLOGY
- ADVANCED DEVELOPMENT – ADO, QMDO (SOME CASES QMR OR SDR)

  CONCEPT DEFINITION PHASE → CDP
- ENGINEERING DEVELOPMENT – QMR, SDR

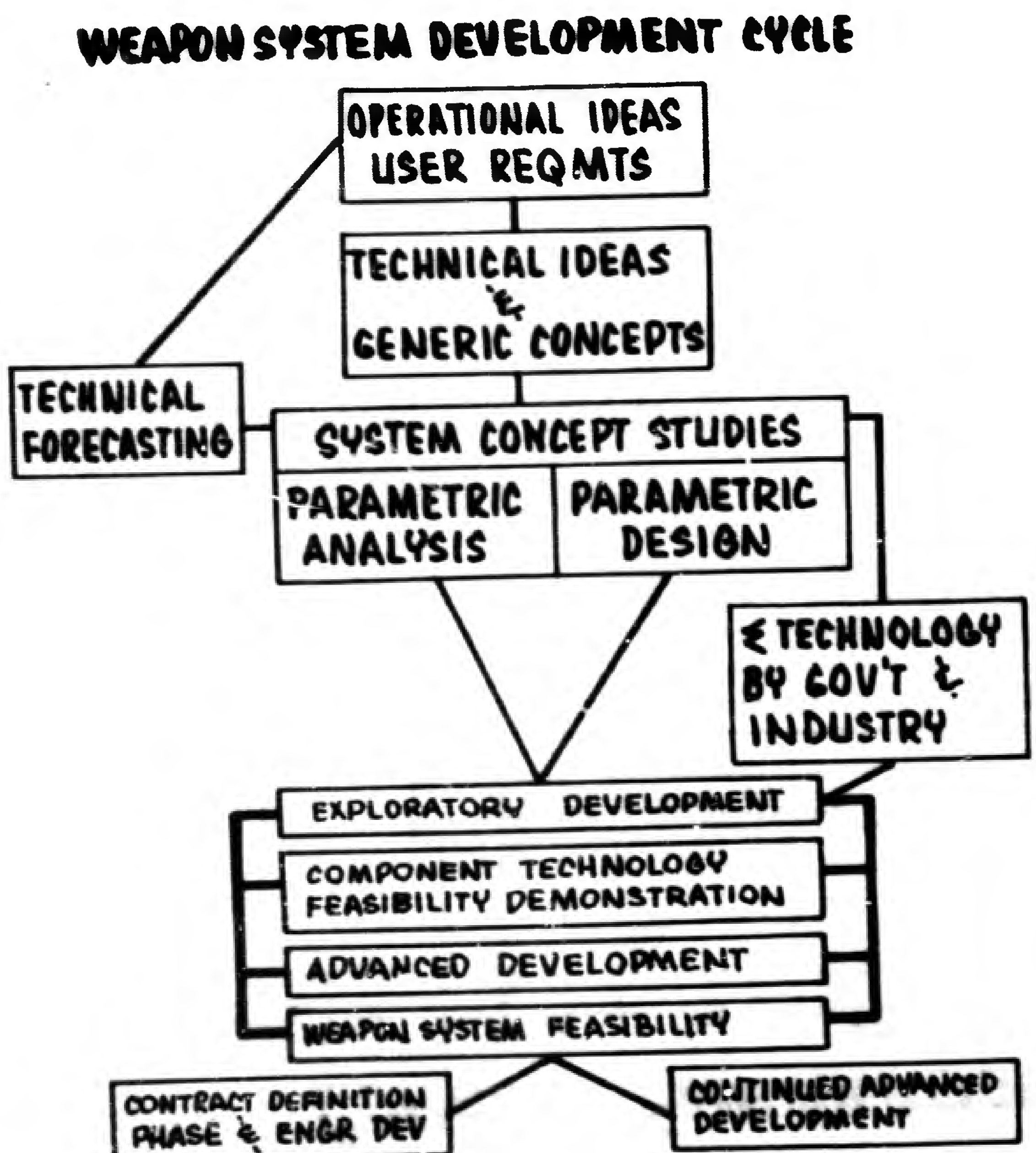
SLIDE 4

CONCEPT FORMULATION PHASE

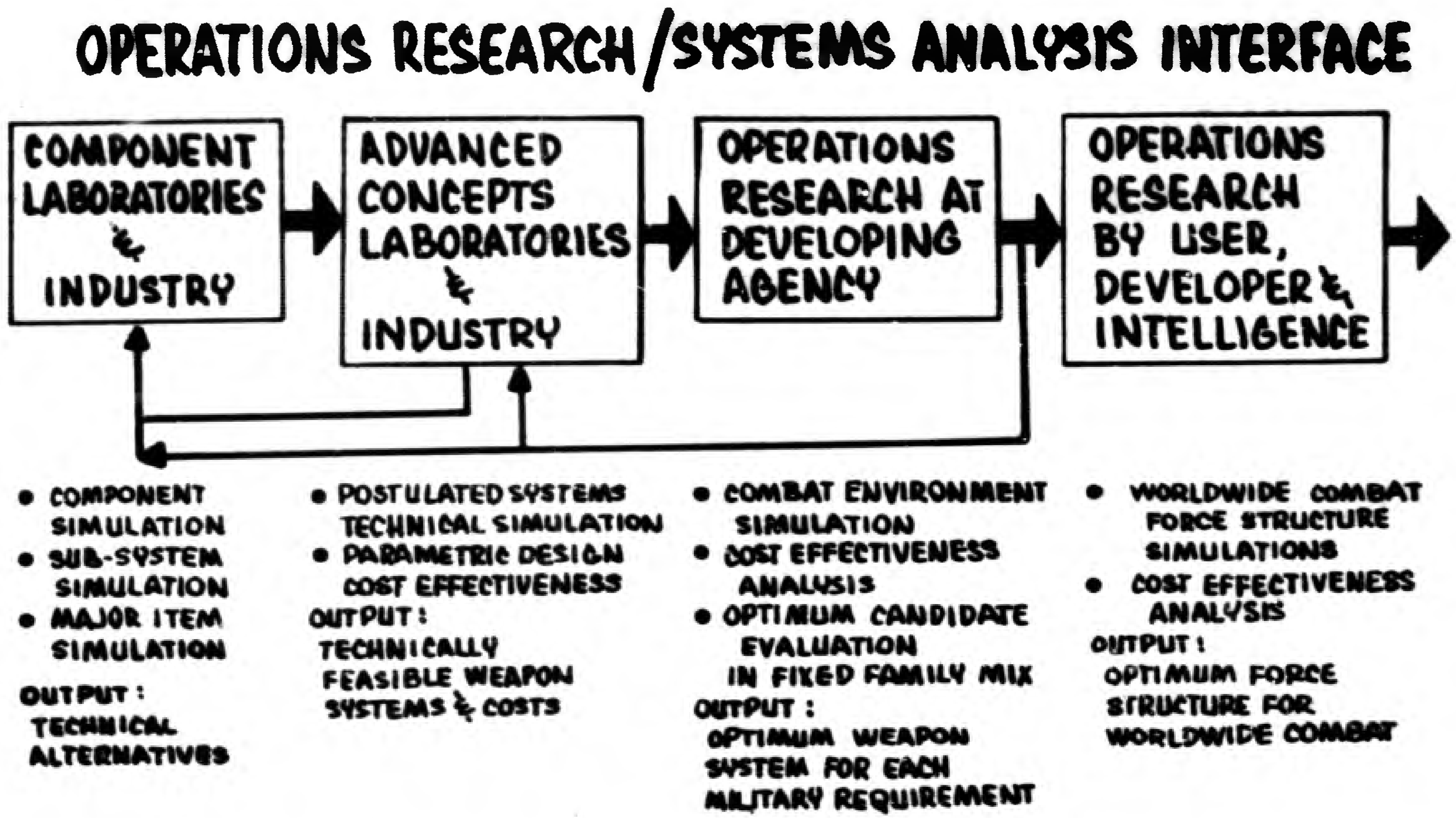


1. CDC DEVELOPMENT GUIDELINES
2. MATERIEL SYS. STUDY INITIATED
3. SYS. TRADE-OFF/DES. MOD DEV. INITIATED
4. COMPONENT DEV. INITIATED
5. PRELIMINARY SYS. DES. COMPLETED
6. SELECT TECHNOLOGY FOR REFINED SYS. DES.
7. REFINED SYS. DESIGNS COMP.
8. COMPONENTS FEAS. DEMONSTRATED
9. COMP. SYS. DEFIN. (MSLS & GUNS)
10. INITIATE CDP
11. COST EFFEC. OPT.-FAMILY-MIX STUDY COMPLETED
12. ENGR. DEV. CONTR. AWARDED

SLIDE 5

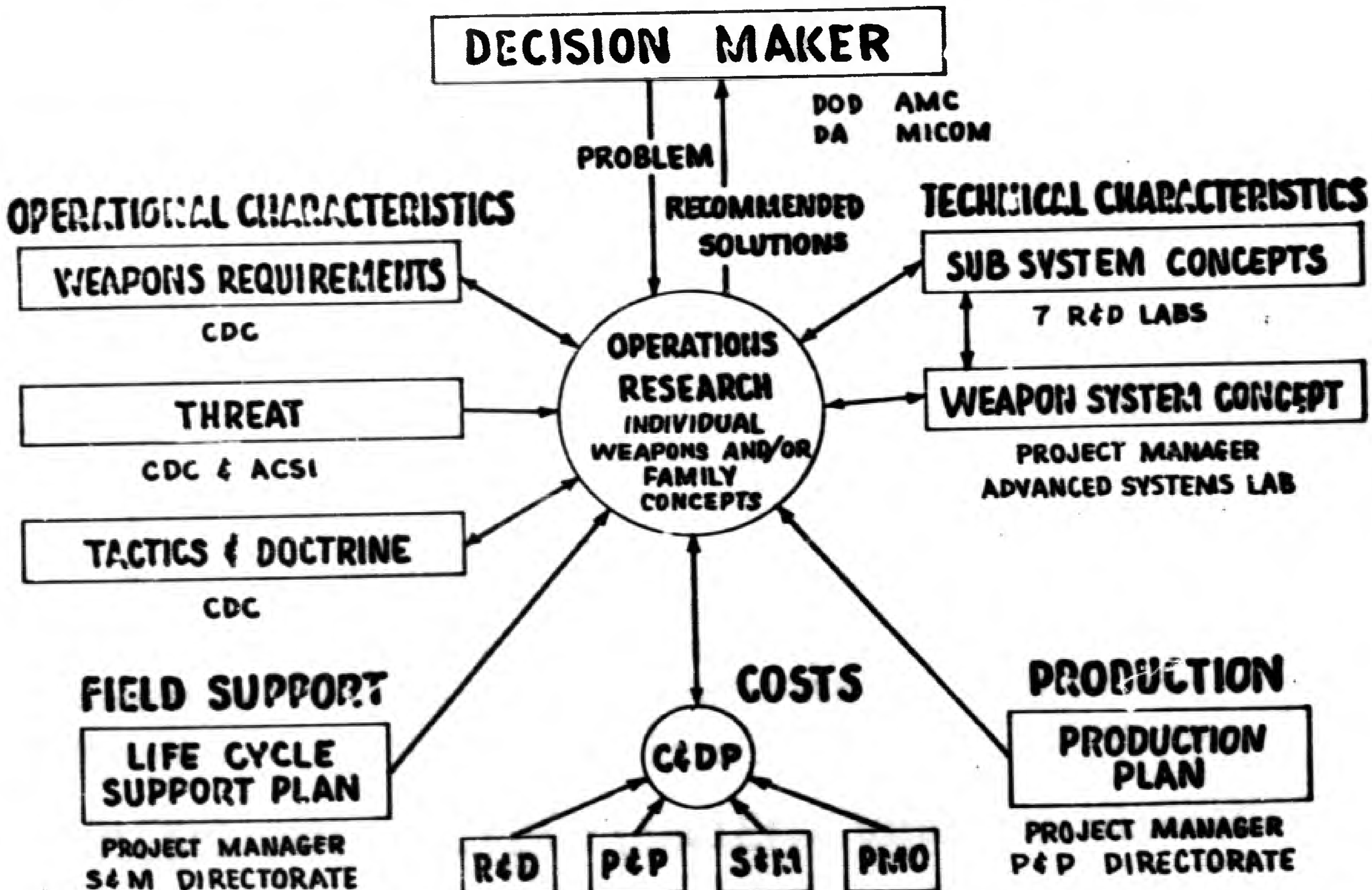

WEAPON SYSTEM DEVELOPMENT CYCLE
OPERATIONAL IDEAS
USER REQMTS
TECHNICAL IDEAS & GENERIC CONCEPTS
TECHNICAL FORECASTING
SYSTEM CONCEPT STUDIES
PARAMETRIC ANALYSIS
PARAMETRIC DESIGN
€ TECHNOLOGY BY GOV'T & INDUSTRY
EXPLORATORY DEVELOPMENT
COMPONENT TECHNOLOGY FEASIBILITY DEMONSTRATION
ADVANCED DEVELOPMENT
WEAPON SYSTEM FEASIBILITY
CONTRACT DEFINITION PHASE & ENGR DEV
CONTINUED ADVANCED DEVELOPMENT

SLIDE 6


OPERATIONS RESEARCH/SYSTEMS ANALYSIS INTERFACE
COMPONENT LABORATORIES & INDUSTRY
ADVANCED CONCEPTS LABORATORIES & INDUSTRY
OPERATIONS RESEARCH AT DEVELOPING AGENCY
OPERATIONS RESEARCH BY USER, DEVELOPER & INTELLIGENCE
• COMPONENT SIMULATION
• SUB-SYSTEM SIMULATION
• MAJOR ITEM SIMULATION
OUTPUT: TECHNICAL ALTERNATIVES
• POSTULATED SYSTEMS TECHNICAL SIMULATION
• PARAMETRIC DESIGN COST EFFECTIVENESS
OUTPUT: TECHNICALLY FEASIBLE WEAPON SYSTEMS & COSTS
• COMBAT ENVIRONMENT SIMULATION
• COST EFFECTIVENESS ANALYSIS
• OPTIMUM CANDIDATE EVALUATION IN FIXED FAMILY MIX
OUTPUT: OPTIMUM WEAPON SYSTEM FOR EACH MILITARY REQUIREMENT
• WORLDWIDE COMBAT FORCE STRUCTURE SIMULATIONS
• COST EFFECTIVENESS ANALYSIS
OUTPUT: OPTIMUM FORCE STRUCTURE FOR WORLDWIDE COMBAT

SLIDE 7

MICOM OPERATIONS RESEARCH PROCEDURES



SLIDE 8

V ANALYTICAL MODELS USED AT MICOM

A. CLOSE SUPPORT WEAPONS SIMULATION

MODIFIED DYNTACS (OSU)

B. GENERAL SUPPORT WEAPONS SIMULATION

DEMS (LMSC)

PEN AIDS (BMI)

C. AIR DEFENSE WEAPONS SIMULATION

MADS (ARC)

ENGAGEMENT BOUNDARIES (MICOM)

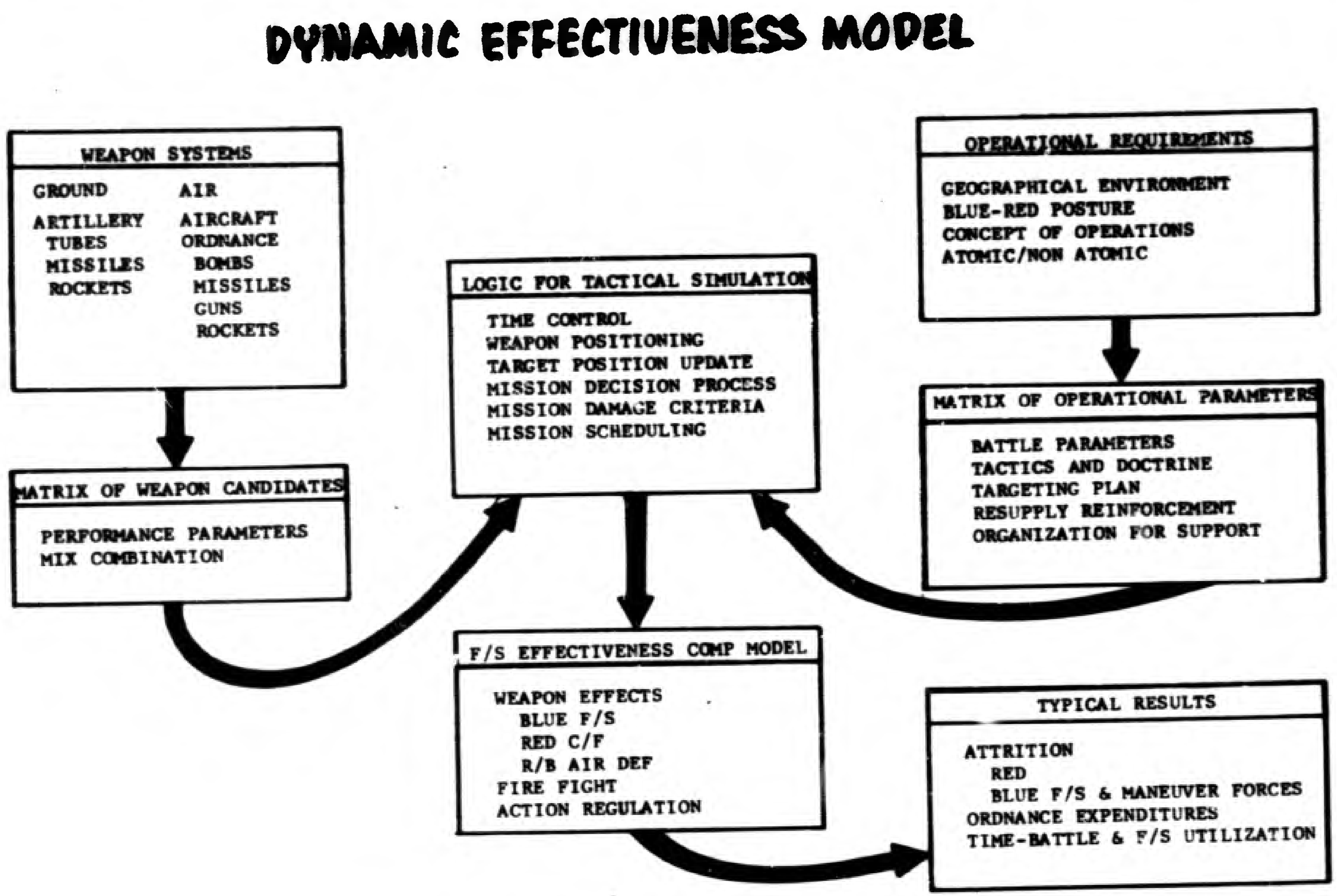
D. COST (RAC)

SLIDE 9

MICOM CLOSE SUPPORT MODEL FEATURES

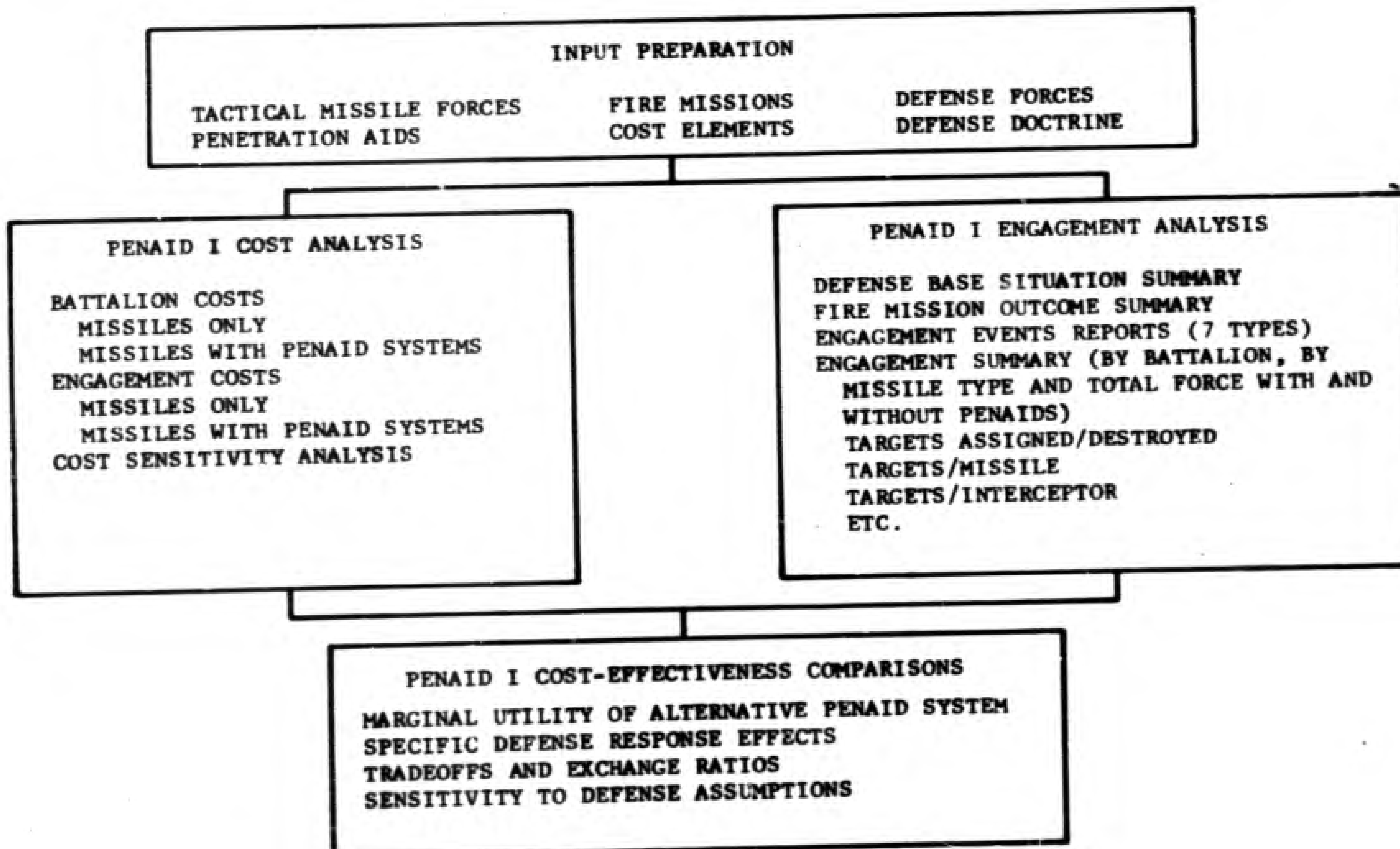
1. Terrain and Environment Representation - Europe
2. Intelligence - Target Acquisition and Communications
3. Tactical Decision - Computes Assault Route
4. Firing - Accuracy and Lethality of Direct Fire Weapons Assessed
5. Indirect Fire
6. Fire Controller - Assigns Target
7. Movement - Computes Elements Desired Position at End of Current Event
8. Movement Controller - Monitors and Updates Set of Tables Making Current Formation Direction, and Speed of Movement Readily Available
9. Event Timer - Computes Time to Perform Current Event
10. Sequence Controller - Examines Element Positions to Determine if Objective Has Been Reached

SLIDE 10


DYNAMIC EFFECTIVENESS MODEL
WEAPON SYSTEMS
GROUND
ARTILLERY
TUBES
MISSILES
ROCKETS
AIR
AIRCRAFT
ORDNANCE
BOMBS
MISSILES
GUNS
ROCKETS
MATRIX OF WEAPON CANDIDATES
PERFORMANCE PARAMETERS
MIX COMBINATION
LOGIC FOR TACTICAL SIMULATION
TIME CONTROL
WEAPON POSITIONING
TARGET POSITION UPDATE
MISSION DECISION PROCESS
MISSION DAMAGE CRITERIA
MISSION SCHEDULING
OPERATIONAL REQUIREMENTS
GEOGRAPHICAL ENVIRONMENT
BLUE-RED POSTURE
CONCEPT OF OPERATIONS
ATOMIC/NON ATOMIC
MATRIX OF OPERATIONAL PARAMETERS
BATTLE PARAMETERS
TACTICS AND DOCTRINE
TARGETING PLAN
RESUPPLY REINFORCEMENT
ORGANIZATION FOR SUPPORT
F/S EFFECTIVENESS COMP MODEL
WEAPON EFFECTS
BLUE F/S
RED C/F
R/B AIR DEF
FIRE FIGHT
ACTION REGULATION
TYPICAL RESULTS
ATTRITION
RED
BLUE F/S & MANEUVER FORCES
ORDNANCE EXPENDITURES
TIME-BATTLE & F/S UTILIZATION

SLIDE 11

MICOM PENETRATION AIDS MODEL



SLIDE 12

OPERATIONS RESEARCH MICOM AIR DEFENSE SIMULATION

OUTPUT SUMMARY

1. Detected
2. Acquired
3. Evaluated
4. Track While Scan Drop
5. Ft Channel Assigned
6. Chan. Switch to
7. Drop Ft Chan. Assignment
8. Ft Lock On
9. Ft Evaluate
10. Launch Missile(s)
11. Begin Reload
12. Abort Missile(s)
13. Intercept Kill
14. Intercept Non Kill
15. Fast Track Drop
16. Launcher Assigned
17. Reloaded
18. Disengage
19. Re-engage
20. Enemy Contact
21. Site Suppressed

SLIDE 13

MICOM SYSTEM-ORIENTED COST MODEL

INPUTS

- RDT&E, PEMA, AND O&MA COSTS
- COSTS FOR 25 WEAPON SYSTEMS
- COSTS FOR 9 SUBSYSTEMS FOR EACH
- SELECTIVE SUPPRESSION OF INPUTS

OUTPUTS

- PROVIDES TIME-PHASED AND/OR NON-TIME-PHASED COSTS
- CALCULATES LEARNING CURVE DATA
- PROVIDES TOTAL LIFE CYCLE PROGRAM COSTS
- SIX DIFFERENT OUTPUT FORMATS
- BUILT-IN SENSITIVITY ANALYSIS
- WEAPONS FAMILY MIX COST

SLIDE 14

VI TYPES OF STUDIES PERFORMED BY MICOM

A. QUANTITATIVE ANALYSIS

- COST EFFECTIVENESS ANALYSIS OF A NON-NUCLEAR SERGEANT
- EXTENDED RANGE LANCE-SERGEANT TRADE-OFF STUDY
- COST EFFECTIVENESS ANALYSIS OF SAM-D
- COMPARATIVE EVALUATION OF THE ANTI TACTICAL BALLISTIC MISSILE CAPABILITIES OF THE ARMY AIR DEFENSE SYSTEMS
- AIR DEFENSE OF CONUS

B. QUALITATIVE ANALYSIS

- LOGISTICS OF ROCKET ENGINES, SOLID VS LIQUID
- MANPOWER EVALUATION OF COMPETING WEAPON SYSTEMS

C. STATE-OF-THE-ART ANALYSIS

- FREE WORLD'S MISSILE THREAT TO THE SOVIET FIELD ARMY
- MAXIMUM CARGO CAPABILITIES OF TRANSPORT VEHICLES

SLIDE 15

SUMMARY

1. THE ENTIRE LIFE CYCLE OF A WEAPON SYSTEM MUST BE PLANNED AND DOCUMENTED DURING THE FIRST PHASE OF LIFE

2. EACH STEP IN THE LIFE CYCLE MUST BE PROVED AND APPROVED BEFORE THE NEXT STEP IS FUNDED

3. INCREASINGLY CLOSE COORDINATION AMONG INTELLIGENCE, CDC, AMC, AND COMBAT ARMS AGENCIES IS REQUIRED TO OPTIMIZE WORLDWIDE FORCE STRUCTURES

4. WITHIN AMC, OPERATIONS RESEARCH TECHNIQUES AND SIMULATION MODELS ARE NECESSARY AND VALUABLE TOOLS IN THE TECHNICAL DESIGN OF WEAPON SYSTEMS

SLIDE 16

OPERATIONS RESEARCH DURING DESIGN AND DEVELOPMENT OF AN ANTI-AIRCRAFT SYSTEM

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Missile Systems Division
Raytheon Company

Cognizant Agency: U. S. Army Missile Command

Industry becomes involved in an anti-aircraft system to provide technical depth and capabilities for manufacturing and management. Operations analysis is part of the total contribution by an industrial contractor mainly to complement this primary role of development and production. Operations analysis for this purpose is the subject of this paper, though it can be noted that industry may be called upon to assist government agencies in the prior and subsequent phases: the requirements phase, during which a military service determines what should be developed, and the ownership phase, involving determination of how to use the system after it has been acquired.

This paper outlines the areas in which an industrial contractor employs operations analysis in getting his part of the job done to bring a new system into being. Before proceeding, however, let us all acknowledge that while getting the job done at any phase there is a continuing need for program justification. When questions are asked, all interested parties stand ready to supply answers. Survival of a program for its full life cycle requires that a strong cost/effectiveness posture be demonstrated at any time that the program may be challenged. To convince a decision maker, whether inside or outside the Army, often requires the joint efforts of the requirements agency, the program management office, the contractor, and the user. Many of the briefing slides are prepared by operations analysts. The balance of this paper will set aside this "selling" activity and deal only with the subject of getting the development job done.

Another aspect of operations analysis that will be set aside in this paper is the use of scientific methods as a guide in managing the activities of an industrial contractor while performing system development. This can be termed "internal" operations analysis. The topic here is "external" operations analysis, whereby the operations being analyzed are those of the military user while performing the mission for which the system is being developed.

System development is a process of exploiting the technologies to create the end product. It would be simple to state that the system development involves collaboration among designers, analysts, and managers. This would imply that operations analysis is a specialized discipline practiced only by people who wear a certain type of badge. (No differentiation is made here among the phrases operations research, operations analysis, and systems analysis.) Operations analysis is not necessarily a tight specialty. To reflect the full scope of operations analysis in the team effort involved in development of a system, the following definition is employed here:

> Operations analysis includes any analytical thought process that anticipates operational use of the system.

Based on this definition, operations analysis is performed on occasion by designers, planners, and managers. An operations analyst is merely a person who spends most of his time at it.

To extend this definition, operations analysis is usually oriented toward either (1) performance of the system as it yields cost/effectiveness or (2) procedures by which the system is operated or supported.

Parametric trade-offs to provide the basis of design decisions are the dominant operations analysis contribution to system development. Even the most minor decision at the sub-assembly level, made by one man based upon what he considers to be simply engineering judgement, usually involves a quantitative inter-play among parameters. A basic two-dimensional trade-off can often be performed readily in the mind of a man. One of the two quantities is degraded by a known amount to achieve a better buy (a favorable trade) in improvement of the second quantity. A two-dimensional trade-off may involve performance factors only, penalty factors only, or one of each. Using a missile as an example:

(1) Range may be reduced to allow faster speed, both being performance factors.

(2) Diameter may be increased to allow less length, both being penalty factors.

(3) The penalty factor of weight may be increased to improve the performance factor of range.

Trading between two quantities implies that all other parameters are constant. To a mathematician, this signifies that partial derivatives are involved. In a complex system, or even its subsystems, many more than two parameters are involved. The mathematician is challenged to formulate the various parametric interrelationships. Experts in many technologies must provide the partial derivatives, often referred to as sensitivity functions. Most distressing of all, considerations appear that are difficult to evaluate quantitatively in the performance/penalty domain. System features that are difficult to quantify in consistent units, if on any basis at all, include flexibility, mobility, vulnerability, maintainability, supportability, transportability, and technical risk. Proper weighting of such features, along with the quantitative data that can be generated relative to some of the performance factors and some of the penalty factors, is the challenge of the system manager. He must be astute, and the key members of his technical team must be acclimated to making trade-offs among multiple parameters, some expressed in units inconsistent with others.

The role of the operations analysis specialist in the team effort of trade studies is to provide the ground rules that translate the needs of the user into the domain of design parameters. The needs of the user ultimately should be expressed in terms of value on the battlefield. Even though development of the system has been preceded by careful evolution of its requirements, a complete statement as to the quantitative value of every system performance factor is not likely to be available. A mathematician who is going to optimize value of design parameters desires that the wishes of the user be expressed by "indifference functions." Latitude in design choice by the contractor exists only between the specified minimum in some performance factor and the specified maximum in some penalty factor. Within this region, an indifference function, if specified, would define in terms of performance/penalty factors the "even trade" - no preference, hence indifference. An example would be the function, such as a graph, indicating the missile weight variations that the user would be willing to incur to achieve more or less maximum intercept range. Various of these indifference functions remain to be negotiated during development of the system so that fuzzy trade-off criteria can be resolved.

The latitude in making trade-offs, and in negotiating fuzzy criteria, decreases as the program proceeds through its phases. During Concept Formulation, systems of different types can be compared. During Contract Definition, trade-offs are generally at the sub-system level, although some "what if" questions may remain relative to major perturbations of the selected system configuration. During design and development, trade studies are done mainly to justify Engineering Change Procedures (ECP's) from the controlled system configuration, and the acceptability of changes decreases as the months of development effort progress.

Another occasion for the operations analyst to wrestle with measures of value is in establishing the fee structure of a multiple-incentive contract. Agreement on such a contract implies matching the value of the level of effectiveness the system provides to the total cost to the government of developing, procuring, deploying, and supporting that level of effectiveness. Once agreed upon, such a contract defines an overall indifference function. The customer by signing implies that he has no preference as to where the outcome of the effort lies within the specified field of indifference. The contractor is motivated to earn a maximum composite fee. (Maximizing fee can involve operations analysis of a high order. There are two players in the game, the contractor and Lady Nature. As the limitations of technology become known, the contractor can adjust his strategy. A colleague of mine delivered a paper on this topic at the 28th National Meeting of ORSA in November 1965. It had a compelling title, "Profit Maximization on Incentive Contracts," and presented an interesting analytic approach, but I have said that "internal" operations analysis will not be included in this paper.)

In addition to parametric trade-offs, there are many other areas of attention during the engineering process that involve operations analysis under my definition of "any analytical thought process that anticipates operational use of the system." Reliability, maintainability, safety, electromagnetic compatibility, and human factors engineering are among such areas of attention. Design for reliability and maintainability, and prediction of equipment availability, encompass a spectrum of disciplines extending from elegant mathematics to the most pragmatic aspects of quality control of parts or access to modules for replacement. The frame of reference is the operational environment and operating modes planned for the system. The reliability goals intertwine with the objectives for availability of the system and with the support plan, which I shall discuss shortly. Similar comments can be made for considerations of safety and electromagnetic compatibility, where the results of extremely detailed examination of potential failure effects must be interpreted for the impact on operational effectiveness of both equipment and personnel. These interpretations are dependent on deployment of the system and the doctrines and modes for its operation.

Relative to human engineering, every designer is a human and has lived and worked with humans and therefore considers himself qualified to establish the man/machine interfaces for his piece of equipment. Specialists in human factors are required on the development team, however, to assure consistent practices across the system, and to incorporate design features that are known to be sound by past experience and test, not merely based on individual intuition.

In the man/machine area, the next generation anti-aircraft systems are forcing us to deal with factors that were of little concern a few years ago. New equipments may involve (1) automatic data processing by digital devices for fire control, (2) automatic system test and fault isolation by the digital processor, (3) phased-array radars suitable for the multiple functions of surveillance, acquisition, pre-launch fire control, and in-flight guidance of the missile, and (4) building-block construction of the system, allowing the equipment complement of deployed fire units to be tailored to the defense objective at each firing site. These features give flexibility. In attempting to exploit this flexibility, a man can get dizzy. Allocation of the building-block modules to a firing site requires decisions by a human. Choice of the operating mode of multi-function radar, the allocation of its power and the beam time among the several functions and among the several types of targets, requires decisions by a human. Choice of the operating mode of an automatic processor, with various possible degrees of intervention by a human operator, requires decisions by a human. And then with the fire unit on site and operating in the selected modes, said human operator must perform his tasks as associated with these modes, ready at any time to change his procedures to fit a casualty mode that may be initiated because of subsystem failures, countermeasures, or unpredicted circumstances of a battle. For the next-generation systems, the role of the operator is shifting from that of a mechanical sequencer to that of a maker of decisions among branching alternatives, from operation on-line to operation by exception. Designers must implement equipment interfaces with the men so that these decisions can be made at speeds consistent with the fast response of the system. Along with the design features, guidelines must be developed for the personnel who will be involved in system operation and in planning deployment and employment of the system. There must be procedures for "management flexibility."

Another feature of some anti-aircraft systems being considered for the next generation is an ability to engage more targets simultaneously than is possible with present-generation systems. This also confronts us with a new problem in human engineering because of the criticality of the decision whether to explcit this rapid-fire capability or to conserve ammunition. Corollary to a capability to destroy targets at a gratifying rate is the tendency to empty launchers at a frightening rate.

Although most of the areas of attention for operations analysis described here are adjuncts to hardware engineering, various of them lead to studies of the classical OR type. Some of these are listed on Table I. This list by itself could be made the program for a symposium, with a paper or even a session on each topic. The first activity listed, functional analysis, has always been the starting point for orderly analysis of complex systems. This process has in recent years been formalized to provide a framework for trade studies and for system integration. This functional framework leads to the hardware breakdown structure of the controlled configuration.

TABLE I

CLASSICAL OPERATIONS ANALYSIS STUDIES

- o Functional analysis to define functions within the mission and delineate subsystem functions and interfaces
- o Transport of the equipment and men to the theater of action, including contingency situations
- o Mobility as used to deploy within the theater, to stay with moving forces, and to reduce targetability of the defensive sites
- o Emplacement and march order
- o Surveillance and target engagement, including supporting fire among adjacent sites (including complementary weapons) as integrated by available facilities for command, control, and communications
- o Deployments for various levels of defense, including site selection for favorable terrain visibility and supply routes

Studies of the type listed on Table I involve mathematical modeling to some extent. Use of mathematical analogs that represent the system itself to validate the design by simulation are activities beyond my definition of operations analysis. Such simulations anticipate system tests, which constitute the moment of truth short of actual battle. Simulations can also be used after testing, to increase the sample size at less cost than real-life testing. I have stated that operations analysis is most concerned with performance and procedures. Relative to test and simulation, therefore, operations analysis is involved mainly in planning an experiment that will validate predicted performance. Then, if performance proves to be not as predicted, operations analysis is part of the exercise to devise cost/effective design fixes, perhaps combined with changes in operating procedure to compensate for deficiencies.

Planning tests to validate a system as complex as those required for anti-aircraft defense is particularly challenging because limitations of funding do not allow a large sample size. Taken together, the set of tests conducted by the contractor during development and by TECOM during evaluation represents an inadequate statistical sample relative to scientific criteria for high confidence. In recognition of this, tests are not planned as a statistical experiment to score the system based only on the gross outputs, such as miss distance. Instead, analysis prior to testing identifies all of the indicators, however subtle, that can be used to extend the interpretation of the results. Sophisticated instrumentation is then devised to record these indicators. A small test sample can then yield a large amount of information. Planning of the tests themselves thus becomes subordinate to planning what data to gather and how to interpret it, all relative to performance of the system as it results in value on the battlefield.

There are two areas that require the OR specialists to use the most powerful intellectual and mathematical tools available to them. I call these the battle simulation, which addresses itself to the engagement of multiple attackers by multiple defensive sites (in contrast to the one-on-one basis of most analyses, tests, and simulations) and the life-cycle simulation, which characterizes the complex inter-relationships among all the factors involved in deployment, operation and support of the system for its full life cycle following initial acquisition.

A battle simulation using a digital computer is a war-gaming approach that is most often used to test the influence of a conceptual weapon on the outcome of battle, or to establish a most suitable force-level mix. Similar analytical methods are required to guide development, however, mainly in the area of computer software programs and the role of the human operator. This analysis tests launching rules, concepts of command and control, and the implications of imperfect communications among firing sites. Design decisions are reached, along with an assessment of the effect of the system on the outcome of battle.

A life-cycle simulation involves digital computer simulation not only of the system itself but also of the support system, its parts stockage and its operating and maintenance personnel. The computer program then simulates deployment of the system in the field and operation over the spectrum of missions it is expected to see during its life cycle. This simulation provides a means for addressing the interrelated life-cycle factors listed on Table II. By Monte Carlo sampling, the program yields effectiveness indices, cost sensitivities, and safety indices. By inputing a number of feasible support plans, the most cost/effective one can be identified. The requirements for implementation of this plan become known (inventories and supply points, crew sizes and skill levels, repair or discard doctrines, etc.) along with predictions of system availability and life-cycle cost. On any basis of measuring the magnitude of a digital computer program, this is a "big calculation."

Although "big calculations" are described as a sort of climax to this paper, I do not want them to interfere with what I intend as the theme, that the activity called operations analysis is pervasive during design and development of an anti-aircraft system by an industrial contractor. Almost everybody does it on occasion, and it impacts in almost every area of the total effort. It is a part of system engineering. It is disciplined by the total job that needs to be done.

TABLE II

INTERRELATED LIFE-CYCLE FACTORS

Performance

Operations, capability, vulnerability, failure effects

Safety

Failure modes, hazard levels, propagation

Reliability

Environment, stress, aging, wearout, failure modes

Maintainability

Access, tools, handling equipment, disconnects

Maintenance

Fault detection, skill levels, replacement levels, test equipments

Logistics

Stock levels, stockage points, transport methods

Cost

Equipment, facilities, personnel, publications, replacement modules, transportation

ROLE OF COMBAT DEVELOPMENTS COMMAND IN THE DEVELOPMENTAL PROCESS

PRESENTED BY

LTC LOUIS E. ABELE

HEADQUARTERS, U. S. ARMY COMBAT DEVELOPMENTS COMMAND
FORT BELVOIR, VIRGINIA

The United States Army Combat Developments Command (USACDC) had its inception as a separate command in 1962. Army Regulation 10-12 sets forth the missions and principle functions of Combat Developments Command (CDC). These are:

(1) To formulate and document current doctrine for the Army-in-the-field, for Army participation in the unified defense of the United States against air attacks, and for Army support of civil defense.

(2) To determine, in anticipation of the nature of land warfare in the future, the kinds of forces and materials needed and how these forces and materials should be employed.

To state these missions in a simplier manner, CDC has the task of answering three questions concerning the Army-in-the-field:

(1) How the Army shall fight?

(2) How the Army shall be equipped?

(3) How the Army shall be organized?

The best place to start to explain the manner in which answers are obtained for these questions is to discuss the Army's Disciplined Management Model. In this model, the Developmental Process is divided in four phases: (1) Concept Formulation, (2) Definition, (3) Development and Production, and finally (4) Operations and Disposal (See Figure 1). The answer to the question of "how to fight" is begun in CDC by the development of a list of operational capabilities objectives (OCO's). From these CDC progresses next through the definition phase by spelling out, in greater detail and refinement, tactics and operations that may be used to meet these objectives, and selects what appears to be, after evaluation, the best approach to meeting the OCO's. Then during the

PHASE	MAJOR AIMS
CONCEPT FORMULATION	1. DEFINE PROBLEMS & OBJECTIVES 2. IDENTIFY SOLUTION OPTIONS 3. ASSESS MERITS OF SOLUTION OPTIONS 4. SELECT GENERAL APPROACHES 5. INITIATE ACTION
DEFINITION	1. REFINE OBJECTIVES 2. VERIFY FEASIBILITY 3. SELECT SPECIFIC APPROACH 4. DEFINE DEVELOPMENT PROGRAM
DEVELOPMENT & PRODUCTION	1. REALIZE SELECTED APPROACH 2. PRODUCE "FIRST" PRODUCT
OPERATIONS & DISPOSAL	1. OBTAIN REQUIRED QUANTITY 2. TRAINED UNITS

FIGURE 1

development and production phase, CDC produces a field manual for this approach. Validation of the doctrine which the approach prescribes takes place during the operations and disposal phase, either by means of troop tests or actual operations. An answer to the question of "how to fight" has now been developed (See Figure 2).

In answering the question of "how to equip" and "how to organize" CDC progresses through the same four phases, but there is little vertical alignment between these activities. For example, the Qualitative Materiel Requirement (QMR) is one of the last major steps in concept formulation for materiel but phase-wise CDC is much farther along in answering the question of "how to fight". Type classification, which results from successful validation testing of the first production materiel takes place during the development and production phase. Follow-on production takes place during the operations and disposal phase and provides the hardware for the troops in the field. Successive refinements in answering the first two questions also influence and play a role in answering the question of "how to organize" by the structuring of units and the developing of tables of organization and equipment. Because of this fact, the activities involved in answering the last question are less susceptible to a clear demarcation between phases. An overview of the development process for the Army-in-the-field is thus shown by the three bar graphs in Figure 2.

It becomes clear that while one speaks of the phases of the development process as a whole it does not necessarily follow that a sharply defined demarcation line between phases exists through which all activities progress at the same time. Rather, the nature of the activity under consideration determines which phase that activity is in and, at many points in time, that phase will differ from the phase used to describe the position of the overall development process.

Another way to visualize the development process is to think of the process as an arrow whose base is fairly broad, whose flanks at the base are somewhat poorly defined, and whose direction at the base is not precisely established (See Figure 3). As the arrow passes through successive refinements the shaft is narrowed, the flanks are given better definition, and the arrow as a whole is given more precise direction--all of which permits it to home in on the objective: trained units in the field. Since we are thinking of the arrow in the sense of the overall development process, one could add the phases through which it passes as it is refined. The picture presented so far, however, is incomplete since it does not show how the successive refinements are realized. There is, of course, insufficient room in Figure 3 for all of the refinement actions but for illustrative purposes a few are shown. Army Materiel Command (AMC) actions are shown above the arrow and CDC actions are below the arrow.

Having established the parameters of the development process, CDC's part of developing the Army-in-the-field will now be discussed. The most important and far reaching task for CDC and the one having the greatest

THE DEVELOPMENT PROCESS

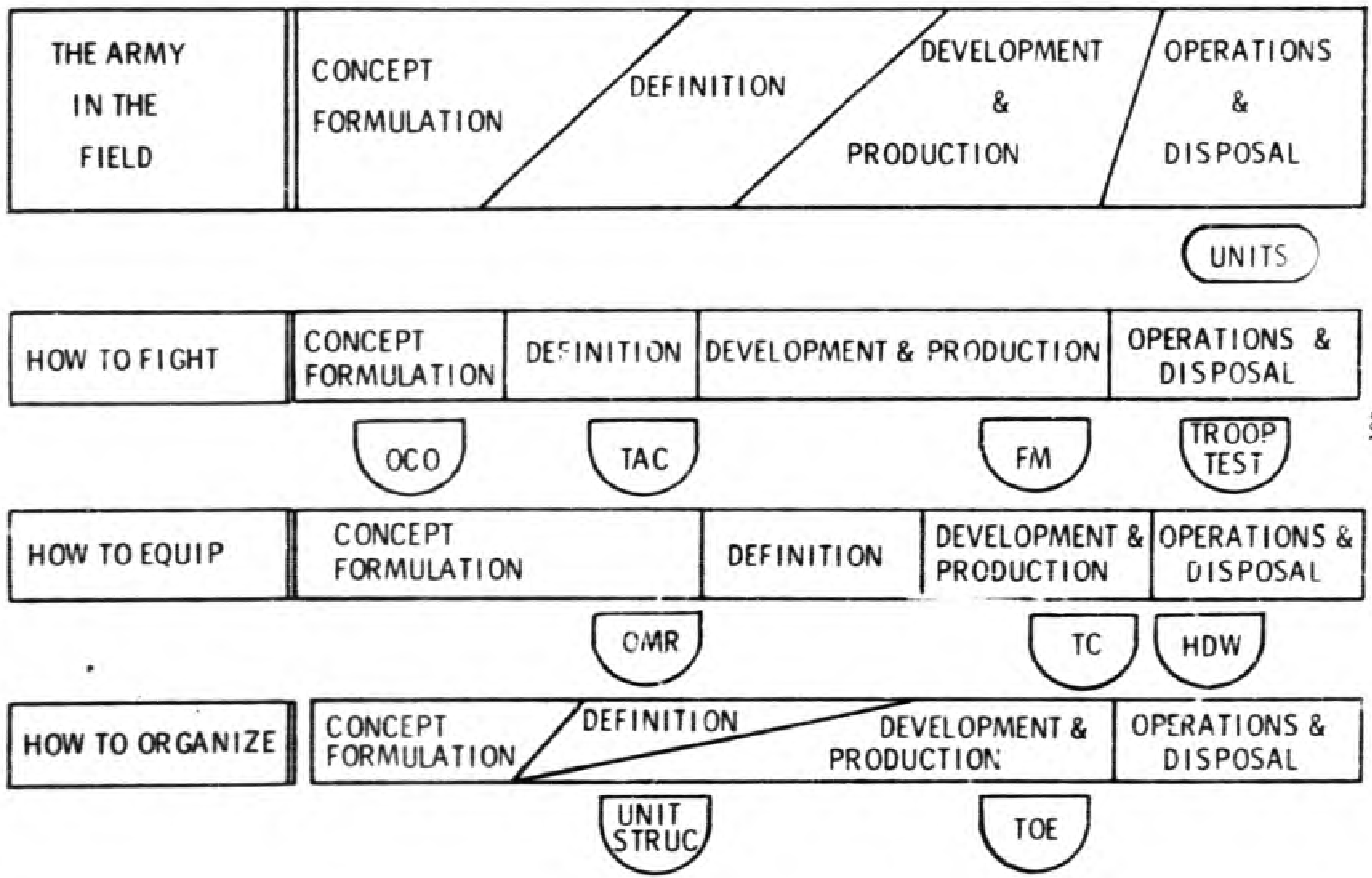

FIGURE 2

THE DEVELOPMENT PROCESS

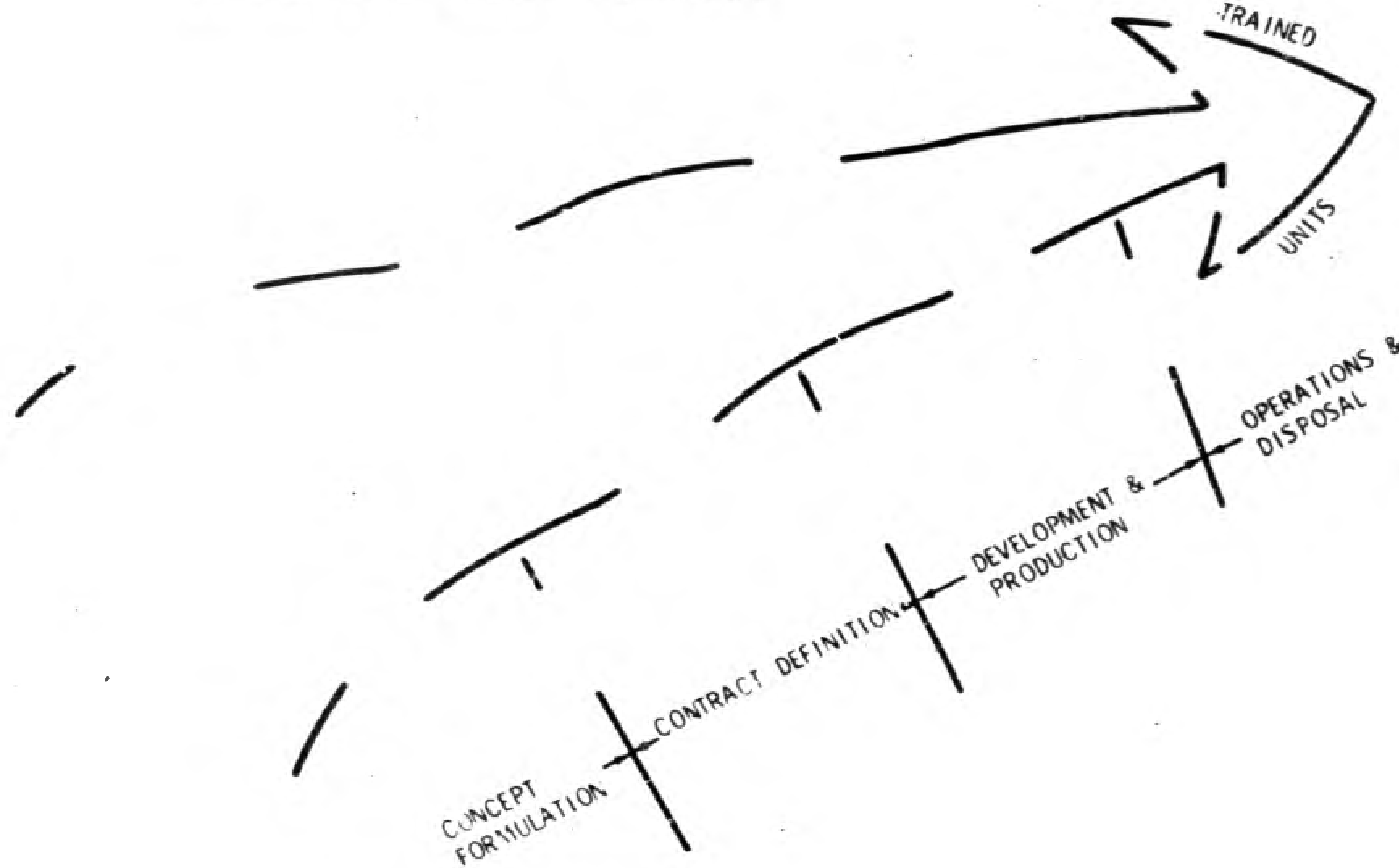

FIGURE 3

impact on the Army is the work being presently done for the long range time period. A small effort now, aimed at that period, can have a significant impact on the Army of the future and provide a tremendous pay-off. It is not difficult to transpose the bar chart of Figure 2 into the arrow of Figure 3, and doing so results in the visualization of the process as shown in Figure 4. Tactical and operational determinations (how to fight), the material development (how to equip), and the organizational design (how to organize), flow through the arrow. To this CDC adds two additional functions:

(1) An environment and threats function; i.e., "what do we have to fight?"

(2) An evaluation function; i.e., "how well are we doing in our doctrine, materiel and organizations against the threat?"

The latter function of evaluation is continuous throughout all phases of the refinement process and culminates with the validation of the entire development process when trained units are equipped and operate in the field.

The whole process has its inception, of course, in the concept phase, the end product of which is a report called The Land Combat System Study. By studying current events and trends in the world arena, nation by nation and region by region, the world environment or backdrop setting is established. Economic, demographic, social, and political trends, as well as intelligence available from the Defense Intelligence Agency, Army Intelligence, and the Foreign Science and Technology Center are all examined (See Figure 5). From these CDC forecasts the plausible conflict situations that could exist in the future, the antagonist in these situations, and their importance to the United States. Together these forecasts constitute the threats with which the United States might be confronted in the future.

Next, by analyzing U. S. policy and strategy and the forecasted threats, the tasks which the Army might be called upon to perform are deduced. These efforts result in a document called the Threat Forecast and Army Tasks. Concurrently, with producing the Threat Forecast and Army Tasks, CDC prepares, assisted by AMC, a compendium of those materiel options which might be available twenty to twenty-five years hence. To assist in this task, the Army Materiel Command is forming an advanced Materiel Concepts Laboratory which will employ scientists from many fields with close liaison with industry and the AMC commodity commands. This group will constantly search for scientific and technological advances which could give improved or revolutionary equipment capabilities up to 25 years in the future. This will provide the information on what science tells us today is possible in the future if we want it.

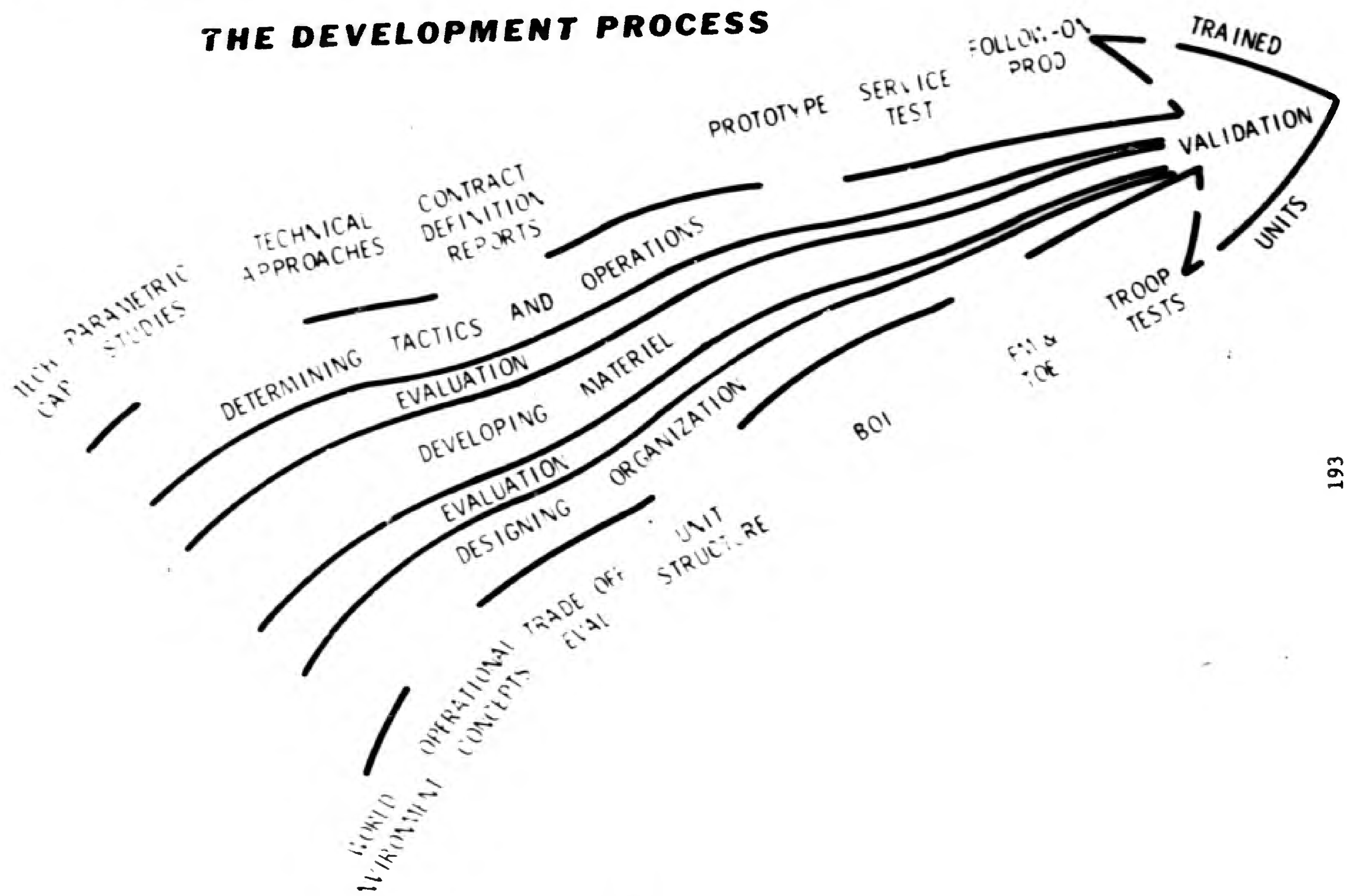
THE DEVELOPMENT PROCESS
TECH GAP
PARAMETRIC STUDIES
TECHNICAL APPROACHES
CONTRACT DEFINITION REPORTS
PROTOTYPE
SERVICE TEST
FOLLOW-ON PROD
TRAINED
VALIDATION
UNITS
DETERMINING TACTICS AND OPERATIONS
EVALUATION
DEVELOPING MATERIEL
EVALUATION
DESIGNING ORGANIZATION
BOI
TROOP TESTS
WORLD ENVIRONMENT
OPERATIONAL CONCEPTS
TRADE OFF EVAL
UNIT STRUCTURE

FIGURE 4

THE DEVELOPMENT PROCESS
WITHIN CDC

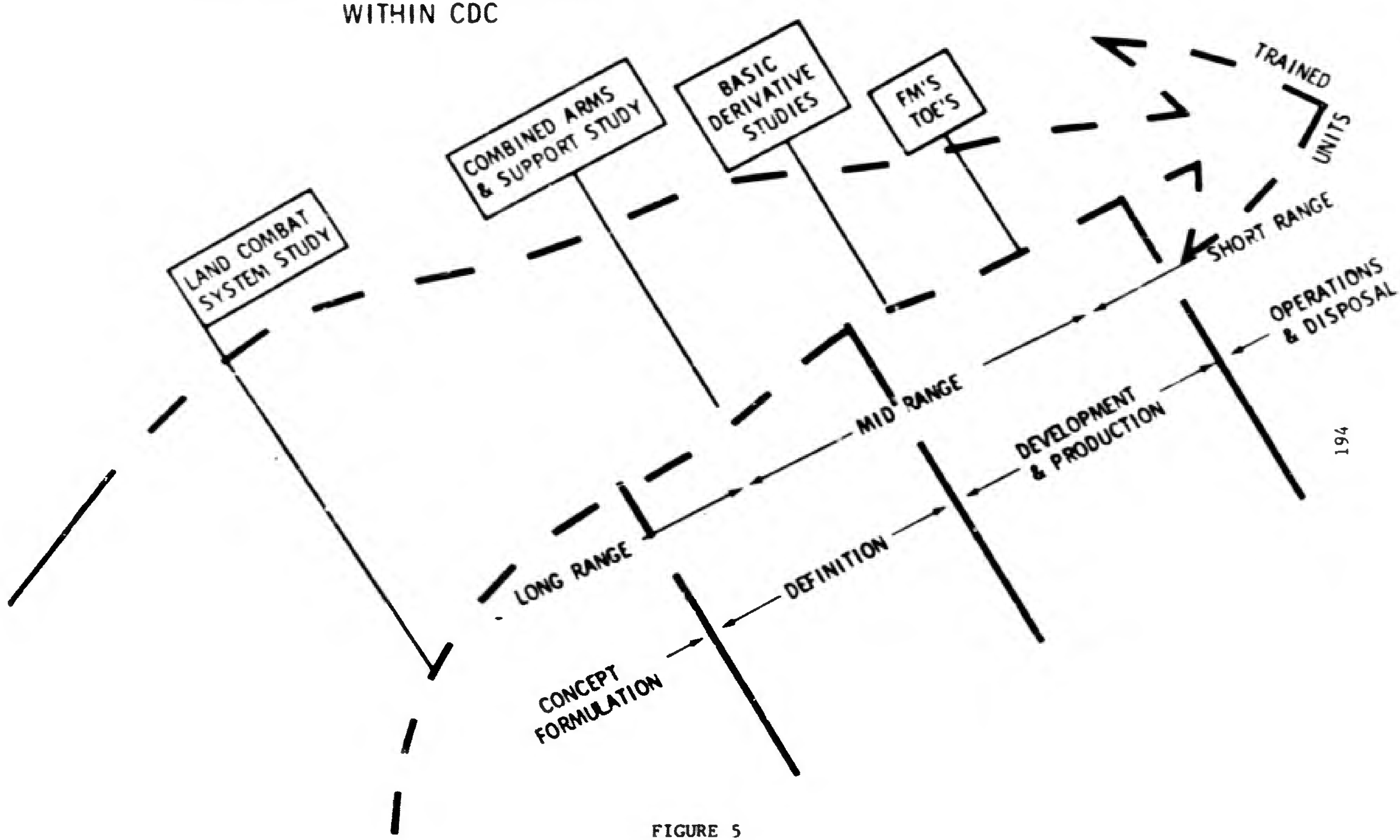

FIGURE 5

Using the approved Threat Forecast and Army Tasks and the compendium of plausible materiel options, CDC next develops the alternative concepts by which the Land Combat System should be able to counter the threats. For example, two alternative concepts might use different combinations of fire and movement to cope with a given threat. One concept might stress the mobility of forces which carry short range but highly destructive firepower with them. Another concept may stress the mobility of small lightly armed teams whose principal task would be to find targets while the application of firepower is obtained from extremely long range and highly accurate weapons. The mobility of the firepower in the second concept does not and need not match that of the lightly armed target seeking elements.

The alternative concepts are then subjected to a preferential analysis. The resulting Land Combat System Study in addition to containing the alternative concept and preferential analysis will delineate:

(1) operational capabilities objectives to guide laboratories, science and industry in research and exploratory development and to guide CDC in the development of doctrine.

(2) policies for the development of tactics, materiel, and organizations.

(3) priorities for development, experimentation, and analysis.

In summary, the Land Combat System Study provides unifying guidance by defining what is to be done for subsequent development of doctrine, materiel, and organization, and, as mentioned earlier, it is here in the concept phase that the greatest pay-off is realized. With the Land Combat System Study completed, CDC moves into the definition phase (See Figure 6).

The more specific definition of the Land Combat System is then initiated by first developing a study called the Combined Arms and Support (CAAS) study and then deriving 19 branch and functionally oriented studies called Derivative studies. The Combined Arms and Support study deals with division and higher levels of command and corresponding logistical echelons. The branch and functionally oriented studies or Basic Derivative studies deal with the brigade and lower levels of command. Examples of these branch and functional studies are Infantry, Armor, Supply and Maintenance.

A very close coordination of these efforts is required since the Combined Arms and Support (CAAS) study and basic background for the Derivative studies are developed concurrently. Further, as CDC works with the research and development agencies in AMC the materiel requirements for the Army of the future are better defined and must be reflected in both the Combined Arms and Support study and the Derivative studies (See Figure 6).

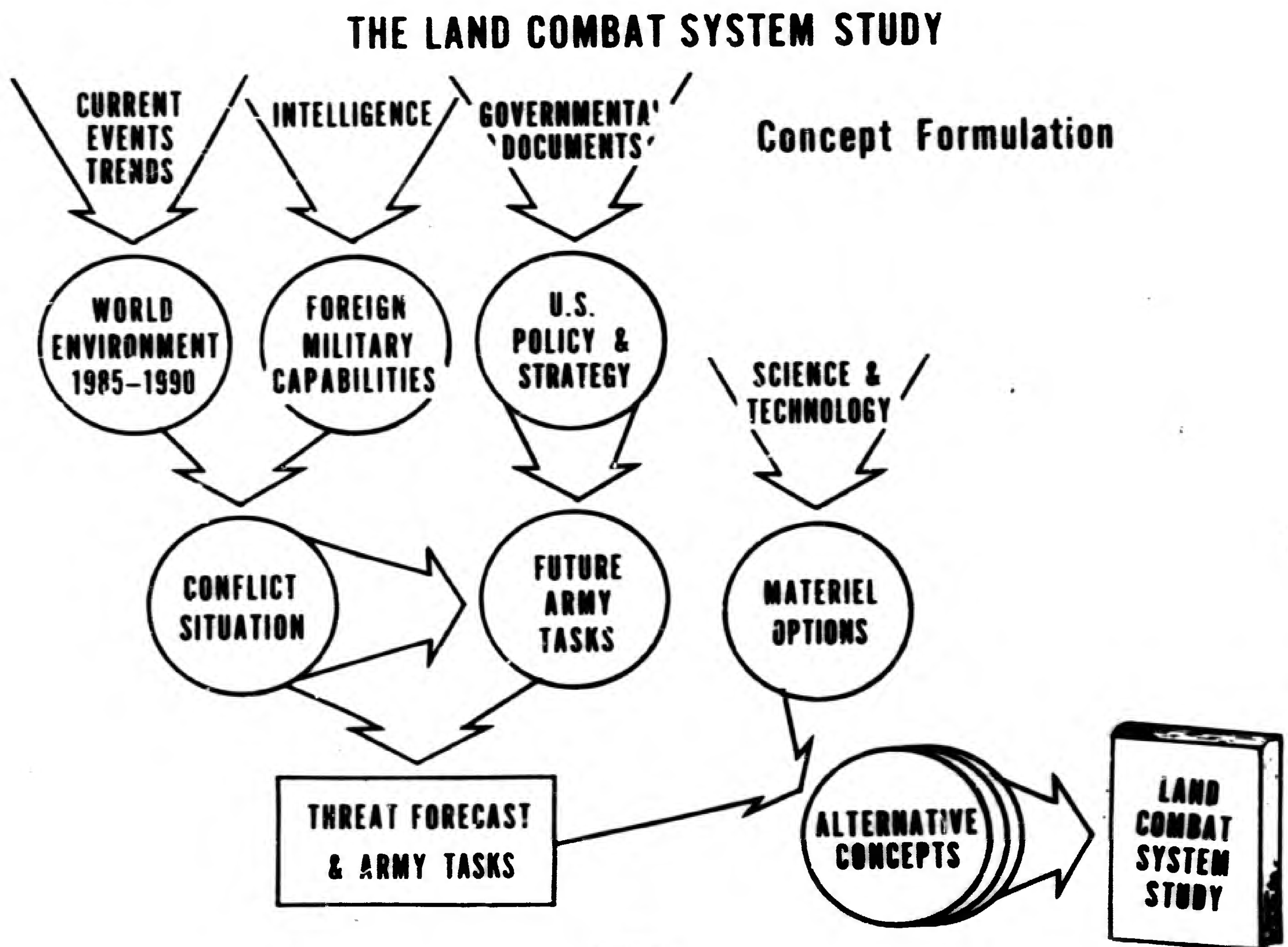
THE LAND COMBAT SYSTEM STUDY
Concept Formulation
CURRENT EVENTS TRENDS
INTELLIGENCE
GOVERNMENTAL DOCUMENTS
WORLD ENVIRONMENT 1985–1990
FOREIGN MILITARY CAPABILITIES
U.S. POLICY & STRATEGY
SCIENCE & TECHNOLOGY
CONFLICT SITUATION
FUTURE ARMY TASKS
MATERIEL OPTIONS
THREAT FORECAST & ARMY TASKS
ALTERNATIVE CONCEPTS
LAND COMBAT SYSTEM STUDY

FIGURE 6

Prior to the completion of the CAAS study work commences on war gaming the tactical and organizational concepts for evaluation purposes. Upon completion of the Derivative studies, they, together with the CAAS study, will be subjected to systems analysis to discover possible trade-offs, gaps and inconsistencies. At this point CDC completes the CAAS study to include any revisions which may be indicated as a result of the systems analysis. The materiel development process throughout this time would have provided inputs to and received inputs from the areas of tactics and organization. Sufficient time would have passed to bring these actions out of the realm of the long range time frame. The next step for CDC in the development and production phase would be to monitor the development of materiel by AMC and to participate in its testing to insure that the materiel meets the requirements of the Army-in-the-field. Final materiel development testing will provide CDC with the information needed to complete the Basic Derivative studies and to prepare the field manuals and tables of organization and equipment for use by the Army-in-the-field.

During the final phase of the development process, CDC validates its previous work by troop tests or actual operations in the field. Based on information gathered in the field, CDC provides for the short range improvements by suitable modifications to the field manuals and tables of organization and equipment and AMC does likewise by product improvement to existing materiel.

By following this systematic design of a total Land Combat System CDC intends to create a flexible, multi-capable Army--able to react in all known environments and capable of accomplishing any foreseeable task. More pointedly, CDC intends to propose a concept that will not handcuff an Army to a particular environment, task, or tactical situation, but instead will permit an Army to meet and defeat any threat which might be posed.

PROBABILITIES OF MINE FIELDS AND COST-EFFECTIVENESS OF BARRIER SYSTEMS*

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Office of the Deputy Chief of Staff for Military Operations
Washington, D. C. 20310

ABSTRACT

The first part of this paper reviews the straight-forward probabilities of pressure-actuated and tripwire mines, and combinations thereof. Necessary assumptions and real-life conditions are described and treated. The number of men who would actuate all the mines in different density mine fields is determined. The assumptions of "pure" randomness is denied and a recommended deliberate geometric pattern making use of knowledge of average stride length is suggested. A modified or "binary" Poisson function is derived and compared with the straight-forward probability function. The second part of this paper then considers the ultimate or gross effect of any barrier system. The distance of penetration denied an enemy and the time delay to engage in decisive combat, obtainable at a cost, are expressed in a cost-effectiveness measure.

*The analysis is strictly the author's and no reflection or implication of US Army or Department of Defense practice or doctrine is intended or implied.

INTRODUCTION

There exists practically no open literature on the mine field emplacement problem, what a mine field accomplishes, and the cost-effectiveness of a mine field or other types of barrier systems. Mines and related devices (demolition and non-explosive) are essentially deterrents or barriers to enemy forward movement. Mines are generally considered to be randomly disbursed, and they may be in a scattering by air drop. More usually, the intent is to make the mine distribution or emplacement appear to be random to the enemy, but for greater effectiveness the mines are deliberately separated from each other in an overall random-type field pattern of rows and clusters. Thus, undesirable or excessive clustering due to random processes alone are avoided. Deliberate separation of mines also avoids sympathetic detonation. Field tactics require identification and knowledge of the location of mines and mined areas for possible removal by friendly troops at a later date -- but self-sterilization built into mines can modify this requirement.

Security prevents revelation of field effects, sensitivity, ease of detection or removal, or special doctrine. But the emplacement of mines and methods of evaluation of effectiveness can be challenging to the ingenuity of the operations researchers using the common knowledge of probability theory and cost-effectiveness discipline or modeling. It is hoped that this paper contributed toward stimulation of innovation of analytic techniques and improvement of operations.

I. MINE FIELD PROBABILITY ANALYSIS

The probability of initial intercept, P_{ii}, of a single insurgent by a land mine field appears to be a straight-forward coverage or "search theory" problem.[1/] The usual solutions will be presented below, but the necessary assumptions will be identified and the expected variance from the real world performance will be described. A geometric analysis of a deliberate, regularly spaced mine field indicates that far fewer mines are needed for a given probability or that actual probabilities of initial intercept are greater than those prescribed by the current theoretical, random probability formulas.

Two types of antipersonnel mines are considered: a pressure-actuated, point-initiated mine and a pull-actuated, tripwire-initiated mine. The point-initiated mine, a small mine with a 2-inch diameter pressure plate, will be emphasized. The small point mine can be easily emplaced and effectively camouflaged against detection, whereas the wire of the tripwire mine must be above-ground and might be observed or felt in time to avoid activation even by an unsuspecting insurgent who moves and observes very carefully.

An important assumption is made that the insurgent, although always suspecting the presence of observers or observation devices and booby traps or mines, does not know with certainty the actual location of the

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1/ Antipersonnel mines, only, are discussed. Antitank or other mines are not included.

mine field. Generally, the presence of fences or posted signs and markers tells him of the possible existence of a danger area, but actual bounds of the mine field are not known to him. Further, suspecting an actual bound of a mine field area, he will be or should be in real doubt whether that mine field is a phony or dummy mine field or contains live mines by themselves or in combination with dummy mines. The strategy of live and dummy mine emplacement must be such that a condition of uncertainty exists for the insurgent. He will only be certain when a mine is set off, but P_{ii} will be valid up to this point in time of mine initiation.

The probability P_1 of initiating or locating a single mine by a single step is simply the ratio of effective bootprint area, A_v (Figure 1) to the total area A_m (Figure 2).

$$P_1 = \frac{A_v}{A_m} \tag{1}$$

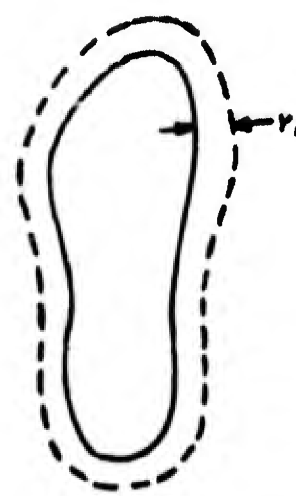
For L/L_s steps, this becomes: $$P_1 = \frac{L}{L_s} \cdot \frac{A_v}{A_m} \tag{2}$$

and the probability of not locating one mine, or conversely of a point source locating an effective footprint area (which includes the diameter of a mine), is:

$$P_0 = 1 - \frac{L \cdot A_v}{L_s \cdot A_m} \tag{3}$$

For n mines, equation (3) becomes:

$$P_0 = \left(1 - \frac{L \cdot A_v}{L_s \cdot A_m}\right)^n \tag{4}$$



Effective Bootprint Area, A_v

Figure 1

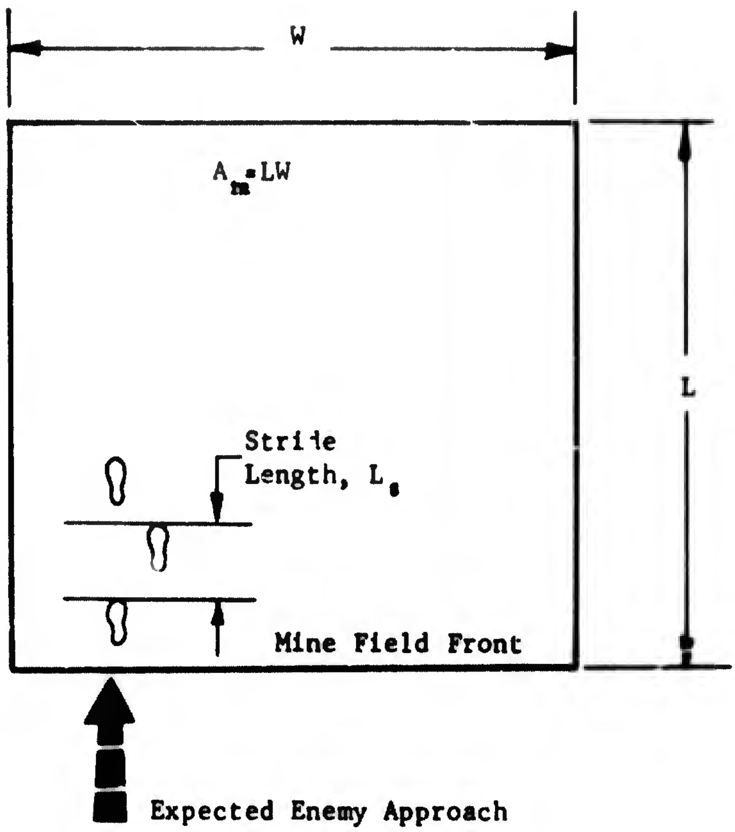

W
A_m=LW
L
Stride
Length, L_s
Mine Field Front
Expected Enemy Approach

Figure 2

and the probability of initial intercept, P_{ii}, becomes:

$$P_{ii} = 1 - \left(1 - \frac{L \cdot A_v}{L_s \cdot A_m}\right)^n \qquad (5)$$

Reliability, R, of less than one reduces the number of effective boot-print areas, and the P_{ii} becomes:

$$P_{ii} = 1 - \left(1 - \frac{R \cdot L \cdot A_v}{L_s \cdot A_m}\right)^n \qquad (6)$$

Information is available about the average length of stride, L_s, of an insurgent, but L may vary greatly from situation to situation. Since $LW = A_m$, this can be introduced in equation (6) to eliminate L as follows:

$$P_{ii} = 1 - \left(1 - \frac{R \cdot A_v}{L_s \cdot W}\right)^n \qquad (7)$$

Finally, W can be taken for convenience as one (1) meter in length, designated as a linear meter of trace, and n therefore is transformed to the number per meter of trace with the designation of rho sub one (ρ_1):

$$P_{ii} = 1 - \left(1 - \frac{R \cdot A_v}{L_s}\right)^{\rho_1} \qquad (8)$$

For small values of A_v/L_s and large values of ρ_1, a good approximation is the exponential form:

$$P_{ii} = 1 - e^{-\frac{R \cdot A_v}{L_s} \cdot \rho_1} \qquad (9)$$

Using the following values:

$R = 0.90$

$A_v = 0.0396$ sq. meter (including a 2-inch mine diameter)

$L_s = 0.70$ meter

the equations (8) and (9) can be rewritten as:

$$P_{ii} = 1 - (1 - .0510)^{\rho_1} \qquad (10)$$

and

$$P_{ii} = 1 - e^{-.0510\rho_1} \qquad (11)$$

Plots of P_{ii} for different values of ρ_1 for equations (10) and (11) are presented in Figure 3. The closeness of these two curves is apparent.

The analysis for a tripwire mine is somewhat similar. The diameter of the mine or the area of the footprint, however, are inconsequential. The important parameters are the width of the field, d_m, in which the mine is centered (since two tripwires are used in two opposite directions), and the walking stride of a man, W_m:

$$P_1 = \frac{d_m + W_m}{W} \qquad (12)$$

$$P_0 = \frac{d_m + W_m}{W} \qquad (13)$$

$$P_{ii} = 1 - \left(1 - \frac{d_m + W_m}{W}\right)^n \qquad (14)$$

$$P_{ii} = 1 - \left[1 - \frac{R(d_m + W_m)}{1}\right]^{\rho_2} \qquad (15)$$

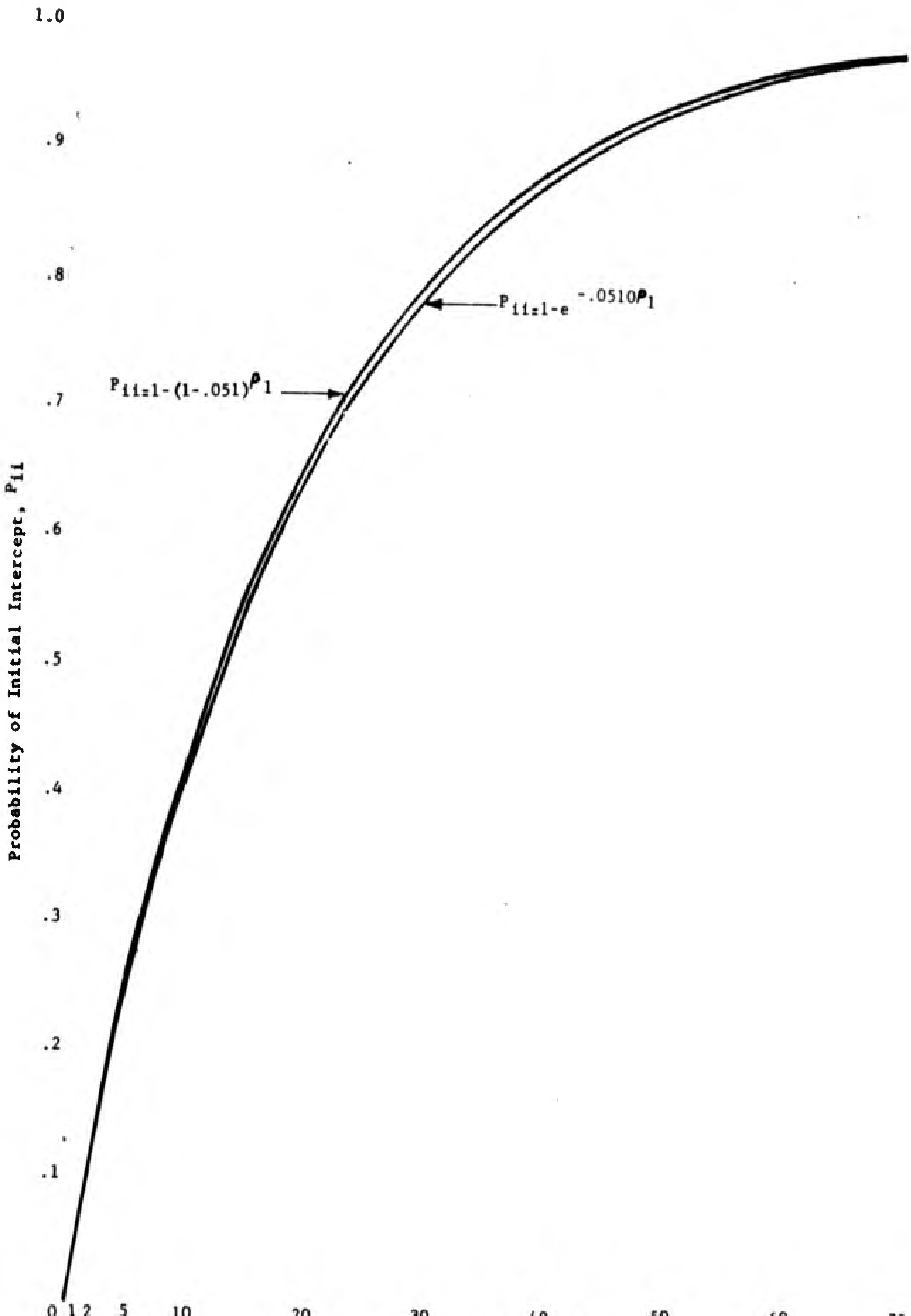
and

$$P_{ii} = 1 - e^{-R(d_m + W_m)\rho_2} \qquad (16)$$

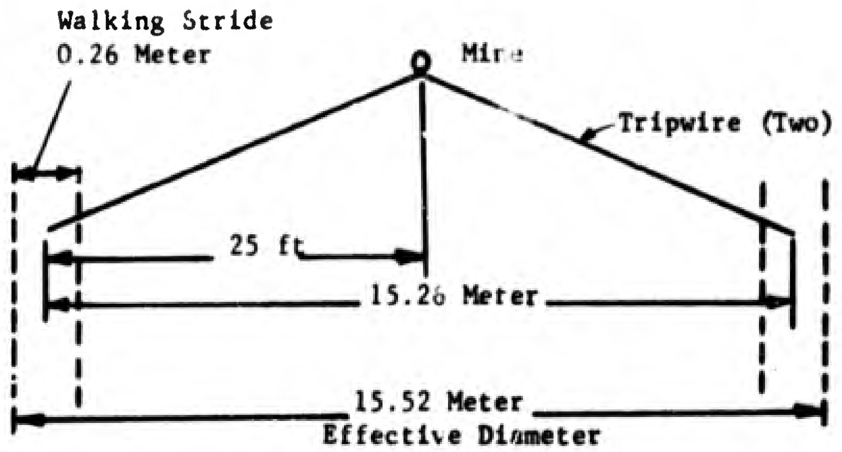
The applicable data assigned are (Figure 4):

d_m = 15.26 meters (for two wires)

W_m = 0.26 meter



ρ_1=No. of mines per meter of trace Figure 3



Walking Stride
0.26 Meter
Mine
Tripwire (Two)
25 ft
15.26 Meter
15.52 Meter
Effective Diameter

Figure 4

$R = 0.90$

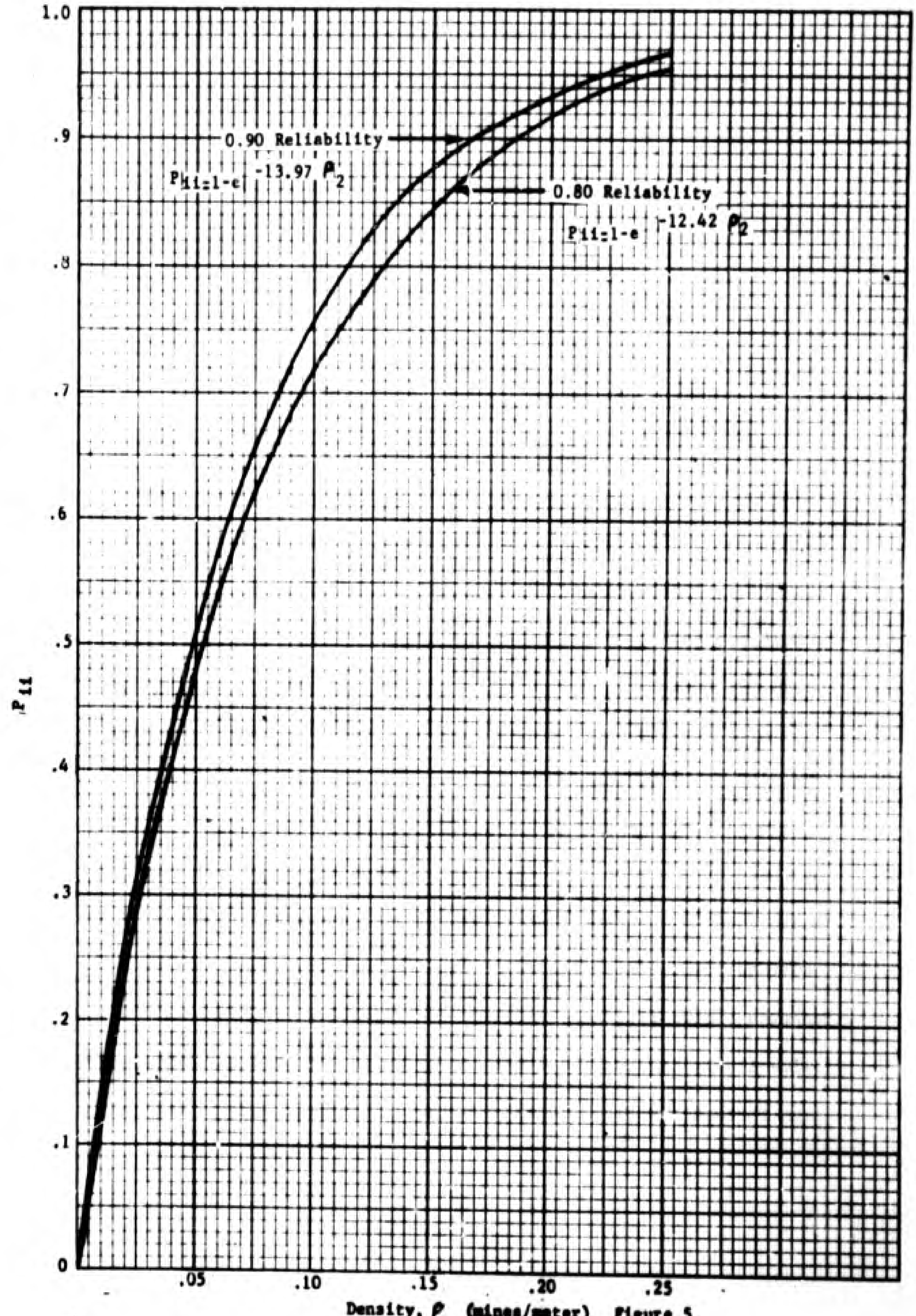
which yields for equation (16):

$$P_{ii} = 1 - e^{-13.97\rho_2} \qquad (17)$$

The corresponding curve for Equation 17 and for one using a mine reliability 0.80 are given in Figure 5.

It will be noted that the tripwire mine, as specified above, has a very much higher P_{ii} than the pressure-actuated mines. For a density, ρ_2, of 0.10, which for example would be obtained by planting one tripwire mine per ten meters of trace, a P_{ii} of 0.75 is obtained. It might appear that the small pressure-actuated mines could be dispensed with since 26 or 27 of these mines per <u>one</u> meter of trace would be needed for the same 0.75 probability of initial intercept. The problem, however, is that a wary or experienced insurgent, even though unsuspecting of the actual presence of a minefield, should be able to detect visually or tactually an above-ground wire. The marking, cutting, overstepping, or removal of a tripwire would not prove difficult. On the other hand, a buried nonmetallic pressure-actuated mine can only be avoided by inch-by-inch ground probing, denying or excluding the use of heavy equipment such as rollers or driving forward groups of animals.

It would appear that the joint use of both types of mines is necessary. This can be done analytically assuming an unsuspecting and unwary insurgent for both types of mines. It is obvious that both types are in the same set, that is, their probabilities are not mutually



Density, ρ_2 (mines/meter) Figure 5 exclusive. Either a pressure-actuated mine or a tripwire mine, but not both, is actuated. Mathematically, the union of the two probabilities is wanted, but not the intersection, thus:

$$P_{ii}(A + B) = P_{ii}(A) + P_{ii}(B) - P_{ii}(AB) \tag{18}$$

Substituting:

$$P_{ii}(A) = 1 - e^{-.051\rho_1} \quad \text{and} \quad P_{ii}(B) = 1 - e^{-13.97\rho_2},$$

we get:

$$P_{ii}(A + B) = 1 - \left(e^{-.051\rho_1}\right)\left(e^{-13.97\rho_2}\right) \tag{19}$$

By assigning values for ρ_1 and ρ_2, and obtaining a ratio of ρ_1/ρ_2, equation (19) can be used to plot the $P_{ii}(A + B)$ against ρ_1/ρ_2, as in Figure 6. The solid lines are the pressure-actuated mine densities and the broken lines are for the tripwire mine densities. As an example, for 10 pressure-actuated mines per meter of trace and 0.10 tripwire mines per meter of trace, a ratio of 100/1 exists and the P_{ii} is 0.85.

Artillery or small-arms firing coverage of a mine field area and the mine field effectiveness are mutually supporting. Without coverage of a mine field by possible artillery or small-arms fire or, at least, by observers, a mine field becomes a source of supply of mines and explosives to an enemy instead of being a deterrent or barrier. With coverage, timely application of fire against insurgents who have entered a mine field can increase the effectiveness, such as the P_{ii}, primarily by causing the diversion of an insurgent from a straight-line path through the field, with or without a first immediate motionless

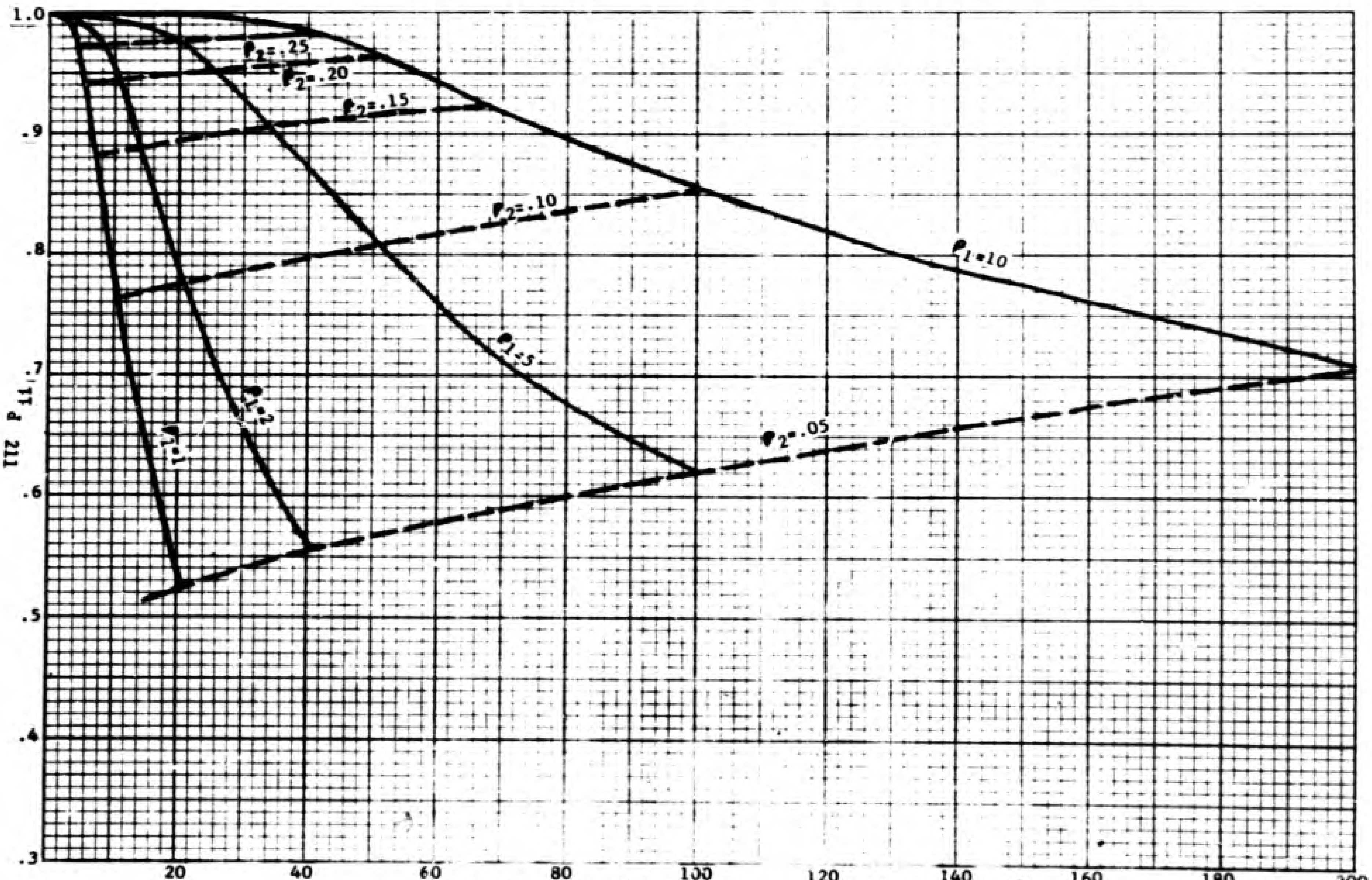


Figure 6 ρ_1/ρ_2 ρ_1 for pressure-actuated mine; ρ_2 for tripwire type response (e.g., lying prone or taking cover). The insurgent, having entered a mine field and suddenly fired upon by artillery or small arms, might retreat over his previous path, as in Path 1 of Figure 7. But this might not appear to him to be as safe as dashing forward or sideways toward a location of better cover or protection. On the average, one can consider that he takes a resultant 45° path, as Path 2 of Figure 7. The resulting P_{ii} is calculated as follows:

$$P_{ii} = P_A + P_B - P_{AB}$$

$$P_{ii} = 1 - \left(e^{-.051\rho_1/2}\right)\left(e^{-.051\sqrt{2}\,\rho_1/2}\right) \qquad (20)$$

For $\rho_1 = 46$ and a 0.90 P_{ii} for an uninterrupted, straight path, Equation (20) yields a higher P_{ii} of 0.94.

Consider now the offensive breaching of a mine field by an enemy force. If the insurgents enter the field singly, that is, randomly, and at different points, the probabilities of initial intercept, P_{ii}, should apply for randomly distributed mines. Thus, if the mine field has a density of 20 pressure-activated mines/linear meter, 0.65 of the insurgents should be casualties.

However, if the enemy elects to storm through but remain in file formation, the men in the forward positions are likely to become casualties and thereby reduce the number of mines likely to be encountered in their lane by their followers. After a sufficient number of casualties the result will be a lane free of mines. For different density mine fields, the question is asked as to how many insurgents on the average

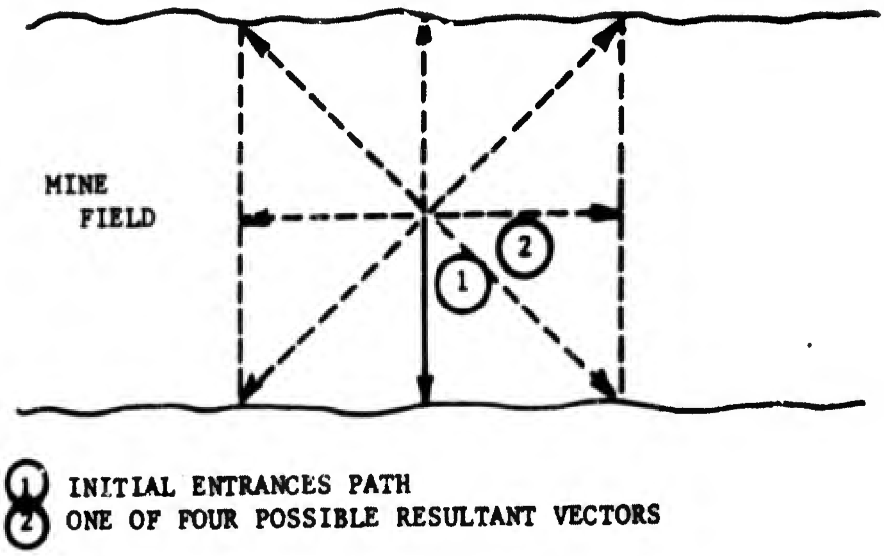

MINE
FIELD
1
2
1 INITIAL ENTRANCES PATH
2 ONE OF FOUR POSSIBLE RESULTANT VECTORS

Figure 7

must go through in order that a cleared lane will result? Up to this point, what percentage of casualties will there be for such an action?

The method of calculating the probabilities for file formations involves an iterative process where each casualty reduces the field by one mine for the remaining men. For example, for a density of 2 mines/meter ($n = 2$) and 2 men ($m = 2$), $P_{n/m}$ of exactly two men setting off two mines is $P_{2/2}$ or: $P_2 \cdot P_1$ or $\prod^{2} P_i$. This is equal to (0.098)(0.051) or 0.050. For three men, there are three possible combinations for setting off two mines: $P_2 \cdot P_1 \cdot q_0 + P_2 \cdot q_1 \cdot P_1 + q_2 \cdot P_2 \cdot P_1$, where q_i (probability of not hitting a mine) $= 1 - P_i$. Since $q_0 = 1$, $q_1 = q$, and $q_2 = q^2$,

$$P_{2/3} = P_2 P_1 (1 + q + q^2) \tag{21}$$

$$P_{2/3} = .050 (1 + .949 + .901) = .143$$

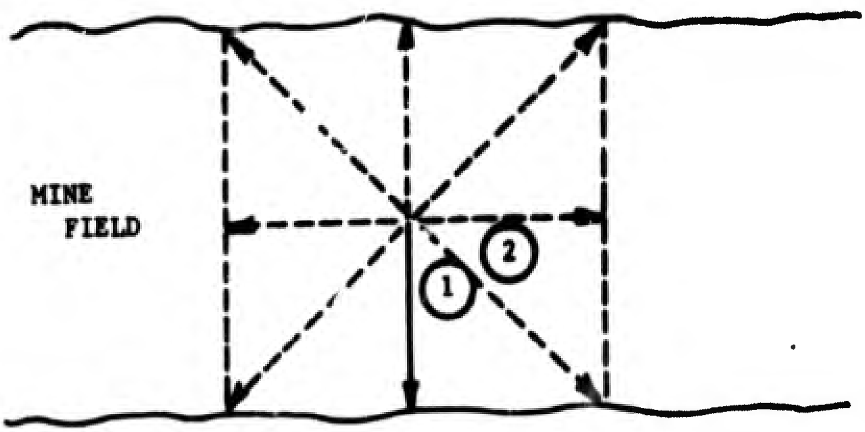
For a mine field with a density of 5 mines/meter:

$$P_{5/5} = \prod_{1}^{5} P_i$$

$$P_{5/6} = \prod_{1}^{5} P_i + \prod_{1}^{5} P_i \left(\sum_{a=1}^{5} q^a\right)$$

$$= P_{5/5} + \prod_{1}^{5} P_i \left(\sum_{a=1}^{5} q^a\right)$$

$$P_{5/7} = P_{5/6} + \prod_{1}^{5} P_i \left(\sum_{b=1}^{5} q^b \sum_{a=1}^{b} q^a\right)$$



(1) INITIAL ENTRANCES PATH
(2) ONE OF FOUR POSSIBLE RESULTANT VECTORS

Figure 7

must go through in order that a cleared lane will result? Up to this point, what percentage of casualties will there be for such an action?

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$$P_{2/3} = P_2 \, P_1 \, (1 + q + q^2) \qquad (21)$$

$$P_{2/3} = .050 \, (1 + .949 + .901) = .143$$

For a mine field with a density of 5 mines/meter:

$$P_{5/5} = \prod_{1}^{5} P_i$$

$$P_{5/6} = \prod_{1}^{5} P_i + \prod_{1}^{5} P_i \left(\sum_{a=1}^{5} q^a\right)$$

$$= P_{5/5} + \prod_{1}^{5} P_i \left(\sum_{a=1}^{5} q^a\right)$$

$$P_{5/7} = P_{5/6} + \prod_{1}^{5} P_i \left(\sum_{b=1}^{5} q^b \sum_{a=1}^{b} q^a\right)$$

$$P_{5/8} = P_{5/7} + \prod_{1}^{5} P_i \left(\sum_{c=1}^{5} q^c \sum_{b=1}^{c} q^b \sum_{a=1}^{b} q^a \right)$$

or, generally:

$$P_{n/m} = P_{n/m-1} + \prod_{1}^{n} P_i \left(\sum_{m=1}^{n} q^m \sum_{l=1}^{m} q^l \cdots \sum_{a=1}^{b} q^a \right) \qquad (22)$$

where the number of summation "terms" in parenthesis is equal to (m-n). Results of the calculations are given in Figure 8. It will be noted that for a .90 probability of setting off all the mines in fields of densities 5, 10 and 15 mines, that 84, 93, and 103 men, respectively, are needed.

At the .90 probability level, for the mine field densities of 5, 10, and 15, the percent of casualties for the number of men required to set off all the mines are 6 percent, 11 percent, and 15 percent, respectively.

The application of probabilities in the preceding paragraphs assumed a random distribution of mines. Test of the probabilities of P_{ii} was attempted using random number generation (Monte Carlo trials) of the mine locations. A regular stride of 0.7 meter was used to create a path through the mine fields. The results indicate that the probability calculations and the Monte Carlo trials are in approximate agreement. However, it is evident that the actual practice of laying mine fields is not by a random distribution or scattering. Deliberate spacing or separating of mines is practiced. Truly random location of mines, to correspond with the use of the probability formulas, will result in clustering and relatively large spacings at random between clusters.

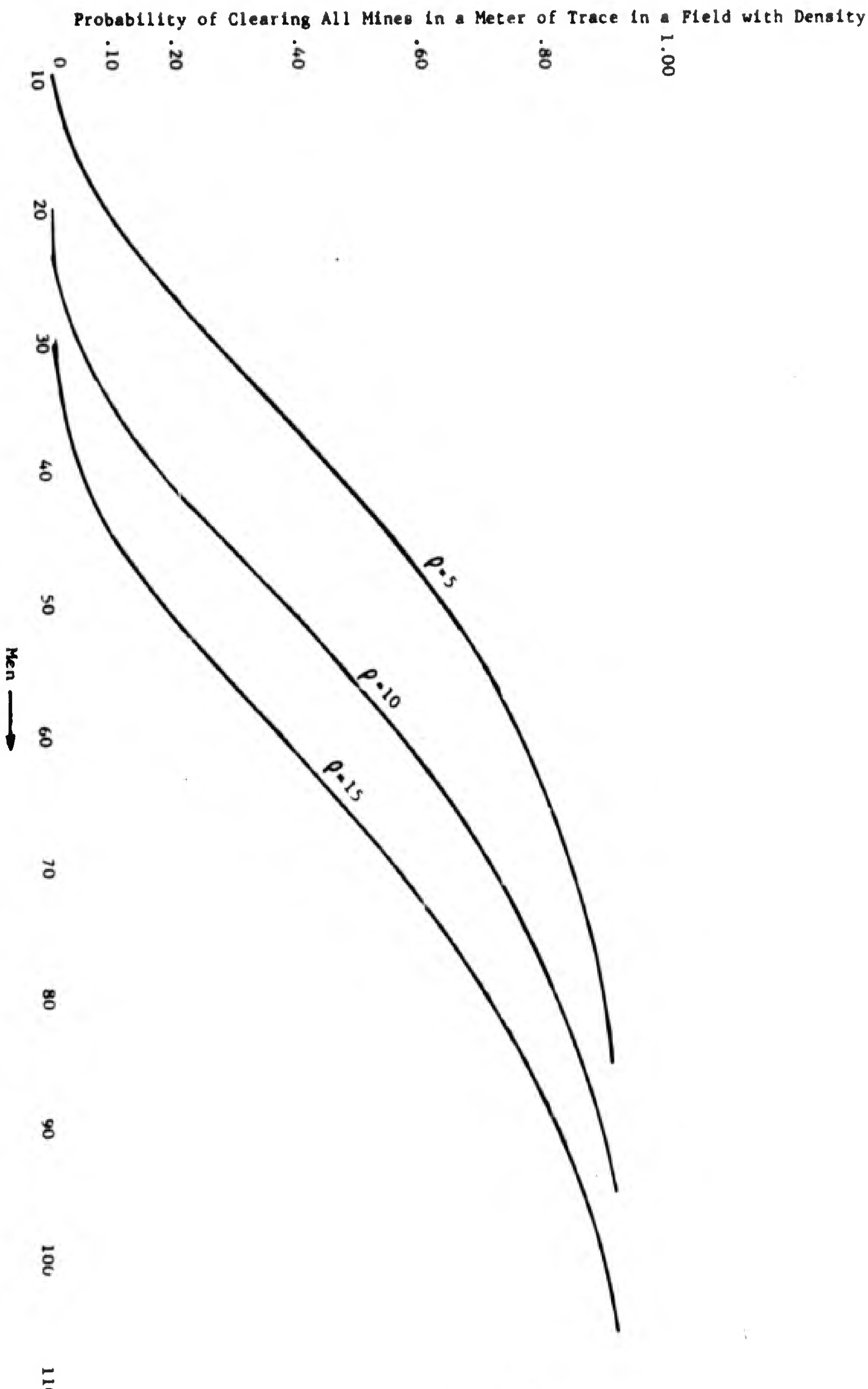

Probability of Clearing All Mines in a Meter of Trace in a Field with Density
0
.10
.20
.40
.60
.80
1.00
ρ=5
ρ=10
ρ=15
10
20
30
40
50
60
70
80
90
100
110
Men

Figure 8

Regular spacing or separation of mines avoids the formation of tight clustering and open spaces between them.

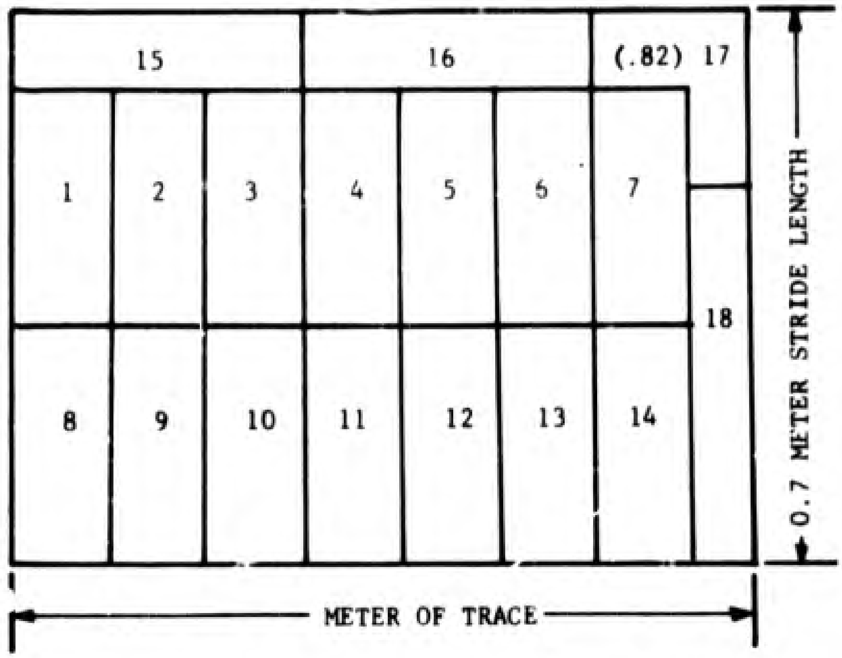
In a graphical lay-out exercise, when mines were relatively evenly spaced in a field, improvement in the number of hits resulted. Care was taken not to use even multiples of the stride length of 0.7 meter. For example, spacing between mines was attempted using 0.5 meter between mines. It would appear that for improving performance since information exists about an average stride length that such information should be used in mine emplacement.

There is more than one reason for separating mines as distinct from having them in a perfectly random pattern, which would contain uneven between-mine spacings and clusters. For example, one other reason is the avoidance of sympathetic detonations. However, a perfectly geometric pattern such as a checkerboard arrangement is also to be avoided since an enemy may recognize the pattern for use in their rapid removal or location of mines. Keeping this in mind, an attempt therefore was made to design a deliberate, well-spaced pattern containing the minimum number of mines for the interdiction of a man striding through a field with a known average-stride length. The problem of ease of placing the mines, which is the problem of the direct labor cost (and minimum time), must also be considered. Even though the mine field may be deliberate and well-spaced to the mine planter, this same mine field should appear to be random to the enemy, that is, the enemy cannot recognize the pattern from his random approach.

A candidate for this optimal deliberate pattern was arrived at by examining the basic, most compact coverage in a single stride-length area. The basic unit area into which at least one boot area must fall, unless the average stride of 0.70 meter is violated, is shown in Figure 9. If 18 mines, each located at the midpoint of an area, are packed solid in this area, then there is a 1.00 probability of a casualty, or .90 probability if the mine reliability figure is 0.90.

Consider now that the relative positions of mines, as established by the Figure 9 geometry, is held but that the 18 mines are distributed _in depth in the same meter of trace_. The same initial intercept probability, as for the solid mine embedded area (Figure 9) should hold. Thus, 18 mines for the deliberately designed case of Figure 9 should have the same effectiveness as 44 mines for the randomly dispersed mines (see 0.90 figure on Figure 3).

A simple means for planting 17+ mines/linear meter of trace for a 10-meter deep mine field is to use a 10.2- meter length of tape, marked off every 0.612 meter along its length. By using two marking stakes as shown in Figure 10, mines can be placed in the desired locations. Considering the random, relatively perpendicular approach of an insurgent to the mine front, the mines should appear to be as random as the currently prescribed clustered planting of mines. Variations of the direction of the angle can also be resorted to, forming a "herringbone" pattern for a large mine field, also shown in Figure 10. Traversing the field _exactly between_ two rows is the only possibility of missing



A. STRIDES 1 TO 14 : AVERAGE EFFECTIVE BOOT AREAS, $0.0396M^2$

B. AREAS 15, 16, 18 : EQUIVALENT BOOT AREAS

C. AREA 17 = .82 OF AN EQUIVALENT BOOT AREA

Figure 9

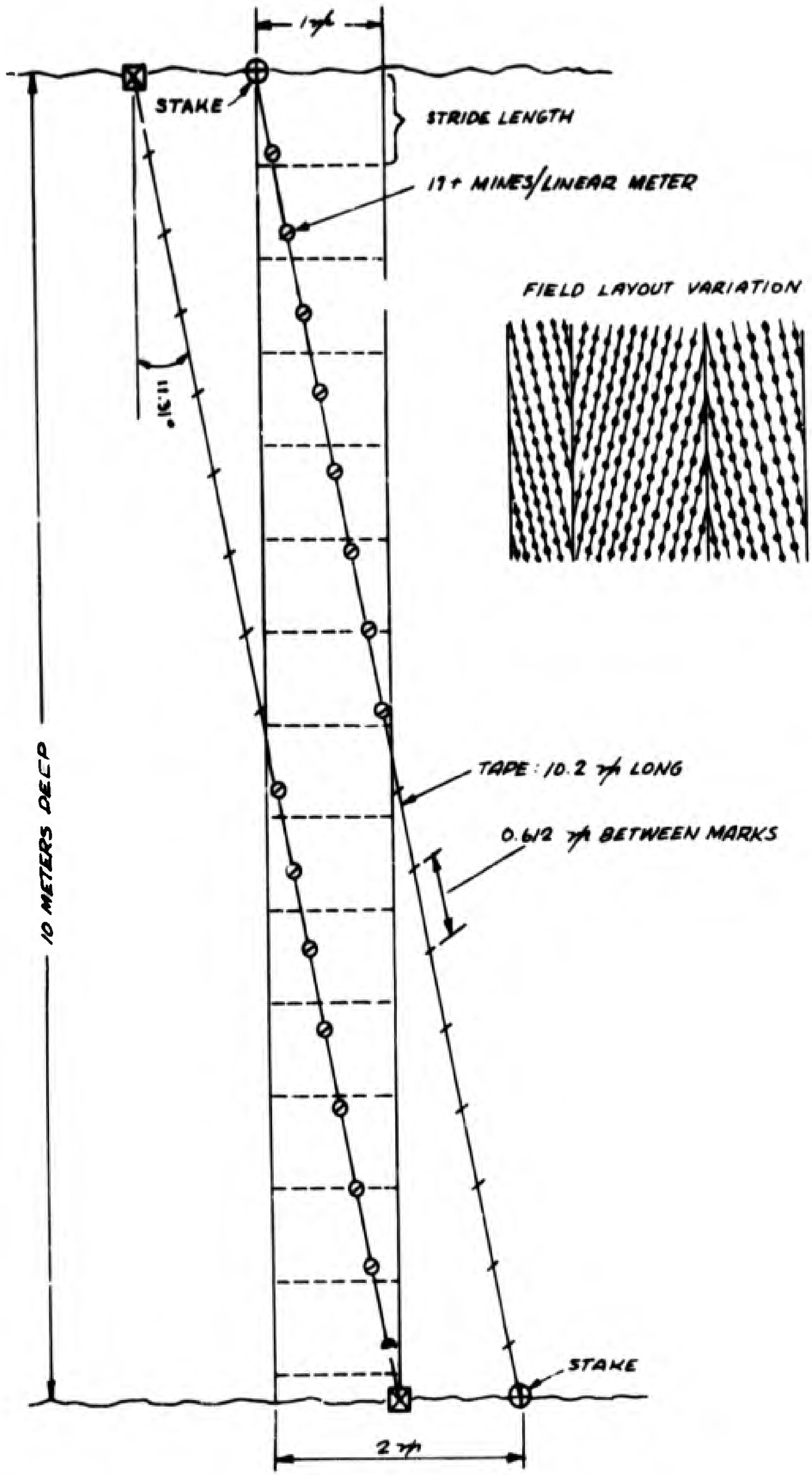

1 m
STAKE
STRIDE LENGTH
17+ MINES/LINEAR METER
FIELD LAYOUT VARIATION
11.31°
10 METERS DEEP
TAPE: 10.2 m LONG
0.612 m BETWEEN MARKS
STAKE
2 m

Figure 10

the mines and this feat will be exceedingly rare in occurrence once the tapes and stake marks are removed.

It can be seen that the use of the probability formulas for randomly distributed items yield lower probabilities which are inconsistent with those for deliberate optimally emplaced mines. Thus, if complete coverages of a unit area (one stride length by one meter) is provided (or distribution of the same number of mines for complete coverage over any depth of field), the probability of no casualties, $P_0(1)$, should equal one. Also the probability of no casualties when there is absolutely no coverage, $P_0(0)$, should be equal to zero, as with current formulas. More seriously, the probability of initial intercept, P_{ii} or P_1 is taken as: $1-P_0$; that is, it is the probability of one or more hits in the form of $1-e^{-\phi\rho}$ where ϕ is the coverage factor and ρ = density or number per meter (if one meter of trace is used, $\rho = n$, the number of mines/linear meter). But, there can be only one hit or casualty per mine; one or more has no meaning in this sense.

Considering the two limits now imposed on P_0, that is,

$$P_0(0) = 0$$
$$P_0(1) = 1 \tag{23}$$

One can postulate that

$$P_0(0 \leq \phi\rho \leq 1) = (1-\phi\rho)e^{-\phi\rho} \tag{24}$$

This relation can be derived in the usual manner as for the Poisson function (Ref. 1) considering that the constant of integration for P_0 is not simply "1" when $P_0(0) = 0$, but that the constant is equal to

"(1-$\phi\rho$)" to satisfy both conditions of Equation (23). When $\phi\rho = 0$, the "constant" is then exactly "1", but when there is full coverage, i.e., $\phi\rho = 1$, the "constant" in the equation for probability of failure is "0".

Since there cannot be a multiplicity of successes or casualties for any one mine or one footprint area, there is only a P_1 and it is necessary that

$$P_0 + P_1 = 1 \tag{25}$$

or

$$\begin{aligned} P_1 &= 1-P_0 \\ &= 1-(1-\phi\rho)e^{-\phi\rho} \\ &= 1-e^{-\phi\rho} + \phi\rho \, . \, e^{-\phi\rho} \end{aligned} \tag{26}$$

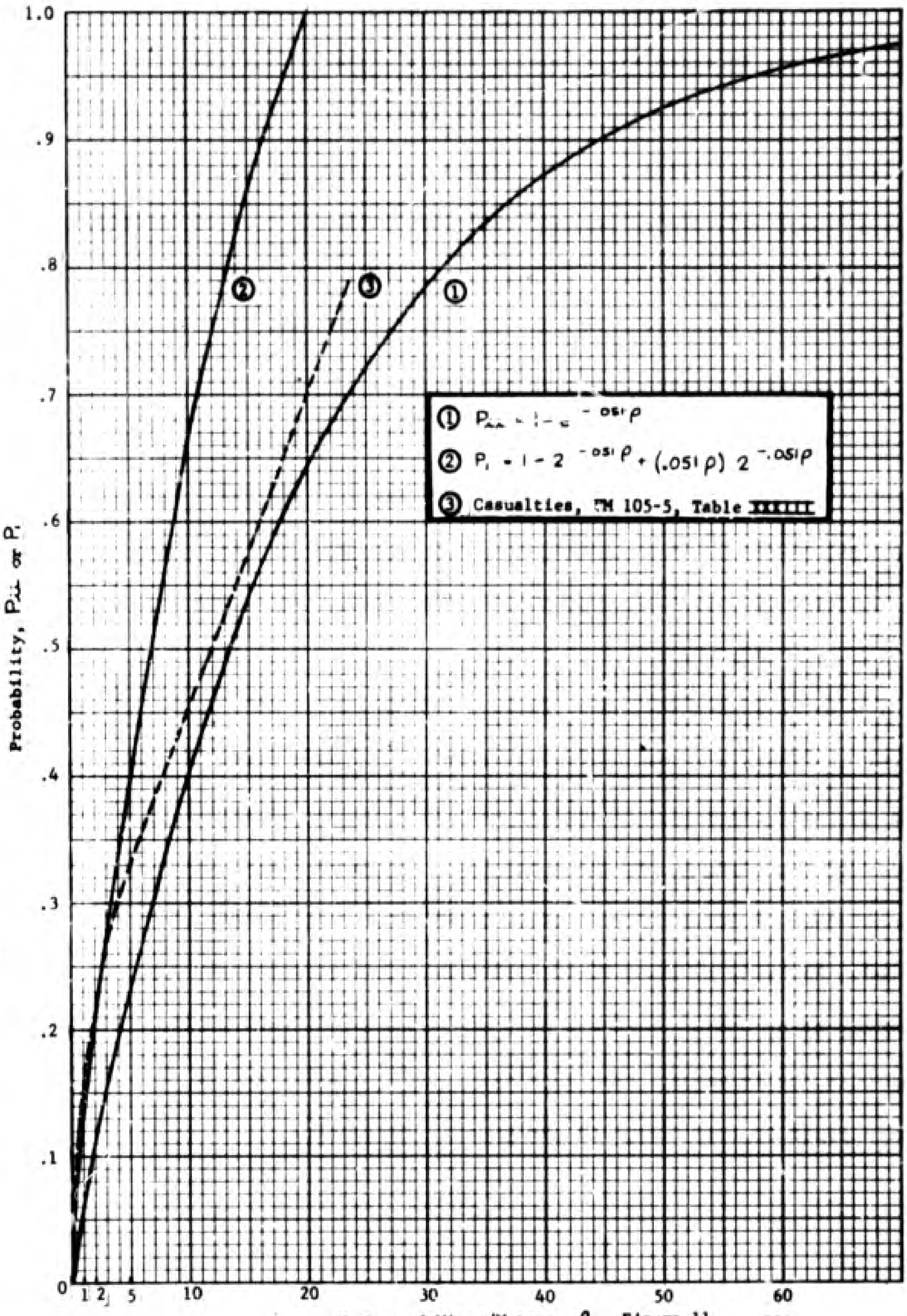
Lastly, since the number of successes of casualties does not extend from 0 to ∞ for one mine but is either 0 or 1, the use of the natural base "e" is not considered by the author as appropriate as the base "2" for this binary case. Thus, it is conjectured that

$$P_0 = (1-\phi\rho)2^{-\phi\rho}$$

$$P_1 = 1-2^{-\phi\rho} + \phi\rho \, . \, 2^{-\phi\rho} \tag{27}$$

For the cases considered in this study, plots for Equations (26) and (27) are relatively close.

A comparison is made of the use of Equation (27) with the original exponential form of Equation (11) in Figure 11. The Equation (27) is interpreted as representing the optimally-distributed mines making use of the knowledge of the effective footprint area, the average stride



Number of Mines/Meters, ρ   Figure 11

length, and a means for emplanting mines for full coverage. On the other hand, the Equation (11) "search theory" type of distribution represents the probabilities for a truly random distribution of mines. Since current mine-laying practice uses a "randomizing" technique <u>in an orderly and well-spaced manner</u>, real-life probabilities of casualties may be somewhere in-between. In Figure 11, there is a third plot of casualty figures taken from FM 105-5, Table XXXIII (Ref. 2). This third plot representing average field or experience data does indeed lie between the two functions described above. Very good agreement between the field expectations and our base 2 Equation (27) appears from 0 to 0.3 probability. Above 0.3 probability, a straight-line set of points seems to have been taken along a mid-course; intuitively, one may question seriously whether a straight line would ever be obtained.

The total system of a mine field consists of the mine field itself and the artillery and small-arms coverage of the same area. The mine field is ineffective and subject to easy destruction or breaching without weapons fire coverage. On the other hand, the mine field contributes to effectiveness of casualty production in an area where weapon fire is applied. Analysis of mine field emplacement has been covered in preceding paragraphs. Analysis of probability of hit and number of casualties due to weapon fire coverage is very similar and is included in this paper to contribute to the general rationale.

The major parameter is the coverage factor, $\emptyset$, which is expressed as:

$$\emptyset = N \cdot \frac{A_L}{A} \cdot M \cdot F \qquad (28)$$

Where N = Number of shots

A_L = The lethal area, e.g., the vulnerable and exposed profile of a man

A = Unit area in which fire is delivered

M = Number of men

F = An accuracy factor which varies with A_L/A, but which is usually of unit value

The probability of hitting M men, P(M), is also expressed as the fraction of casualties occurring due to the coverage provided, and is:

$$\begin{aligned} P(M) &= 1-P_0 \\ &= 1-e^{-\emptyset} \\ &= 1-e^{-N \cdot \frac{A_L}{A} \cdot M \cdot F} \end{aligned} \qquad (29)$$

The density, D_M, of men, which is M/A, can be substituted in the equation and for F=1, we get:

$$P(M) = 1-e^{-N \cdot D_M \cdot A_L} \qquad (30)$$

The expected number of casualties, E(M) is:

$$\begin{aligned} E(M) &= \sum_{m=1}^{M} m_i \cdot P(M) \\ &= M \cdot P(M) \\ &= M(1-e^{-N \cdot D_M \cdot A_L}) \end{aligned} \qquad (31)$$

And the percentage of casualties is:

$$\%(M) = \frac{N\,P(M)}{N} \times 100$$

$$= (1 - e^{-N \cdot D_M \cdot A_L}) \times 100 \qquad (32)$$

For the weapons fire coverage of a mine field, consideration must be given to the <u>unit area</u>, A, used directly in Equation (28) or in calculating the density, D_M, for use in Equations (30), (31), or (32). The usual use of an assigned area in which a squad, platoon, or company may be distributed is not applicable since there is a high probability that the insurgents will proceed more or less in a single file through a mine field, keeping an average interval between each man for safety.

An initial salvo of fire, because of the surprise element, may be expected to result in percent of casualties given by Equation (32). If the enemy elects to stay in file formation for forward or retreat movement, the preceding description of effect of mines applies. If the enemy deviates from the path, he runs the risk of meeting an increased number of mines by a factor of $\sqrt{2}/2$, as discussed in deriving Equation (20).

II. A BARRIER COST-EFFECTIVENESS MODEL

The previous section provided insight and understanding for the field engineering and design aspects of mine fields and other barrier types. It did not, however, provide true measures of effectiveness for comparison of alternatives. The following paragraphs examine the problem of cost-benefit or cost-effectiveness measures.

Reference (3) considered that tactical effectiveness of a barrier system is to be measured in terms of increased delay imposed upon an advancing enemy. statable in terms of days of delay. Also considered was the concept of a "multiplier effect" whereby any delay to an advancing enemy provides additional time for the defender to lay down additional barriers through which the attacker must move. Although not stated, one must clarify what is delayed. This can only mean, in an advancing attacker-defender relation, the delay in time for the advancer to engage the defender in decisive combat--small or large in scale. The defender wants to buy time before he is ready for an engagement with the attacker but, just as important, he wants to limit the forward ground advance or intrusion by the attacker. For example, the defender (by not spending time on barriers) can avoid an engagement and gain considerable time by retreating at least as fast, or almost as fast, as the attacker advances. But for the considerable time gained, considerable territory will also be lost to the attacker.

Before constructing the symbolic model for these qualitative statements, the appropriateness and practicality of a "barrier factor" must be examined. Reference (3) used the following equation from Reference (4) to calculate a rate of movement through a barrier zone (V_B) as follows:

$$V_B = \frac{S}{S + VT} V_0 \qquad (33)$$

where, S = Depth of the barrier system or defensive zone

V_0 = Rate of advance without barrier but with opposition

V = Rate of advance, without barrier and without opposition on open, flat terrain (cross-country rate).

T = Time required to breach an undefended barrier (i.e., without opposition)

The expression S/(S + VT) is the barrier factor used to modify V_0. The S and T terms are measurements or field determinations for the distance and time through the barrier system and the V term is presumably a free cross-country rate without barrier.

To see clearly how these are related in Equation 33, rearrange the terms as follows:

$$V_B = \frac{SV_0}{S + VT} = \frac{V_0}{\frac{S}{S} + \frac{VT}{S}} = \frac{V_0}{1 + \frac{V}{S/T}} = \frac{V_0}{1 + \frac{V}{V_B}} \qquad (34)$$

where V_B, determined from S and T, is the rate of advance with barrier, but with no opposition. The ratio V/V_B should be greater than unity being a ratio of rate of advance without barrier to the slower rate with barrier. Examples using certain data given in Reference (4) however make V/V_B come out as a fraction less than unity. Further, there is a special case where V_0 can be equal to V. When there is no opposition, using $V = V_0$ it can be shown by the formula that $V_B > V_0$ when V_B should be less than V_0. Lastly, using the Reference (5) table, the directly calculated barrier factors for any specific force ratio and differing degrees of opposition are not constant, hence Equation (33) cannot apply.

In a search for a rationale that might have led to Equation (33), the "multiplier effect" possibility was considered. If the left-hand side of the equation is recognized as an adjusted V_B, or V_B', then it is clearly different from and less than the V_B in the denominator of the right-hand side expression. Further, the cross-country rate V is in effect the same as the rate without barriers being present, that is, $V = V_0$, so that:

$$V_B' = \frac{V_0}{1 + \frac{V_0}{V_B}} = \frac{V_0 V_B}{V_B + V_0} = \frac{V_B}{\frac{V_B}{V_0} + 1} = \frac{V_B}{1 + \frac{V_B}{V_0}} \qquad (35)$$

Since there is no question now that V_B/V_0 is a fraction less than unity, the following expansion is valid:

$$V_B' = V_B \left[1 - \frac{V_B}{V_0} + \left(\frac{V_B}{V_0}\right)^2 - \left(\frac{V_B}{V_0}\right)^3 + - - - \pm \left(\frac{V_B}{V_0}\right)^n \right] \qquad (36)$$

It thus appears that a rate of advance through a barrier system, V_B, has been successively reduced by the multiplier effect to get an adjusted rate, V_B'. The Equation (35) can then be rearranged to the form of Equation (33) so that it could be applied against any V_0 rate under conditions of opposition but without barriers present. Since, however, the degree of opposition does effect the adjustment of the advance rate through a barrier, the use of the Equation (33) is not strictly applicable as an across-the-board adjustment. It is further recognized now that the "barrier factor" of Equation (33) is an adjustment to account for the "multiplier effect" but not necessarily an adequate measure of the effectiveness for comparing alternative barrier systems. This latter purpose will be pursued in the following discussion.

It would appear therefore that the direct effect of a barrier is simply, for V_B and a corresponding V_0 with or without opposition but determined from field or engineering measurements of S_B, T_0 and T_B for a particular tactical solution, force ratio, and terrain type:

$$V_B = \frac{S_B}{T_B} \quad \text{and} \quad V_0 = \frac{S_B}{T_0} \tag{37}$$

$$\text{Barrier Factor, } y = \frac{V_B}{V_0} \tag{38}$$

where subscript B indicates presence of a barrier and subscript 0, no barrier. S_B is the depth of the field or zone being considered and represents the distance separating the attacker and the defender. It is concluded that no formula can be used to determine a barrier factor, but the latter must be determined from field operation or engineered estimates.

The dynamics of the tactical situation must be considered. Previous discussion considered the attacker-defender interplay and the so-called "multiplier effect." The problem, restated, is to evaluate the worth or cost-effectiveness of alternative barrier systems, that is, systems where one side finds itself on the defensive and wishes a delay in time and/or to inhibit the physical advance of the attacker. Different degrees of opposition by artillery and troops over a specified terrain and with different force ratios should be specified and held "constant" in the evaluation of different barrier systems (or perhaps no barrier system would be desirable). Delay, again, means the slowing down of the attacker in reaching a decisive engagement with the defender.

Consider first that the defender does not elect to set up any barriers or obstacles, but retreats at some rate, V_D, which is some fraction x, $0 < x < 1$, of the rate of advance, V_0, of the attacker. If S_0 is the distance separating the attacker and defender, when the attacker moves a distance S_0, the defender moves a distance of $x\,S_0$ from S_0 to S_1. The attacker now moves up to S_1 and defender moves a distance $x(S_1 - S_0) = x(xS_0)$ or x^2S_0, up to S_2. Eventually, because of the ever decreasing separation distances, the attacker engages the defender at S_n. The total distance traversed by the attacker is:

$$S_{TA} = S_0 + (S_1 - S_0) + (S_2 - S_1) + (S_3 - S_2) \text{---------} (S_n - S_{n-1}) = S_n$$
$$= S_0 + xS_0 + x^2S_0 + x^3S_0 + \text{----------------------} + x^nS_0$$
$$= S_0 (1 + x + x^2 + x^3 + \text{------------------------} + x^n)$$
$$= \frac{S_0}{1-x}, \text{ where } x < 1.0 \qquad (39)$$

Similarly, the total distance traversed by the defender is from S_1 to S_n, or:

$$S_{TD} = \frac{xS_0}{1-x} \qquad (40)$$

For both Equations (39) and (40), $x = V_D/V_0$, where $V_D < V_0$. When the defender's rate of retreat equals the attacker's rate of advance, $x = 1$ and they never meet. When $x = 0.9$, the attacker catches up with the defender at $S_0/(1-0.9)$ or at a distance of 10 S_0. Similarly when $x = \frac{1}{2}$, the distance is $2S_0$ and when the defender holds his ground, that is, $x = 0$, they meet as expected at a distance of S_0. Substituting V_D/V_0 for x, Equation (39) becomes:

$$S_{TA} = S_n = \frac{S_0}{1 - \frac{V_D}{V_0}} = \left(\frac{V_0}{V_0 - V_D}\right) S_0 \qquad (41)$$

Consider now that the defender elects not to merely retreat but he engages in his two possible kinds of action:

1. The area with depth S_0 is mined, booby-trapped, fenced, blown up, or torn up, i.e., strewn with obstacles to create a barrier zone.

2. Within the time available, which is the sum of the original time the attacker takes to traverse the separating distance, S_0, and the <u>time gained</u> by slowing down the attacker's rate of advance as a result of adding the barrier zone, he continues to construct obstacles as he retreats.

The defender now retreats not at the rate of V_D but at a slower rate, V_C, which is equivalent to his barrier construction rate. At best, V_C might equal V_D but generally will be less because of the time and effort required to set up obstacles rather than go into a relatively free retreat or withdrawal.

The attacker moves through the barrier zone with a rate, V_B, which is equal to his original cross-country rate, V_0, reduced by the barrier factor, y. That is, $V_B = yV_0$ or $y = V_B/V_0$. As before, for V_0, the rate of advance V_B is determined by the attacker's mobility, his force ratio, the type of terrain, and the degree of opposition from artillery and other non-barrier deterrents.

The total distance the attacker moves through the barrier (B) zone until he can engage the defender is now:

$$S_{TA}(B) = S_n(B) = \frac{S_0}{1 - z} = \frac{S_0}{1 - \frac{V_C}{V_B}} = \left(\frac{V_B}{V_B - V_C}\right) S_0 \tag{42}$$

where z is the fraction of V_B that is the defender's rate, i.e., $z = V_C/V_B$; or if $V_C \geq V_D$, $z = V_D/V_B$, then:

$$S_{TA}(B) = \frac{S_0}{1 - \frac{V_D}{V_B}} = \left(\frac{V_B}{V_B - V_D}\right) S_0 \tag{43}$$

Since the distance traveled through the barrier zone by the attacker up to the point of engagement is known (Equation 42) and the distance he would have traveled if no barriers were constructed under a free withdrawal or retreat condition is also known (Equation 41), the reduced penetration by the attacker (or miles gained to the defender) due to the presence of the barrier system is the difference, thus:

$$\text{Miles of Reduced Penetration} = S_{TA} - S_{TA}(B)$$

$$= S_0\left(\frac{V_0}{V_0 - V_D}\right) - S_0\left(\frac{V_B}{V_B - V_C}\right)$$

$$= S_0\left[\frac{V_0}{V_0 - V_D} - \frac{V_B}{V_B - V_C}\right] \qquad (44)$$

This is <u>one</u> objective of constructing barriers and the greater the value of Equation (44), the more valuable will be an alternative barrier system.

Again, the total distance $S_{TA}(B)$ of Equation (42) is known and is easily used to find <u>the time</u> of travel through the whole barrier system up to point of engagement. Thus,

$$T_B = \frac{S_{TA}(B)}{V_B} \qquad (45)$$

If no barriers were present in the distance $S_{TA}(B)$, the attacker could advance at the faster, unburdened rate of V_0, or

$$T_0 = \frac{S_{TA}(B)}{V_0} \qquad (46)$$

It now becomes clear that the <u>time gained</u> by the defender due to the barrier alone is the difference of Equations (45) and (46) as follows:

$$\text{Time Gained} = T_B - T_0$$

$$= \frac{S_{TA}(B)}{V_B} - \frac{S_{TA}(B)}{V_0}$$

$$= S_{TA}(B)\left(\frac{1}{V_B} - \frac{1}{V_0}\right) \qquad (47)$$

This is the **second** objective of constructing barriers and the greater the value of Equation (47), the more valuable will be an alternative barrier system.

The two benefits, described above, can only be obtained at a cost of installing a barrier system. The appropriate cost here would be the **incremental** cost to the Army and this is essentially the cost of materials and items used in the barrier. That is, once used in the face of an advance by an attacker it is reasonable to assume that the materials are lost for future use and **must be replaced** in the Army inventory. Further, men and man-hours of effort are not appropriately incremental costs and are excluded. The recommended cost-effectiveness or cost-benefits model is the product of the two benefits and is therefore:

$$\text{Worth of barrier system, } W = \frac{S_0 \cdot S_{TA}(B) \cdot \left[\dfrac{V_0}{V_0 - V_D} - \dfrac{V_B}{V_B - V_C}\right]\left[\dfrac{1}{V_B} - \dfrac{1}{V_0}\right]}{D \text{ (Dollars} \times 10^6)}$$

$$= \frac{S_0^2}{D} \cdot \left[\frac{V_B}{V_B - V_C}\right]\left[\frac{V_0}{V_0 - V_D} - \frac{V_B}{V_B - V_C}\right]\left[\frac{1}{V_B} - \frac{1}{V_0}\right] \quad (48)$$

Expanding and rearranging terms,

$$W = \frac{S_0^2 \,(V_0 - V_B)\,(V_B V_D - V_0 V_C)}{D\, V_0\, (V_0 - V_D)\,(V_B - V_C)^2} \quad (49)$$

Equation (49) can be further simplified if use is made of the previously defined ratios, x, y, and z which are repeated as follows:

1. $x = V_D/V_0$ · Ratio of retreat rate to attacker's rate, without barriers.

2. $y = V_B/V_0$ · Barrier Factor, ratio of attacker's rate through barrier system to his rate without barriers.

3. $z = V_C/V_B$ · Ratio of barrier construction (or retreat) rate to attacker's rate through barrier system.

Using these ratios, the following is obtained:

$$W = \frac{S_0^2 \quad (1 - y)\ (x - z)}{DV_0\ y\ (1 - x)\ (1 - z)^2} \tag{50}$$

For any scenario, given the force ratios, type of terrain, and degree of opposition of the defender, the rates of V_D and V_0 and initial distance S_0 separating the forces can be estimated and these remain invariant in evaluating alternative barrier systems using Equation (50). Three parameters only need be estimated for a barrier system. First, the replacement costs D for all materials and items used. Second, the rate V_B to which the attacker has been reduced by the various obstacles in the barrier system. Third, the rate V_C at which the obstacles can be created or emplaced--which is assumed to determine the rate of withdrawal or retreat by the defender forces.

Equation (50) then is a cost-benefits or cost-effectiveness measure in units of reduced penetration distance—gained time per dollar invested. Alternative mine fields or barriers can be compared in terms of the very objectives postulated by both the user and the budgeteer.

REFERENCES

1. Feller, W., "An Introduction to Probability Theory and Its Applications", Volume 1, Chapter 17, 2nd Edition, John Wiley & Sons, 1957.

2. Department of the Army, FM 105-5, Field Manual, Maneuver Control, Washington, D.C.

3. Office, Chief of Engineers, ESSG, ADM Study (Classified Document), Part II, Page B-6, Washington, D.C., July 1965.

4. Army War College, 1959-1960 Analytic War Game Control Manual (U) (Classified Document), Course 3, Part I, Page ix-6, Carlisle Barracks, Pennsylvania.

5. ____________, Table XII-5.

COST-EFFECTIVENESS ANALYSIS OF THE TERRAIN-VEHICLE SYSTEM

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ABSTRACT

This report outlines the mathematical terrain-vehicle analysis currently being employed by the Economic Engineering Branch of the U. S. Army Tank-Automotive Command, Warren, Michigan, in its cost-performance studies. It includes a series of comments which describe the deficiencies of the model and make suggestions for improvements. It also describes the type and form of terrain data, presently unavailable, which is needed to make these studies more realistic. Three new measures of vehicle quality are introduced; these are measures of performance, utility, and cost-effectiveness.

Introduction

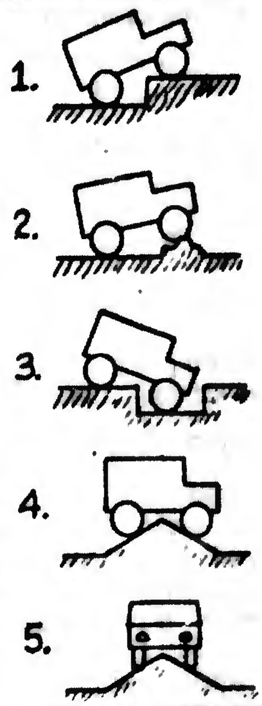
Vehicle effectiveness must be analysed in relation to the medium in which the vehicle operates. The design of aircraft requires knowledge of aerodynamics, and the design of water-craft requires knowledge of hydrodynamics. Similarly, the design and evaluation of ground vehicles requires knowledge of terramechanics. Terrain is a much more complex medium than the other two and has great variability, requiring vehicles designed for different types of terrain to be differently configured. It follows that in order to evaluate vehicles for specific off-road missions, one must have detailed terrain data available.

Terrain Model

The mathematical terrain model presently used by this office is described in Table 1. For each obstacle, its average extent is given (length only for linear obstacles; length and width for square obstacles), its density in the terrain in number of obstacles per square mile, and its maximum size or limiting value. This model includes only a sample of the obstacle types which would occur in a real terrain, and must be considered hypothetical. Items 1 through 5 are illustrated; the others are considered self-explanitory. In the following sections, the length and density are used to calculate the probability of encounter, and the maximum size or limiting value is used to calculate the probability of overcoming the obstacle.

Table 1 (Figure 1) - TERRAIN MODEL

LINEAR OBSTACLES	LENGTH (feet)	DENSITY (#/sq.mi.)	MAXIMUM SIZE
1. Step up or down	500	.12	30"
2. Bump	200	.04	22"
3. Ditch	500	.06	24"
4. Ridge-transverse	1000	.03	60°
5. Ridge-longitudinal	1000	.03	60°
6. Turning radius	1000	.02	23 ft.
SQUARE OBSTACLES	**EXTENT (miles)**	**DENSITY (#/sq.mi.)**	**LIMITING VALUE**
7. Soft soil	0.5	.033	K=2
8. Water crossing	0.1	.10	56" depth



Mathematical Analysis

1. The probability of overcoming an obstacle of type i, P_{oi}, is calculated differently for the different types of obstacles.

a. For obstacles of types 1, 2, 3, 4, 5, and 8, this value is:

$$P_{oi} = \frac{\text{vehicle performance}}{\text{maximum size of obstacle}}$$

b. For the turning radius, item 6, this value is:

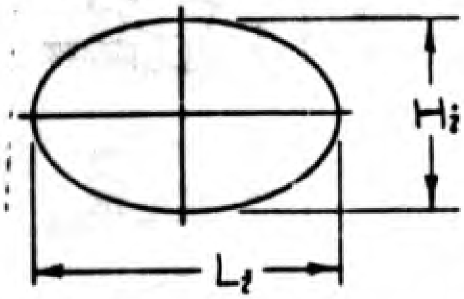
$$P_{o6} = \frac{\text{maximum radius desired}}{\text{vehicle performance}}$$

c. For the soft-soil obstacle, item 7, the limiting value of K=2 is given in Table 1. The opposite limit is taken to be a value of K=10, a reasonably hard soil that all vehicles can easily negotiate. For the other obstacles, the opposite limit was zero, and did not appear in the equations. For item 7 the equation is:

$$P_{o7} = \frac{10 - \text{vehicle performance}}{10 - 2}$$

In all cases, the value of "1" is assigned if the calculated value exceeds "1". As is evident from these equations, a uniform distribution of the obstacle size is assumed. To simplify the following analysis, the vehicle is constrained to a straight line path.

2. The probability of encountering an obstacle of type i, P_{Ei}, is dependant upon its contour. Assume that this contour can be approximated by an ellipse.



L_i = average maximum dimension.

H_i = average minimum dimension.

FIGURE 2a

Then, if the obstacle is approached at an angle Θ, it presents a dimension R_i perpendicular to the path of the vehicle, where:

$$R_i = \sqrt{H_i^2 \sin^2\Theta + L_i^2 \cos^2\Theta}$$

Assuming that the orientation of such obstacles is random, and thus that they might be approached from any aspect eith equal probability, we would like to know the average dimension of the obstacle across the path. This may be found by integrating the following expression:

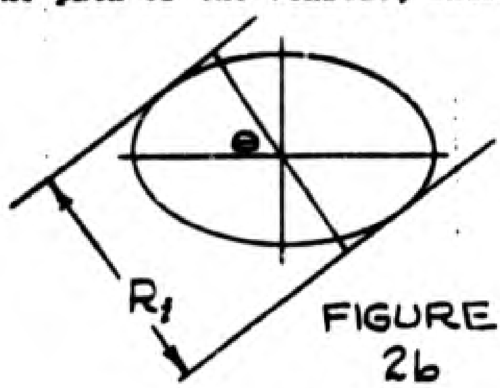


FIGURE 2b

$$\int_0^{\frac{\pi}{2}} R_i \, d\Theta = \int_0^{\frac{\pi}{2}} K_i \, d\Theta$$

where K_i is a constant and is equal to the diameter of an equivalent circle.

This integration produces:

$$K_i = L_i \frac{2}{\pi} \mathbf{E}\left(k_i, \frac{\pi}{2}\right) = L_i r_i \qquad (1)$$

where $k_i = \sqrt{1-\left(\frac{H_i}{L_i}\right)^2}$ is an "oblongness factor", and r_i may be called an "aspect ratio." $\mathbf{E}\left(k_i, \frac{\pi}{2}\right)$ is the complete elliptic integral of the second kind. A table of this function can be found in most mathematics handbooks. Note that if the obstacle is perfectly circular, $H_i = L_i$, k_i = zero, $\mathbf{E} = \pi/2$, and $r_i = 1$; if the obstacle is perfectly linear, H_i = zero, $k_i = 1$, $\mathbf{E} = 1$, and $r_i = 2/\pi$. The limits of r_i, therefore, are 1.0000 to 0.6366.

Finally, then:

$$P_{Ei} = \frac{L_i r_i}{\omega} \qquad (2)$$

where P_{Ei} is the probability that should one obstacle of type i lie in the terrain it will be encountered, and ω is an arbitrarily assumed width of terrain available for the mission.

3. Actually, there is not one obstacle of type i in the terrain, but N_i such obstacles, where:

$$N_i = M\omega D_i \tag{3}$$

M = mission mileage.

ω = width of mission area, as above.

D_i = density of obstacles of type i per square mile.

We are interested, then, in the probability of encountering j of the N_i obstacles, and this is:

$$P_{Eij} = \binom{N_i}{j} P_{Ei}^{\,j} (1-P_{Ei})^{N_i - j} \; ; \quad j = 0,1,2,\ldots,N_i \tag{4}$$

Since encountering zero to N_i obstacles exhausts all possibilities, it is necessary that the P_{Eij} add up to "1", and using the binomial distribution above, this is indeed the case.

We are also interested in determining the probability of successfully overcoming j obstacles, should j obstacles be encountered. Again, by a binomial analysis, this is:

$$P_{oij} = \binom{j}{j} P_{oi}^{\,j} (1-P_{oi})^{j-j} = P_{oi}^{\,j} \tag{5}$$

4. The next step is the evaluation of the probability of success of the mission, should only obstacles of type i be present. Call this P_{si}. This is equal to the probability of encountering no obstacles of type i, plus the sum of the probabilitires of encountering each number of obstacles up to N_i, times the probability of overcoming that number of obstacles:

$$\begin{aligned} P_{si} &= P_{Ei0} + P_{Ei1}P_{oi} + P_{Ei2}P_{oi}^2 + \cdots \\ &\qquad P_{Eij}P_{oi}^{\,j} + \cdots + P_{EiN_i}P_{oi}^{N_i} \\ &= \sum_{j=0}^{N_i} P_{Eij} P_{oi}^{\,j} \end{aligned} \tag{6}$$

Note that this expression is equal to:

$$= \sum_{j=0}^{N_i} \binom{N_i}{j} P_{Ei}^{\,j} (1-P_{Ei})^{N_i - j} P_{oi}^{\,j}$$

$$= \sum_{j=0}^{N_i} \binom{N_i}{j} (P_{Ei}P_{oi})^{j} (1-P_{Ei})^{N_i - j}$$

which, by the binomial theorem, is exactly equal to:

$$= \left[P_{Ei}P_{oi} + (1-P_{Ei})\right]^{N_i}$$

$$= \left[1 - P_{Ei}(1-P_{oi})\right]^{N_i}$$

$$P_{si} = \left[1 - P_{Ei}(1-P_{oi})\right]^{M\omega D_i} \tag{7}$$

Now, it is in our interest not to have to assign an arbitrary width of path, ω, and this can be done by making ω arbitrarily large. In order to do this, we must restate expression (4):

$$P_{Eij} = \binom{N_i}{j} P_{Ei}^{\,j} (1-P_{Ei})^{N_i - j}$$

As ω becomes very large, these binomial terms may be approximated by Poisson terms:

$$P_{Eij} \cong \lim_{n\to\infty} \binom{n}{j}\left(\frac{\lambda}{n}\right)^j\left(1-\frac{\lambda}{n}\right)^{n-j} = e^{\lambda}\frac{\lambda^j}{j!} \qquad (8)$$

In our nomenclature: $n = N_i$, and $\lambda/n = P_{Ei}$. Substituting equations (2) and (3) and solving for λ, results in:

$$\lambda = M D_i L_i r_i \qquad (9)$$

Since N_i becomes arbitrarily large with ω, expression (6) becomes:

$$P_{si} = \sum_{j=0}^{\infty} P_{Eij} P_{oi}^{\,j} = \sum_{j=0}^{\infty} e^{-\lambda}\frac{\lambda^j}{j!} P_{oi}^{\,j}$$

and, since λ is independant of j,

$$P_{si} = e^{-\lambda}\sum_{j=0}^{\infty}\frac{(\lambda P_{oi})^j}{j!}$$

This can be readily summed to:

$$P_{si} = e^{-\lambda} e^{\lambda P_{oi}} = e^{-MD_iL_ir_i(1-P_{oi})} \qquad (10)$$

5. Next, we assume that all obstacles of one type are independant of obstacles of another type. This is reasonable since obstacles of different types, if properly defined, are not likely to overlap or coexist. Therefore, the probability of successfully completing the mission is:

$$P_s = \prod_i P_{si}$$

$$= \prod_i e^{-MD_iL_ir_i(1-P_{oi})}$$

$$= e^{-M\sum_i D_iL_ir_i(1-P_{oi})}$$

$$P_s = \left[e^{-M}\right]^S \qquad (11)$$

where: $$S = \sum_i D_iL_ir_i(1-P_{oi}) \qquad (12)$$

This S can be considered a "measure of performance" of a given vehicle in a given terrain, independant of mission length. P_s is dependant on mileage and is therefore a less useful measure. Note that $[e^{-M}]$ is purely a mileage function and lies between zero and one. Therefore, P_s rises as S drops, and the superior vehicle will have the lowest S value. S contains every factor from the terrain model and is an absolute measure of the terrain-vehicle match.

A measure that includes cruising range may be established by calculating the area under the probability-of-success curve from zero miles to the cruising range, M_c. (see Figure 3) This quantity may be called a "measure of utility", U, and is equal to:

$$U = \int_0^{M_c} P_s \, dM$$

$$= \int_0^{M_c} e^{-MS} \, dM$$

$$U = \frac{1 - e^{-MS}}{S} \qquad (13)$$

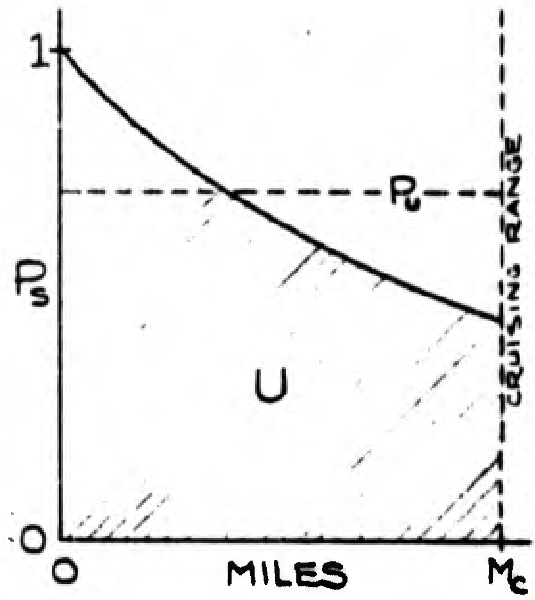


FIGURE 3

This quantity has the dimension of miles. If it is divided by M_c, the result is a dimensionless quantity lying between zero and one. It is tempting to call this a "probability of utility", P_U, where:

$$P_u = \frac{1 - e^{-M_c S}}{M_c S}$$

Actually, P_U is an average of the probability of success curve, as shown in Figure 3. However, P_U has one self-defeating defect: if two vehicles have identical probability of success curves, then the one with the greater cruising range will have a lower P_U, which is contradictory. The quantity U lacks this defect, and is therefore prefered, even though it has a dimension. Note that im this case, the superior vehicle will have the greatest value of U. The quantity U may be multiplied by the cargo capacity, G_c, to produce a measure which includes this factor.

6. The foregoing has been based on mobility performance alone. In a real situation, we are interested in determining how many vehicles will have to be sent on a mission to deliver a specified cargo to a destination. For a 100% cross-country mission, this is equal to:

$$V = \frac{G_D}{G_c P_s} \qquad (14)$$

V = number of vehicles required to be sent on the mission, fully loaded.

G_D = cargo to be delivered (tons).

G_c = cargo capacity of the vehicle (tons).

P_s = probability of success, as before.

Since this equation produces a fractional value, the next larger integral number of vehicles is taken. This number of vehicles can be plotted versus mission miles as in Figure 4. The mileages at which the number of vehicles changes can be calculated by inverting equations (11) and (14):

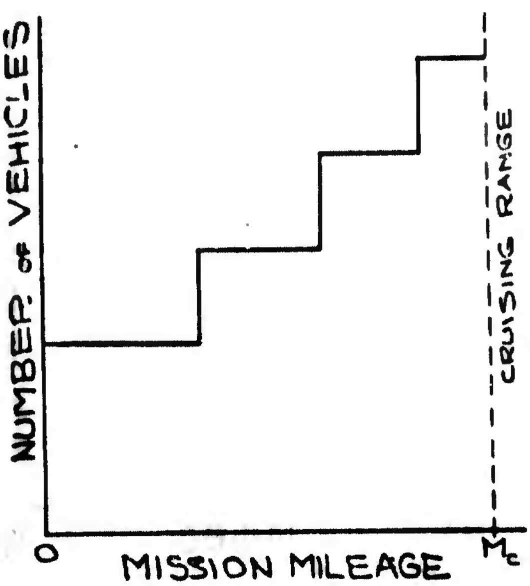


FIGURE 4

$$M = -\frac{1}{S} \log_e \frac{G_D}{G_c V} \qquad (15)$$

where M is evaluated for integral values of V. This graph will be terminated on the right by the vehicle's cruising range.

7. The previous information provides a framework for logistic decisions, but those who must decide between vehicle programs also require information on cost. Costs are of two types: one-time hardware costs, which must be amortized over the vehicle life, and operation and maintenance costs which are usually stated on a per-mile basis.

a. Amortized costs

1) If a vehicle is programmed for a production of V_0 vehicles, and this total initial program cost is $\$_0$ dollars, then $\$_0/V_0$ gives a unit program cost per vehicle. If the vehicle averages M_0 miles of operation until it is due for overhaul, then $\$_0/V_0M_0$ represents an amortized cost per vehicle-mile for this initial period. Similarly, $\$_1/V_1M_1$ gives this figure for the period from first to second overhaul, where $\$_1$ = cost of the overhaul program, V_1 = number of vehicles overhauled, and M_1 = the average mileage to second overhaul (usually 75% of the first figure). If each of these costs is weighted with the number of vehicles involved, and the vehicle is good for n overhauls before its life is ended, then the average initial-and-overhaul cost per vehicle-mile emerges as:

$$C_{I+R} = \frac{\frac{\$_0}{V_0M_0}V_0 + \frac{\$_1}{V_1M_1}V_1 + \cdots + \frac{\$_n}{V_nM_n}V_n}{V_0 + V_1 + \cdots + V_n} \qquad (16)$$

2) The parts support for vehicle maintenance and overhaul usually appears as a seperate program charge under the heading of "PEMA Secondary & Army Stock Fund." This charge, $\$_P$, must be amortized over all of the vehicle-miles. Therefore, this cost per vehilce-mile appears as:

$$C_P = \frac{\$_P}{V_0M_0 + V_1M_1 + \cdots + V_nM_n} \qquad (17)$$

3) If any of the vehicles or parts are salvageable or salable after they have been phased-out, then this program salvage-value, $\$_S$, should be amortized in the same manner as the previous charge:

$$C_S = \frac{\$_S}{V_0M_0 + V_1M_1 + \cdots + V_nM_n} \qquad (18)$$

b. Operation & Maintenance costs

1) Fuel and oil consumption are usually expressed in miles-per-gallon and miles-per-quart, respectively. These costs per vehicle-mile are, then:

$$C_F = \frac{\$/GAL}{MPG} \qquad (19)$$

$$C_L = \frac{\$/QT}{MPQ} \qquad (20)$$

2) Scheduled and unscheduled maintenance are expressed as a manning-index (maintenance man-hours per hour of operation), I_m. This must be adjusted by the average vehicle speed, v_A, in miles-per-hour, and the average charge for maintenance, in dollars-per-hour, to produce the maintenance cost per vehicle-mile:

$$C_M = \frac{I_m}{v_A} \cdot \$/HR \qquad (21)$$

Expressions (16) through (21) may now be combined to produce the total amortized cost per vehicle-mile:

$$C_{TOT} = C_{I+R} + C_P - C_S + C_F + C_L + C_M \qquad (22)$$

When this is plotted as dollars versus miles for various numbers of vehicles, a series of straight lines projecting up from the origin appears, as in Figure 5.

Sufficient information has now been accumulated to determine mission cost. Using the data on number of vehicles from Figure 4 and the data on cost per vehicle-mile from Figure 5, a single graph of mission cost may be plotted, which jumps from one line to another each time an additional vehicle is required. This is illustrated in Figure 6.

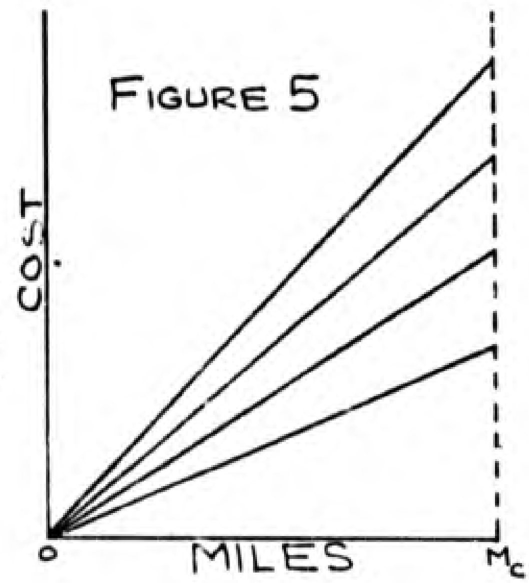


FIGURE 5

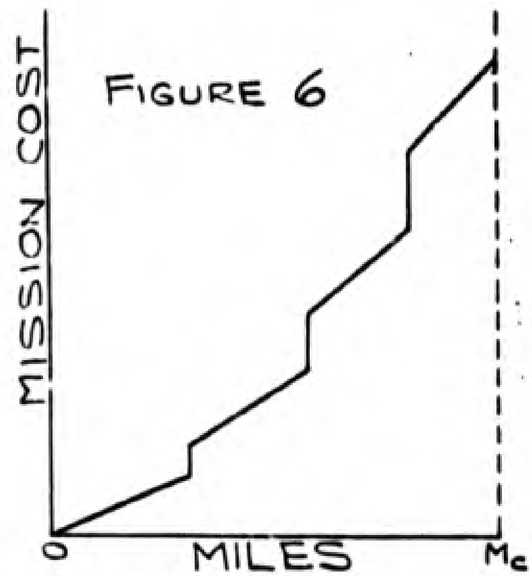


FIGURE 6

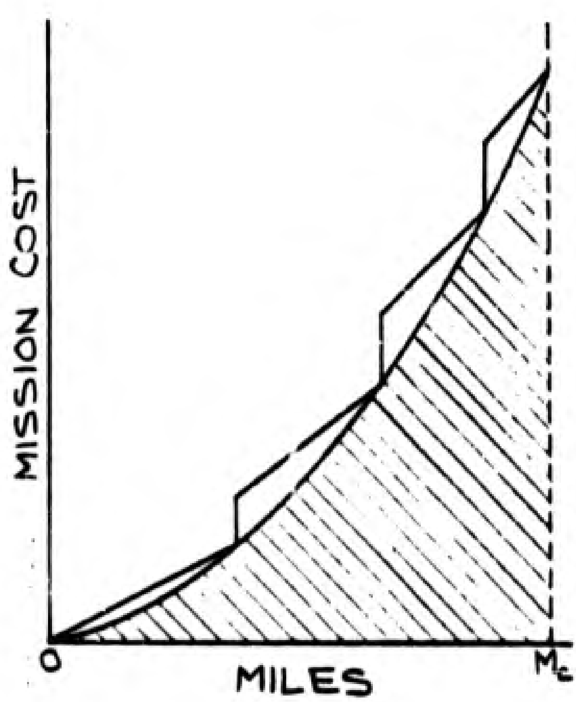
8. We may now devise a final measure, which can be termed a measure of "cost-effectiveness". Call this X. We would like to proceed as in Section 5 and calculate the area under the mission cost curve in Figure 6. However, this curve was produced from the following equation:

$$\$_{MIS} = C_{TOT} V M = C_{TOT} \left[\!\left[1 + \frac{G_D}{G_c P_s} \right]\!\right] M$$

where the double brackets denote "the greatest integer in". This is a discontinuous function which is tied to the delivered load, G_D. For convenience, we shall permit fractional vehicles and revert to the continuous function, expression (14). By doing this, we are confining our interest to the area under the smooth curve in Figure 7. We may now divide out G_D and M to produce a cost per mile per delivered ton:

$$\frac{\$_{MIS}}{G_D M} = \frac{C_{TOT}}{G_c P_s} = \frac{C_{TOT} e^{MS}}{G_c}$$

FIGURE 7



This relation is a function of mileage, and produces a non-linear curve (Figure 8). It might be thought that the value of this function at the cruising range, M_c, would be a useful measure, but this is not so. The curves for two different vehicles may terminate at the same point, and yet not coincide (see Figure 8).

We would like then, to derive an average cost per mile per delivered ton and call this our measure of "cost-effectiveness", X. This is equal to:

$$X = \frac{\int_0^{M_c} \frac{C_{TOT} e^{MS}}{G_c} dM}{M_c}$$

$$= \frac{C_{TOT}(e^{M_c S} - 1)}{G_c M_c S}$$

This X is somewhat less than the true average by the percentage indicated in Figure 7, but since all vehicles will suffer a similar percentage drop, a ratio of two X's will still produce a realistic measure of "improvement". X, then, contains all of the factors we have previously considered and is independant of delivered load and mileage.

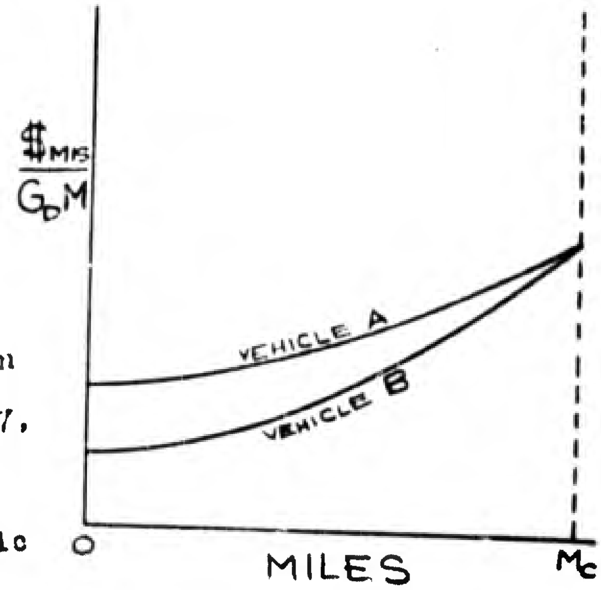


FIGURE 8

SUGGESTIONS FOR FURTHER WORK

Comments 1-9 relate to terrain models; comments 10-12 to vehicle data; and comments 13 & 14 to mathematical modeling in general.

1) There could be established for each type of obstacle, a probability of being able to avoid it. This would require information about the contiguity of obstacles of different types in the terrain, and knowledge of the amount and continuity of hard, unimpeded ground. Two obstacles would be considered contiguous if they are separated by less distance than the width of the vehicle. This could best be expressed in "contiguity functions": $Q_{AB} = B_{AB}/B_B$, $Q_{BA} = B_{BA}/B_A$ where B_{AB} = average boundary in common between obstacles of types A & B, respectively. This would give in one function, a mathematically useful measure of both the obstacle frontage facing the vehicle, and the continuity of unimpeded ground between obstacles. The probability of avoidance would then logically take the form: $P_{Ai} = 1 - \sum Q_{Mi}(1 - P_{on})$ Framing avoidance as a probability brings into consideration the fact that, when confronted with two contiguous obstacles, a driver will select the lesser of those two; on one occasion, obstacle A may appear more formidable; on the next occasion, obstacle B may seem so. In other words, no one obstacle type would always be avoided, unless it were always isolated and surrounded by unimpeded ground. This probability of avoidance must be inserted into the foregoing equations in such a manner as to produce the following results: first, the total amount of terrain available for the mission will be reduced if obstacles of one type are avoided, and consequently the probabilities of encountering obstacles of all other types will increase; second, the mission path will change from straight to sinuous, and therefore its total mileage

will increase. Also, the probability of encounter developed here will become useless, since it is based on a straight-line vehicle path and a linear presentation of the obstacle across the path. A now probability of encounter will have to be devised on an areal basis, taking into consideration the sinuosity of the mission path.

2) Another improvement would be to establish for each type of obstacle, the speed at which the vehicle can traverse it. This would aid in determining the total time required for the mission.

3) Also, it would be desirable to know the %-slip pf the vehicle's wheels or tracks over the various types of obstacles and terrain which it will encounter. This would allow determination of the mission mileage "seen" by the engine, and permit a more accurate analysis of fuel consumption. Note that the straight line mission mileage, M, because of avoidance is less than the actual mission mileage, M_A, which because of slip is less than the mileage seen by the engine, M_E, which cannot be greater than the vehicle's cruising range, M_C. Thus: $M < M_A < M_E \leq M_C$.

4) A discrete or continuous distribution of the obstacle size, rather than a simple maximum size, would permit a more accurate determination of the probability of overcoming the obstacle type. This distribution is most important for the soft-soil obstacle type, as it directly effects speed and slip.

5) A more realistic classification of obstacle types is necessary, and indeed what constitutes an obstacle must be clearly defined. Some real obstacles are not included in the model and should be, for instance: the copse, or stand of trees. A copse of small diameter hickory might solidly impede a vehicle, while a banyan copse, with its aerial root system, could easily be knocked aside. The factor defining a copse, then, is not stem diameter or growth pattern but "pushover force". This eliminates consideration of type of growth, and prevents the establishment of several obstacle types when only one exists. All obstacles must be defined in terms of that quality which obstructs (a vehicle). From this viewpoint, a ridge is not one obstacle but three, its flanks being distinguished from its crest. Flank negotiation depends upon the vehicle's grade climbing ability on the up-slope, and upon breaking ability on the down-slope, whereas overcoming the crest depends upon the vehicle's break-over angle. In general, Up-slopes and down-slopes will occur in equal numbers in the terrain, so direction of travel is irrelevant. However, the terrain may have a pronounced slope in the large, as in mountainous areas. In this case, the distinction is very relevant, and measures of vehicle effectiveness in several directions must be established and then averaged.

In many cases, a combination of two obstacle types will be worse than either separately. "Soft-soil-plus-copse" is one such synergistic compound; "soft-soil-plus-up-slope-plus-water" is another, as investigators of river egress know. Many of these compounds need to be considered as separate obstacle types. Other combinations, such as "bump plus water" (where the surface is hard), do not exhibit synergism and need not be considered as separate types. Still other compounds exhibit antagonism, the combination being less obstructive than either separately. "Soft-soil-plus-down-slope" is in this category, since the slope provides a forward vector in the soil and the soil aids in braking the vehicle.

It is important to realize that obstacle types form continuous spectra, and distinguishing one from another requires information about the class of vehicles being considered. For instance, a "ditch" would be distinguished from a "step-down" followed by a "step-up" by being shorter across than the vehicle wheel-base. A "chuckhole" would be distinguished from a "ditch" be being shorter transversely than the vehicle width. A "bump" would be distinguished from a "slope" by being of less height than the vehicle's wheel-base. "Soft-soil" would be distinguished from a fluid medium on the basis of the vehicle's buoyancy and the method of propulsion used. The number of obstacle types which must be established depends upon the tortuousness of the terrain. In fact, this might form a basis of a logical classification of terrains, with an infinite concrete pad at one extreme, and certain sections of the Colorado River basin near the other.

It should be understood by now that the model described at the beginning of this report is grossly inadequate. Better terrain models are most urgently required, and these models could be built along the lines described here.

6. At least three types of water obstacles exist; These are: still water, water with a strong steady current, and turbulent water with whirlpools. These differences would affect a floating or submarining vehicle more than they would affect a fording vehicle. Here, the vehicle's ability to tack against the current or cleave through turbulence becomes important. These actions require engine characteristics which are quite different from those required on land, so the engine in a good amphibian will be a compromise, if high water speed is desired.

The transitional zone between land and water is a different medium from either, although it partakes of the characteristics of both. Any amphibian, which must pass through this zone, must have features which are not required on either land or water, such as highly efficiently grousers, deep tire lugs, a winch or jet assist. It is an unhappy experience watching a vehicle, which is good on both land and water, trying to get from one to the other, when it has not been properly designed to do so. This zone is more critical for a fording vehicle which actually continues to operate on surface when submerged, and therefore has two transition zones: at the upslope from the bottom, and at the water-air interface. Also, a sub-marining vehicle can vary its buoyancy so as to swim, enter and leave the water either as a forder or floater, which ever the situation demands.

This discussion should clarify the nature of these types of obstacles. The soft-soil-plus-water of the transitional zone is, to some degree, a synergistic compound to all vehicles, whereas the soft-soil-plus-water of the bottom affects only fording vehicles, and is not usually synergistic unless the soil is a loose silty muck.

7. Further information is needed about the terrain left over (after all obstacles have been considered), the hard unimpeded terrain. The power spectral densities of this ground surface would aid in determining vehicle speeds. The amount of sloping ground, and the distribution of slope angles would also help. Here some finesse is required, for certainly slopes steeper than some critical angle constitute a type of obstacle. What this critical angle might be would have to depend on the class of vehicles being considered. (Of course, slopes can exist in soft-soil too, up to the angle of repose.)

8. It would be easier if the extent of all obstacles were expressed by an average best-fitting ellipse or at least that average lengths and widths be given.

9. Finally, and most important, the average extents of the various obstacles times their numbers (as determined from densities), plus the amount of unimpeded ground should add up to 100% of the terrain.

The foregoing nine comments are addressed to those interested in constructing terrain models. The following three comments are for vehicle designers and project managers.

10. In order to perform a vehicle analysis for a specific terrain model, there must be a datum available for the vehicle to correspond to each datum for the terrain. In other words, the vehicle designer or project manager must provide an accurate estimate of his vehicle's expected performance on each type of obstacle defined in the terrain. These estimates must be documented by test data. Our terrain models also need to be supported by field surveys.

11. If a vehicle has special features which, in the opinion of the designer or manager, enhance its performance, then it is his responsibility to quantify the value of these features, so that they can be included in the mathematical model analysis. Opinions or judgements may seem compelling to their supporters, but do not fit well into analysis.

12. There is a definite need for more work in the area of relating vehicle geometry to terrain geometry. Such work would allow a mathematical approach to assessing vehicle performance over different types of obstacles, and would aid the designer or manager in providing this data.

13. This report is meant as a format for a cost-effectiveness study of a logistic vehicle, in the absence of supporting vehicles and hostile fire. Therefore, it does not consider force ratios, kill-probabilities, or weapon effectiveness, which are properly in the domain of a tactical vehicle. However, logistic vehicles are sometimes put to tactical use, often unintentionally, as in guerrilla engagements, so a discussion of these factors is pertinent. It is possible to introduce enemy soldiers into the analysis as a type of obstacle with a certain density in the terrain. Of course, this particular "obstacle" is mobile, and tends to concentrate in the vicinity of the vehicle, so the density would have to be modified by a "mobility" factor. The "extent" of this obstacle depends upon the range of his weapon and the other obstacles lying in his line of fire. Note that contiguity functions in this case approach 100%, making him difficult to avoid. His "maximum size" is his firepower, and again a distribution for this value is most important. The vehicle's ability to "overcome" this obstacle depends on its armor protection and weaponry. The mobility for this type of obstacle might be determined by the methods in this report, substituting a man for a vehicle. A similar interpretation would be applied to other types of obstacles in this category,

such as: group-of-enemy-soldiers, enemy-vehicle, enemy-field-piece, etc. Another type of obstacle is a mine, which fortunately does not move around. In this case, the maximum size is its explosive force, and its extent depends upon how close the vehicle must be to detonate it. The probability of encountering this obstacle would have to be modified, since the placement of mines is hardly random. All of these data must be supplied as elements of the terrain model; the mathematics can be adjusted to accomodate them.

14. One final item: "perception" plays a key role in the encountering of obstacles. The recognition that an obstacle exists and is insurmountable rests upon the sensory discernment of the driver, or the optical and electronic aids which he employs for this purpose. Bumps and chuckholes are difficult to see in heavy grass. So are enemy soldiers hidden in the foliage and buried mines. Of course, terrain irregularities can be detected with low-range radar and bodies with near-infrared equipment, so perceptibility depends very much upon the vehicle's apparatus. This factor should be introduced as a modification of the probabilities of encounter and avoidance.

Final Note

The methods described in this report must be considered tentative. Its purpose is to stimulate interest in the field of terrain model construction, and to direct this interest into those areas that would be of greatest utility to the mathematical analyst. The analysis of terrain-vehicle systems should be recognized as a distinct and important discipline within systems analysis, one where relevant data from the physical world can be effectively used, if it is made available in reasonable quantity and in a usable form. These analyses must continue to be based on assumptions and hypothetical models until detailed models of real terrain become available. These models would be of value not only to the military, but to anyone who must use off-road vehicles.

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LARGE SCALE NON-LINEAR SIMULATION - A CRITICAL EVALUATION

Mr. Clayton Thomas
United States Air Force

Since this is to be an audience participation show, I will try not to take too long to state my own biases, what kind of simulation I am talking about, whether I am for it or against it, and the reasons why.

Some people learn from the Bible that you're for something or against it. This truth was impressed on me through an experience in Girl Scouting. Several years ago, at a party in honor of a visiting Girl Scout official, the distinguished lady guest of honor concentrated her attention on the men, putting to each the same question: "Are you one of the pro-Girl Scout husbands or one of the anti-Girl Scout husbands?" (Given these clear cut alternatives, it suddenly occurred to me that maybe I was "anti.")

Fortunately, to be for or against something, you don't have to be able to define it. This I learned from General Max Johnson, now retired and writing for US News and World Report. About ten years ago at one of the University of Michigan seminars on War Gaming, General Johnson remarked, "Gentlemen, I'm not quite sure what this War Gaming is, but I'm for it." Now I'm not quite sure just what Ben Tencer had in mind by Large Scale, Non-Linear Simulation when he organized this session, but in the interests of a lively discussion, I have agreed to be against it.

Seriously, I think we should recognize first of all that it is almost impossible to solve the semantic problem. The British analyst, Tocher, gave a very good presentation on simulation last summer in Boston at the 4th IFORS. Quite earnestly and carefully, he went through all of the proposed definitions that he had heard or could think of, showing that none of these was fully satisfactory.

What I have in mind today when I use <u>simulation</u>, however, is fairly well characterized by the phrase "computer war gaming." One of the early prototypes that many of us in the Air Force first came across was the RAND Strategic Operations Model that came out in 1957. Similar models have been developed by virtually everybody now, at all types of agencies, not only in the strategic area, but also in the areas of tactical forces, airlift, etc.

Rather than trying to give a precise definition, I would like to capture the spirit of simulation. Here some remarks that Marvin Schorr made yesterday on the creative aspects of operations research are suggestive. You recall his analogy of capturing the essence of a field of grass with a few bold strokes of the artist's brush. To extend his analogy, it seems to me that the aim of much large scale simulation is to draw every blade of grass. For some purposes, this may be good--e.g., to give a realistic reminder that there are problems like crabgrass--but for many problems it is probably unnecessary or even self-defeating. Yet this urge to complicate seems to be an almost irresistible aspect of the spirit of simulation. This point was illustrated by a conversation I had last year with an analyst of RAND, now in OSD. Having designed a very detailed tactical simulation model, going beyond its predecessors in many ways, he had been discouraged by the results of its use. He admitted doubts that one can learn anything from such a simulation model. But he added that "if you can learn anything from one of these, it's from mine!" Presumably, it was the only one complicated enough.

A related aspect of simulation, associated with large scale complication, is that it tends to be an "if-then operator" rather than a direct optimizing technique. That is, you can simulate n different cases, and pick out the best--brute force optimization. As some software manufacturers are currently pointing out to us, one can use the results of earlier simulations to guide us in deciding what to test later on. But simulation as such clearly doesn't optimize in the sense that we all learned back in differential calculus, where by setting an expression equal to zero we could pull out the best of an infinite set.

Even as an "if-then operator", however, simulation has not achieved its full promise. Many of us, when we first heard about simulation, had a sense of great anticipation, perhaps astonishment, or even a feeling of euphoria about the future of military operations research. Now, however, for over ten years, we have had a large number of simulations developed by a great variety of organizations. It seems to me that in actual practice, simulation just hasn't lived up to the expectation. There are three reasons for this that I would like to outline and later "flesh out" a bit.

Why hasn't simulation lived up to its promise? My first point--hard to recognize because simulation has such an air of reality about it--is that there are many situations, especially military situations, that are very difficult to simulate faithfully and realistically, even with all the complication that the present state of the art can tolerate. The second point is that whether or not a large scale simulation represents something faithfully, it is awfully hard to use. Simulation tends to be a clumsy, cumbersome device. And the third point is that what even a good simulation provides--synthetic experience or hindsight in advance--is only one of the aids that a decision maker needs. Just as the assessment of actual experience poses difficult analytic problems, where the sheer complexity of experience may be a hindrance to true understanding, so also the synthetic experience provided by simulation is at best only a prelude to analysis. At worst, simulation can siphon off efforts that would be better spent on other pursuits. Now, let me expand on these points.

The first point--that a faithful simulation may not be achievable--is all too often unrecognized, partly because large simulation models, like large war games, give an impression of considerable "versimilitude." The ability to simulate certain physical systems, and some man-machine systems, is so striking that we tend to assume an ability to represent all military situations. In actual practice, however, the quality of our representations is limited by the problem of size and the problem of ignorance.

Let me take first the problem of size. I recall an anguished telephone call about ten years ago from the office of Dr. Howard Talley at the Tactical Air Command. He was trying to use the RAND Strategic Operations Model. It was new then, and we all marveled at it. With 150,000 inputs it seemed large and impressive. Surely, we thought, it must include almost everything. Yet in the first application, problems were revealed. For example, the model only provided three possible values for the amount of aviation fuel stored on a tactical base--zero, a maximum value, and one intermediate value. As Talley pointed out in his phone call, there were serious problems involved in using the model to represent the condition of actual bases. The model size, which had seemed so impressive, turned out to be only a first step, viewed against the backdrop of potential complication, and successors to that early model soon passed the half-million mark in the number of inputs required.

Perhaps even more serious is the problem of ignorance. How do we use the inputs that are available? When we start to calculate numerical values for inputs, or to find them in a planning factors manual, we are reminded of our ignorance. How people behave, how organizations behave, even how certain physical systems behave, is still very much unknown. Though the complexity of large-scale simulations may obscure this difficulty, it does not relieve it.

It may turn out--and this is difficulty number two--that even a faithful simulation model is still not very usable. A very common cause of this is a "data problem". Very mundane but extremely important considerations of obtaining input data for large scale simulation models may discourage their use. There may just not be enough time to obtain the several hundred thousand numbers that some models require. In other cases the difficulty may be even more serious, in that sufficiently good estimates of required input numbers may be beyond the present "state of the art", demanding intelligence sources or techniques of estimation that just don't exist.

In trying to solve the "data problem" of a large model, one may end up worse off than he was with an extremely crude and simple model. Let me illustrate this with a bit of hyperbole. Probably nothing like my example ever happened, because it's going to be so simple that we can see what's going on, but in actual applications where it's harder to penetrate the mysteries of models, still worse things may have happened. Suppose, to get to the example, that one has been using a simple model of the air defense process in which the probability of interceptor success is represented as the product of three probabilities--the probability of detection and conversion, the probability of launching or firing armament, and the conditional probability that the armament once launched or fired is effective in destroying an enemy aircraft. Now let us suppose, further, that in the spirit of large scale simulation, one elaborates the representation by taking the success probability as the product not of three but of one hundred separate probabilities. One way of doing this is to divide a flight of fifteen minutes (about a thousand seconds) into a hundred intervals (of about ten seconds each). Each separate probability could then represent the conditional probability of still being on the "right track" at the end of an interval, given that one was at the beginning of the interval. Now how does one input to such a model--how does one do a sensitivity study? Suppose one recognizes that none of the separate probabilities is likely to be 100% and introduces an upper limit. If one takes this limit to be .99 and, in effect, raises this to the hundredth power, he gets about e^{-1}, around .37, as an upper limit. This is a mistake that would never have been made with the original simple model. Impossible, you say, for any one to make such a blunder. Very likely, with such a transparent model, that mistake would not be made, but how many times have we used such "wholesale inputting" to meet the ravenous requirements of a monstrous model, when we didn't really understand enough about the model's structure to know the implications of what we were doing!

Now, let me turn to the third difficulty of large scale simulation. A simulation that is reasonably faithful or realistic and reasonably usable may still not offer much aid to a troubled decision maker. What many simulations claim to do--provide "synthetic experience" or "hindsight in advance"--can be very useful but often represents only a small part of what a decision maker needs as he faces an agonizing decision. At least, what he gets from many actual simulations is only a small part of what he needs. In many problems there is what Norm Dalkey would call the "axiological difficulty"--we don't know the pay-off or utility function. Knowing what might happen in a given situation doesn't necessarily tell a decision maker how he would feel about it. A simulation can help a great deal, if it is properly structured and accomplished, but more often than not, it is the analyst who gets the benefit of the total context of the simulation and not the decision maker who could really make more effective use of the insights that could be gained from simulation.

Another way of looking at some of these difficulties of simulation is to think of what simulation does best. Dealing with very large and complicated systems, simulation is not so useful as a problem solver as it is in exploring new approaches, and sometimes in training. Though it may be slightly exaggerated, there is considerable relevance in the common remark, "By the time one has designed a simulation in detail, he has already achieved its major benefits in understanding the problem, without making even a single simulation run." Unfortunately, this kind of insight into a complicated system is not easily transferred from the analyst to anyone else. Hence, it is often suggested that special simulations for decision makers and for the training of those who operate "real life" systems should be prepared. It is important to note, of course, that these special purpose simulation devices often involve an "act of faith"--an assumption that we know enough about the problem to cope with its difficulties.

A generalization of the above suggestion, which Norm Dalkey has repeatedly urged, is the formulation of a whole family of simulation models for the representation of some phenomenon. At one end of the scale there could be a very aggregated (and usable) model, with progressive dis-aggregation toward the other end of the scale. Hopefully, one would try to calibrate the (n-1)st of these in terms of the n-th.

Here, I would like to emphasize another avenue to explore in trying to find remedies to some of these problems of simulation. This I think comes down to basic character--the exercise of restraint. That is to say, in many cases we should try to resist the impulse to simulate. Try to find something else that can be done. As General Betts was saying yesterday, don't just assume the technical feasibility of everything that is proposed. When I question the application of simulation, I often am asked, "What convinces you that our analytic techniques are capable of solving these complicated problems?" My rejoinder might well be, "What convinces you that anything is capable of solving these problems?" The fact that n - 1 methods have been found inadequate for the solution of a problem does not mean that the n-th will succeed. And if no method is fully adequate for the solution of a problem, one finds added interest in the cheapest way of not solving it.

This attitude isn't universal, of course. Yesterday, when someone asked if our panel was going to tell whether simulation is "in or out," I told him that it's probably an "in thing" independent of what we say. In emphasizing the perils, rather than the promise, I feel a little bit like a salmon going upstream. But I think I have found a kindred spirit, though I don't know his name. He is the anomymous author of the little article in the May 1967 Astronautics and Aeronautics entitled "What Kind of PhD's for Aerospace?" The author is an engineer who spent a year with the government early in the days of the space program. One of his examples is a report that cost the Air Force $60,000 for the services of two engineers who investigated the following problem: If air starts escaping from a space capsule after particle penetrations, how long do the astronauts have to put on their space suits?

The approach that the space engineers took to this problem was in the spirit of large scale simulation. They devised a large scale computational model, took a special case, and ran off a large number of numerical calculations. Our anonymous engineer-author points out some good alternatives. If you are willing to assume incompressible flow, you have a Bernoulli equation under nice conditions. If you remove the assumption of incompressibility, it takes a few more minutes to get results. You can solve the isothermal case and then the adiabatic case, which give upper and lower bounds for the results of a precise solution.

Such an analytic approach, our anonymous author points out, would have been about three orders of magnitude better than what was actually done by the engineers who had the contract. First of all, it would have been more general, giving more useful information and understanding about the structure of the problem. It would have permitted much more reliable extrapolation to other cases. And it would have cost one whale of a lot less.

So why isn't more use being made of analytic approaches? Well, there aren't enough people interested in them or capable of using them. Our engineer author tried to do something about this. He explored institutional arrangements to give added incentives for the use of analytic methods and found this to be a difficult path to follow, at least in the U.S. He then asked about educational possibilities to exploit in the training of PhD's. He talked with about half a dozen different professors, each of whom gave some reason why it's almost impossible to train PhD's to use appropriate analytic methods: you can't train people to do it; professors don't know how to do it; nobody can do it without years of experience; people just aren't interested in doing it--they have to publish a host of papers that shouldn't be too simple or understandable; etc. So our friend ended up rather depressed.

He grasped at the hope that a statement of the problem might lead to a solution--by someone. And this brings me to the conclusion of my plea. I propose for our discussion period the following topics:

What can be done to encourage our colleges and institutions to train people so that they can do something besides simulation?

What is being done today to remedy the dificiencies of simulation?

What have been your experiences with the successes or failures of the proposed remedies?

I'm not saying that we should never simulate. But for good simulation, and effective problem solution in general, we need other weapons in our arsenal.

LARGE SCALE NON-LINEAR SIMULATION - A CRITICAL EVALUATION

Mr. Alexander Pugh
Massachusetts Institute of Technology

I'll start with the contrast between military and industrial. I think one of the principal differences between our techniques is understanding. You start out with a problem statement (and of course there are the usual problems without problem statements). Someone presents a problem to you, and after studying it for a while, you conclude that it is not really a problem in itself, but a symptom of a problem. You must go a lot deeper in order to get at the real problem.

Secondly, you will want to hypothesize some sort of relationship that you believe is at the heart of this problem. This is trying to guess at the answer before you get there. In fact, I would suggest that if you build a model without a pretty good idea of what the answer is going to be, you will probably leave out what is important. We are talking about feedback systems. We are almost always imbedded in a larger system. One has to look at the larger system and ask a question: are there important feedbacks that must be incorporated from that larger system, or could we limit ourselves to the smaller system? Instead of having a model with 50,000 variables or inputs, we will have a model with something like 150-200 variables. From this model we expect to find out whether the hypothesis is reasonable or whether it fails to confirm the hypothesis. If it confirms, we can pass on to the next step, but in fact, what generally happens is that we find ourselves in an iterative approach. An approach in which, as we define our thinking explicitly in a model, we find that we had overlooked something; the process of model building, even in the case of our simple model, requires a very precise understanding of what we are doing. This means that we will find that another problem statement is more appropriate or another hypothesis is more appropriate before we ever get to the point of actually asking the model if the first hypothesis was reasonable. We finally get a model that satisfies us.

Turning to another one of Clayton's problems, we frequently find that having built this 150 equation model, we now have sufficient understanding to build a 15 equation model of the same situation to demonstrate the same phenomenon. And, of course, having shrunk it to 15 equations, we are in a position now to make it much easier to communicate. At this point, we try to pass along our insights to the decision maker.

Without worrying about the problem of communications, which is a serious one, let me go on to say that, having gotten hold of our problem and expressed it in a model that satisfies us, we need to ask which alternatives are available to us, and from the insight we've developed, we hope we can propose something and test it, which will alleviate the situation. For a complete Industrial Dynamics study, of course, it is also necessary to go through the problem of implementation. This is an extremely tough industrial situation. It means that you must provide reasonable alternatives that people are willing to accept and execute, and, quite frankly, it is one of the toughest parts of our studies. In fact, as I might point out, there is a system involved there, and we've actually done some research in the area of implementation and the systems that are involved in the implementation process.

One of the characteristics that seems to be true of our systems is that we are not trying to refine something in a rather small way. We are not trying to find a slightly better formula to assign aircraft to targets; but rather, as we study the larger system, we find something else is really the determining factor. It is not whether you get 98% efficiency or 100% efficiency out of these aircraft, but perhaps the question of whether you can get supplies to the air bases. It is some larger system like that that is really the determining factor in the behavior. And these questions ultimately become one, not of slight differences of gray, but rather decided situations of black and white. There is one example which after the fact sounds ridiculous, but I think that if you look into real situations in the Air Force, you will find that eventually you discover these black and white situations. In this instance, people were concerned about production, ordering, and so forth, in a factory, and the final truth came out that there was no feedback from the stock of inventory to the production process, except in perhaps a "bang-bang" sense. If the item was out of stock, if it appeared on the back-order list, that item would be produced. Otherwise, if the item got in so large supply in inventory that it began to exceed the capacity of the warehouses, somebody told the factory to change the orders. But in between, there was no control over that particular item. Ridiculous. But I think you will find military situations just as ridiculous as that.

LARGE SCALE NON-LINEAR SIMULATION - A CRITICAL EVALUATION

Mr. Benjamin Tencer
Boeing Company

I may be a little more obstreporous than a few of these gentlemen tend to have been, but if this appears to be so, it is not intended. I am going to try to get at what I think is the crux of our problem, from the beginning, and then go on from there. We all know that after World War II, when the techniques of simulation passed through a rather spectacular development, the data processing industry began to have almost an explosive spurt of growth. And military OR came into the picture in a very large way. And last, but most important I believe, the engineering community, in designing their systems, began to develop the techniques for entering feedback control. I believe if we all examine our consciences and look back, we will find that the successes of the engineer in simulating the physical environment that he found himself in gave us the grandeur that we're operating in. We had expectations of similar successes, and it is my belief that we nave not quite reached them yet. I agree with Clayton that the meaning of simulation has become so indistinct through use that it is almost impossible, without further enlightenment, to talk about it. When you say simulation, each individual conjures up in his own mind an unlimited number of study images. The problem here is primarily one of relative availability of resources. We are living in an era, I believe, where hardware is the easy thing to come by. Analytic talent is the difficult thing to come by. The reason that I named this session "Large Scale Non-Linear Simulation" is that I believe this is the bound that we're moving to. Because of the imbalance in the capital equipment resource versus the analytic competence aspect, our field is beginning to fill up with a large number of people who understand parts of the problem. And simulation appears to be a glamorous route to solutions. If you have limited analytic talent, you converge to the boundary which is, I think always (with the capability of computers today and the techniques available) simply a one-on-one solution. I will throw in every blade of grass, rather than take the time to take sub-components, do analytical type analyses on it, understand the sub-components first, prior to the time you go into the overall picture. Let me stop there a minute; we'll get back to that shortly.

The mathematical reasoning approach to simulation analysis is pretty well accepted by most people in our field. There's one school of thought, however, which still clings to what you might call the linearized form, the optimized forms, the form that is able to be optimized. They believe that you should include in a simulation only observables. These are items which can be statistically verified. At least, there is some probability that if you do use them ultimately you will be able to get a statistical verification on it. You recognize that this is a fantastic limitation when it comes to what we normally do, since statistical verification of probably ninety-five percent of what we have is impossible. Now this is one of the high lights of the distinction between possible success in the industrial environment versus the military environment. In the industrial environment, you have a laboratory, a continuing function which you are able to place under a microscope. You can generate hypotheses which you can then test if you have a reasonable degree of success in selling it to the decision maker, and determine whether or not what you have accomplished has any meaningfulness. We don't have this available to us in the military OR simulation field. We do in a way; we can always structure a real war game in North Carolina and spend ten million dollars or so to get one single data point and then try to generalize from there. It is a real problem. So one of the basic issues here is: as we increase the scope of our simulations (and there is the tendency to do so as the analytic competence of the individuals involved declines), we get more and more of the unverifiable aspects of the problem.

I want to use several words which were coined way back in a 1958 article. When we talk about the engineer that we're trying to learn from in this feedback control system analysis, we find that he has captured the essence of reality. He's dealing with the physical characteristics, physical laws of nature. He has the basic essence of it. The engineer, in essence, is attempting to synthesize a complex system made up of individual structures, the behavioral characteristic of each of which is totally familiar to him. He has a high degree of knowledge about the behavioral characteristics of the transfer functions of all the sub-components of the system he wishes to analyze. What is unknown, of course, is the overall response characteristic of the system. However, when he has finished his simulation, he has a very high degree of confidence in the fact that the behavioral characteristic of the overall system is correct, since it is nothing more than the sum of the behavioral characteristics of the parts, combined in a very complex fashion. This bears very little resemblance, however, to our problems. We have activities that are fundamentally evolutionary, military aspects of the problems that we're attempting to simulate. They are primarily irreversible. The laws of behavior are likely to be not fully understood, the human laws of behavior. Even when fully understood, we find that the intrinsic random component of it still remains very very large. Yet, we're still trying to get behavioral patterns out of the overall system and we don't have a handle on the characteristics of the parts. Now, let's see, what are we really trying to do? Maybe we're trying to reverse the nature of the original process as developed by the engineer. Maybe we're really familiar with the overall behavior of the system and are attempting to infer the characteristics of the parts of the system. Now, if this is true, we've got a real problem. I don't believe this is going to be offensive, but I'll say it anyway: Predictions of the overall behavior of large scale simulations are as numerous as there are knowledgeable military strategists on earth. If we wish to infer the parts by looking at the predictions of the behavior of a system, we're not going to get any unanimity, on the peculiar characteristics of the behavior of systems made up of people and equipment, or even in terms of logistics structures, which we attempt to simulate. We have a real problem in that the knowledge that we have of our systems is fragmentary at both the component level and at the overall level. Not one or the other, so that we can use the approach of going from the general to the specific, or the opposite approach of going from the specific to the general. We lack knowledge in both areas. One of the problems is that when we attempt to capture the essence of reality, which is what we're truly trying to capture, it restricts the scope of the appearance of the analysis. Suppose we decide that we're only going to include in our simulations those things that we have a reasonable degree of certainty that we understand, or the capability to make an educated guess about its behavior, rather than structuring generalized decision rules. These generalized decision rules, of course, would be characteristics that the engineer had developed but based on physical laws of the behavior of the material. You give up uncertainty; you get verifiability; but you get limited applicability. And the decision maker constantly comments on the fact that you are not covering the whole problem. On the other hand, if we decide to go the other way and say that anything that we observe is a significant piece of the analysis, or something that has a sensitivity relationship to the output, we should put it in. After all, we can always test the sensitivity of the characteristics that we have included and later exclude those that have no sensitivity relationship to our outputs. The only trouble is, the human mind works in a rather strange way. When we attempt to describe the problem, we're using a subconscious analytic capability, and very seldom will we try to dream up those things that we haven't observed which may be insensitive.

We then have the opposite approach, the one-on-one which generally gives us the appearance of reality. We can usually, with a little bit of effort, print up dynamic profiles of outputs that will frighten even children in terms of their predictive capability. There is only one problem. When data and knowledge are limited, and there are a large number of variables in a system, these basic performance characteristics in the overall system can be gotten with almost any combination of values for the uncertain variables within their regions of uncertainty. We now have the appearance of reality, but not the essence. Without the data, we are unable to determine whether or not the basic behavioral properties of the individual parts really have any significance to us. I refer to my previous statement, which was that the basic problem here is that, as the analytic competence of the individuals doing the job goes down, there is less and less of a desire to tackle and understand the properties of the individual pieces and take the time that is necessary to develop them. In the environment that we're currently living in, the press for answers is phenomenal. Very seldom, when quoting a two-year time horizon for study, does one get one in two months.

I don't know what we are supposed to do about this. A friend of mine once made a statement in an argument of this nature: suppose that we know that the world is round, but that we can only roughly estimate the curvature of the earth. Will navigation over long distances be improved by assuming that the world is flat? This is a good question. In attempting to describe the system, I would be better off sticking to only those parts with which I am absolutely familiar. I should leave out those parts with which I am only partially familiar and set them to zero, so to speak. Or, would I be better off making an attempt to get in everything I can? Everything that I feel has any possible implication to the problem? I don't know the answer. However, I have come to the conclusion that some place along the line, somebody has to use every bit of knowledge about the problem. That somebody is usually the senior decision maker. In order to make a decision, he must know all of the qualitative and all of the quantitative aspects of the problem. He may want us to put in uncertainty in large degrees. I don't know. We have had and will continue to have great difficulty in communicating just what we are doing to the senior decision maker, who primarily ends up making the decisions supposedly based on the output of our computer. Clayton, again, has a tendency to concur with this in a statement that he wrote back in 1958. He commented on the fact that he deplored the tendency to introduce trappings and ornaments into simulation to give the appearance of reality, where it is the essence of reality that we need to capture. "The popular appeal of war gaming is that it is the best method for teaching and selling war gaming; but its ability to solve is not very well understood."

In a way, war gaming lacks the sure guides to adequacy of solution that analytic non-gaming techniques supply. Clayton feels, and I agree, that we have a tendency always to introduce the complications in the desire to imitate reality rather than capture its basic essence. That is one of the flaws of the activity we're accomplishing that presents our biggest problem. I don't know what we can do about all these things.

In one of the first questions we discussed, Clayton asked if there is any way that we can develop, or get the academic communities to develop, the type of people that are required to change this imbalance, the type of people that are willing to take the analytic approach. I might mention (and I don't know whether or not you will search your souls and come to the same conclusion), that I have gone to a number of these large scale exercises and that I find that whenever I want to really understand a system, I don't put it on the computer and generate large piles of output and then attempt, through various and sundry techniques, to infer the behavior of the system from the output. I find that when I get my true recognition, it comes from going back and simply re-examining the nature of the equations that I've written down in an analytic fashion, getting their basic behavioral properties, and summing them up in my mind. I have a feeling that 90% of everything that we are going to learn from large scale simulations comes to us, or we had it in hand, the day before we started this long, horrendous task of generating sizable alternative outputs on computers. Perhaps the answer to one of our problems is a law requiring six months between the time the analytic framework is established and the time that we begin to run output.

Colonel W. C. Abernathy
Office, Chief of Research and Development

THE ROLE OF CONCEPT FORMULATION IN ARMY PLANNING AND MANAGEMENT

As the title indicates, the purpose of this presentation is to describe the role of concept formulation in Army planning and management. Speaking literally, this is easy because the current role of concept formulation in research/combat developments/materiel development can be described in two words - "increasingly prominent." Of course there is more to it than those two words, as I will bring out subsequently, but it is obvious that systematic concept formulation activities are receiving a greater amount of attention.

For example, several years ago the term "concept formulation" was seldom heard in the Department of the Army Staff, and then within a vaguely defined context. It first appeared in Army Regulation 705-5, which is the cornerstone of our research, development, test and evaluation (RDTE) efforts, in a change published October 1965. Since that time the term has come into more widespread use, and with a more clear-cut understanding of what it actually entails. You noted that concept formulation was the keynote of General Betts' opening address yesterday. He has also emphasized it during other recent speaking engagements.

This presentation will cover the definition of concept formulation, its place in the materiel life cycle, and how it is applied in certain areas of planning and management for RDTE.

The definition of concept formulation contained in Army Regulation 705-5 is as follows.

VUGRAPH 1

A significant event in the role of concept formulation has been its formal recognition as a discrete phase in the management of the Army materiel life cycle. Yesterday General Betts discussed some of the recent actions to improve concept formulation for new items. He pointed out the necessity for sound studies and analyses during that phase to provide desired payoffs during later stages. A look at a schematic portrayal of the materiel life cycle underscores that point strongly.

VUGRAPH 2

The process can be thought of in terms of a directional arrow like this which has a broad base and becomes progressively refined to a head and point.

The life cycle is divided into phases as shown. It begins with concepts for the entire Army of the future. These broad concepts become refined to statements of requirements for specific materiel systems during the latter portion of the concept formulation phase. The cycle for each single system then follows through contract definition, development and production, and operational and disposal phases.

FLIP 1

This life cycle involves more than just hardware development. Throughout each phase there must be specific planning to insure that related organization, personnel, logistics, and evaluation actions are accomplished concurrently with the materiel they support. These related planning efforts must begin during the concept formulation phase for the materiel to insure orderly fielding of the system throughout the Army. Obviously, for the cycle to operate effectively there must be a close working relationship between the Department of the Army headquarters, the combat developer, the materiel developer, and the trainer organizations.

FLIP 2

This schematic portrayal illustrates some of the relationships between the Combat Developments Command (CDC) and the developing agencies. Here we have the user (CDC) analyzing and projecting the world environment to design the land combat system needed at a later date. The user's postulation of future operational needs guides the long range planning and research and exploratory development by the developing agencies.

Results of the research and exploratory developmental effort, fed back to the user, will enable him to refine his broad design and doctrinal studies to state requirements - qualitative materiel development objectives, advanced development objectives, and qualitative materiel requirements - more precisely. The other actions and interactions follow as indicated.

The point is that effective concept formulation involves more than crystallizing ideas for the design of specific materiel. It includes the parallel planning and management actions required to integrate new equipment into the Army, together with the so-called "software" such as revised doctrine, organizational structure, trained people, and supporting supply and maintenance systems. This software aspect of concept formulation is receiving increased emphasis.

VUGRAPH OFF

Having covered the position of concept formulation in the materiel life cycle, let's look at that phase a little closer. First, what is its purpose?

The broad objectives of the concept formulation phase are:

1. To identify future threats and operational capabilities needed to meet the threats.

2. To establish and evaluate alternative technical and operational approaches to provide the best means for attaining the needed capabilities.

3. To establish the basis for further development of selected materiel systems.

With regard to the third objective Department of Defense approval - and money - is required before a major system can proceed through the contract definition phase. The Secretary of Defense has established six prerequisites which must be met before a major system moves into contract definition. These are shown on this vugraph.

VUGRAPH 3

So from a realistic standpoint another objective of concept formulation is to meet the Department of Defense prerequisites for contract definition. This vugraph shows how this is accomplished.

VUGRAPH 4

This is another arrow chart, but it covers only concept formulation, not the entire materiel life cycle. It shows major steps during concept formulation and the coordinated interactions between combat developer and materiel developer.

At the base of the arrow is shown the guidance and direction furnished by joint and Army plans, National and Department of Defense policies, and intelligence estimates. These, together with the Long Range Technological Forecast prepared by the Army Materiel Command (AMC), are used by CDC for studies of future land force organization and operations. CDC, in conjunction with the developer, represented by AMC, prepares broad operational capability objectives as long range goals for the future Army.

The CDC efforts provide guidance for research and exploratory development conducted by the developing agencies which, in turn, provides feedback to CDC broad parametric design information on approaches which may achieve desired operational capabilities. CDC, as the representative of the user, then specifies mission and performance envelopes for a particular operational need, and the developer responds with possible technical approaches and operational and performance tradeoffs.

Subsequently the action proceeds to steps of tradeoff evaluations. cost effectiveness evaluations and engineering feasibility studies. Except for the operational capability objectives, requirements documents are not shown on this vugraph. The qualitative materiel development objective would be prepared here, the advanced development objective here and the qualitative materiel requirement here. (Point)

These procedures insure delineation of responsibilities for and systematic completion of the six Department of Defense prerequisites for contract definition (marked with asterisks) as a part of the concept formulation phase. In following this process we not only justify the system to ourselves, but meet requirements which justify the program to the Department of Defense.

Some of the impact of concept formulation on management is also reflected in this vugraph. A systematic approach in developing broad concepts and refining them to well defined requirements for new equipment shows where Army resources should be allocated for studies, research, and various stages of development. Consequently, efficient concept formulation is central to effective research and development management.

With regard to planning, it was pointed out earlier that doctrinal, logistical, and personnel planning had to be initiated along with hardware planning in order to field materiel systems properly. Many of these plans are prepared by CDC, AMC, and the commodity commands. In addition, both the Department of Defense and Department of the Army have a basic family of plans which guide future strategy and other projected actions, including RDTE objectives.

These plans address the so-called long range - 10 to 20 year period; the mid range - 2 to 10 year period; and the short range - 0 to 2 year period.

There are three joint plans and four Army plans that have a definite bearing on research and development planning. They are listed here.

VUGRAPH 5

The first is the Joint Long Range Strategic Study (JLRSS). This document, prepared annually by the joint staff, addresses the 10 to 20 year future period. It provides a broad strategic appraisal, military concepts, strategies, and guidance to support national objectives. For research and development the plan emphasizes broad operational needs to which the services should direct research and development long range programs. The JLRSS furnishes guidance for developing the operational capability objectives in the early phases of concept formulation.

The Joint Strategic Objectives Plan (JSOP) is prepared annually by the joint staff and addresses the mid range period. It translates national objectives and policies into military objectives, establishes strategy, and provides guidance to support the strategy. Major items of equipment which appear in this plan have the connotation of joint service approval for the required research and development effort involved.

Next is the Joint Research and Development Objectives Document (JRDOD). This is a new document published for the first time this year. It supports both the JLRSS and the JSOP in two ways:

First, by translating the broad strategic guidance concerning operational requirements into long range research and development objectives.

Second, by providing to the Secretary of Defense advice of the Joint Chiefs of Staff regarding the military importance of the research and development effort considered essential to support the national military objectives and strategic concepts.

The four Army plans with research and development implications are the Basic Army Strategic Estimate, the Army Strategic Plan, the Army Force Development Plan, and the Army Research Plan.

The first is the Basic Army Strategic Estimate (BASE). The BASE, prepared annually, addresses the 2 to 20 year future period, and provides the strategic estimate and concepts for all Army plans as well as the Army position for all joint plans. It is the basic document for the Army family of plans. The BASE is written against estimates provided by the intelligence community and the Army Long Range Technological Forecast (LRTF).

Next is the Army Strategic Plan (ASP). The ASP, prepared annually, addresses the 2 to 20 year future period with emphasis on the 2 to 10 year period. It records Army objectives, forces, and deployments for execution of the strategic concepts of BASE, as modified by portions of the JSOP. The ASP provides reasonably attainable objectives and a broad force structure to implement the strategy. For the 2 to 10 year period it provides a basis for developing the objective forces recommended in the JSOP. Long range research and development guidance in the ASP, beginning with the 1967 edition, will include statements of selected operational capability objectives (OCO) and a listing of technologies requiring emphasis if the OCO are to be realized. Mid range research and development guidance will include a listing of major materiel requirements supported, or about to be supported, by development actions.

The Army Force Development Plan (AFDP), prepared annually, addresses the 0 to 20 year future period, with emphasis on the 0 to 10 year period.

The AFDP establishes forces to be supported, basis of issue, program guidance, and guidance for procurement and introduction of modernization items. It, therefore, provides a basis for Army input into JSOP. An important portion of the AFDP is Chapter V, which projects the introduction of modernization items. Equipment that has gone into engineering development as a result of Army concept formulation procedures is reflected in that chapter by line item, estimated type classification date, and desired phase-in period.

The Army Research Plan (ARP), prepared by OCRD, provides guidance to the research and exploratory development programs to insure that they are responsive to the long range concepts and materiel objectives of the future.

These plans are interrelated as shown here.

VUGRAPH 6

Office Chief of Research and Development has made a significant effort during the past year to get the research and development portions of these plans aligned with each other. The goal has been to get objectives and specific systems reflected in their proper time frame and development sequence and to avoid excessive overlaps and duplication in reflecting research and development activities and requirements.

The joint and Army families of plans and the various steps of concept formulation are mutually supporting. The strategic long range plans provide guidance for design of the future land combat system and development of operational capabilities needed by that system. The Army Research Plan translates these needed capabilities into specific research and development goals for the early portions of concept formulation.

Later, the refined requirements appear as specific systems in the AFDP, as the latter stages of concept formulation are completed and the systems enter engineering development.

The flow of guidance between plans and concept formulation activities is not a one-way street. The feedback from the various research and development activities and breakthroughs achieved during concept formulation enable planners and managers to adjust their objectives and establish new operational requirements based on updated technology. A good management information system is essential to a dynamic research and development program.

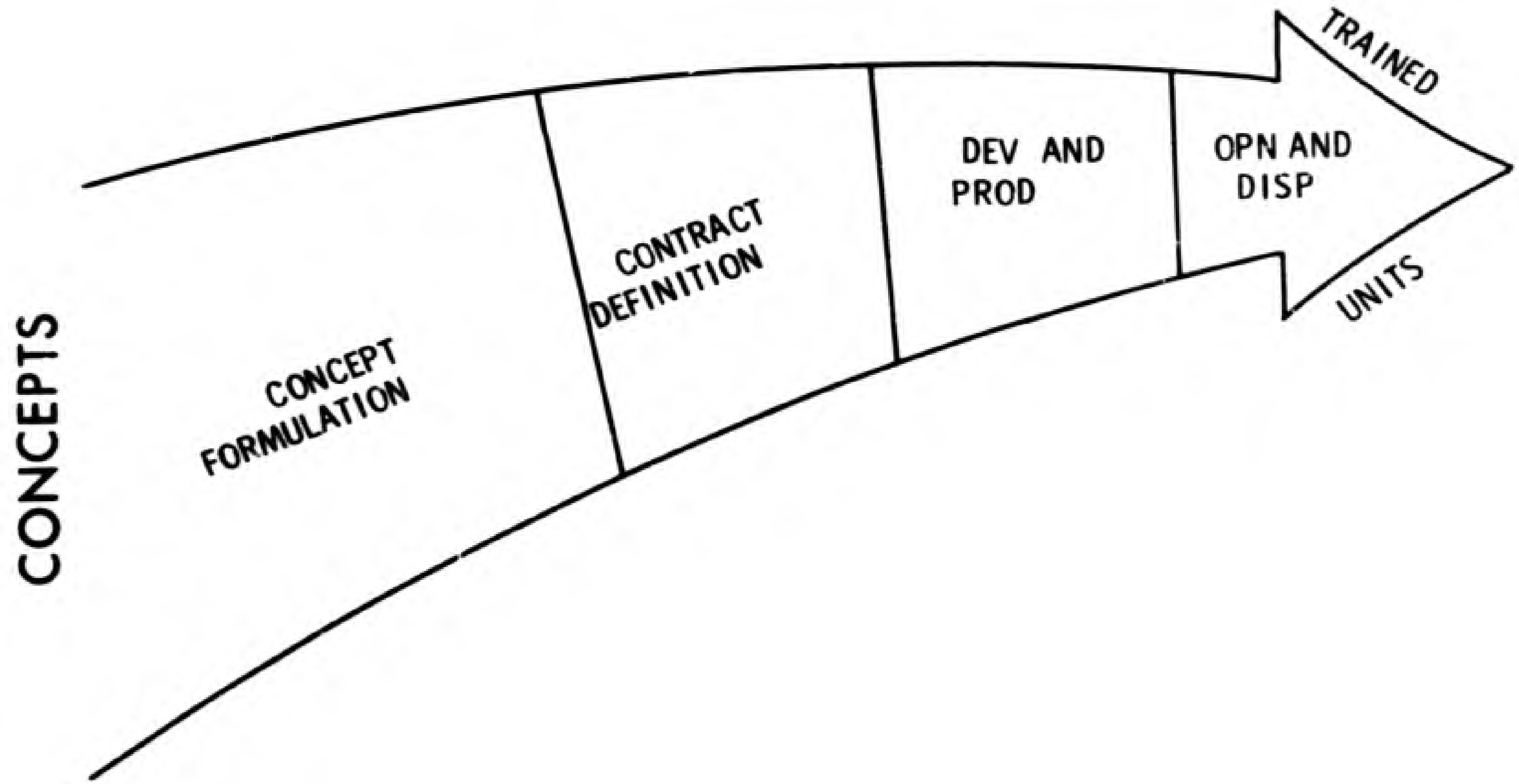
In summary, this presentation has covered the definition of concept formulation, its place in the materiel life cycle, and some of the more important actions essential to the systematic refinement of ideas into credible statements of military requirements before progressing into engineering development. In following an orderly approach to concept formulation the Army justifies a needed system to itself and to the Department of Defense. The disciplined management system which is our continuing goal enables the combat developer, materiel developer, and higher headquarters to do planning and management of the RDTE effort more effectively.

On-going activities and those projected for the future recognize the importance of concept formulation in the materiel life cycle and illustrate why its role can be appropriately described by the term "increasingly prominent." Efficient concept formulation is a key element in planning and managing an imaginative research and development program which will keep the future Army modern.

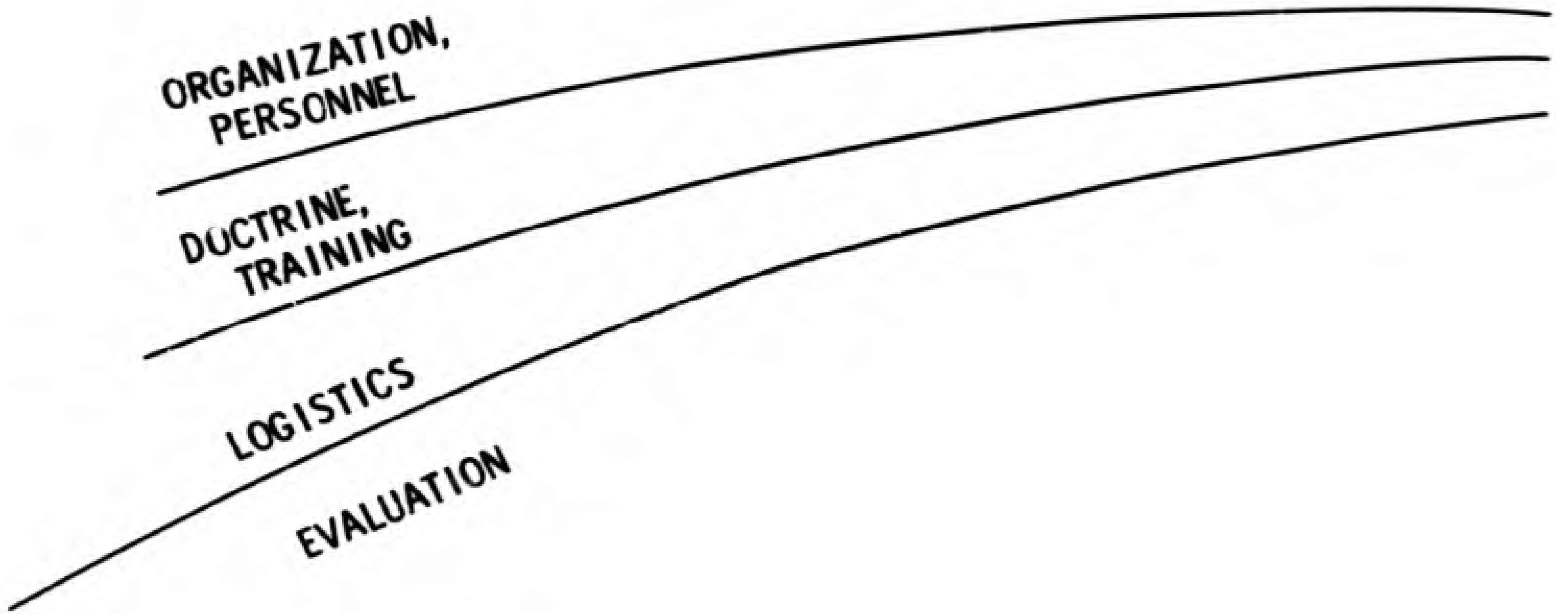
CONCEPT FORMULATION:

EXPERIMENTAL TEST, ENGINEERING, AND ANALYTICAL STUDIES AND OTHER ACTIVITIES WHICH PRECEDE ENGINEERING DEVELOPMENT OR OPERATIONAL SYSTEMS DEVELOPMENT AND PROVIDE TECHNICAL AND ANALYTICAL BASES FOR A DECISION TO INITIATE DEVELOPMENT OF THE ITEM OR SYSTEM.

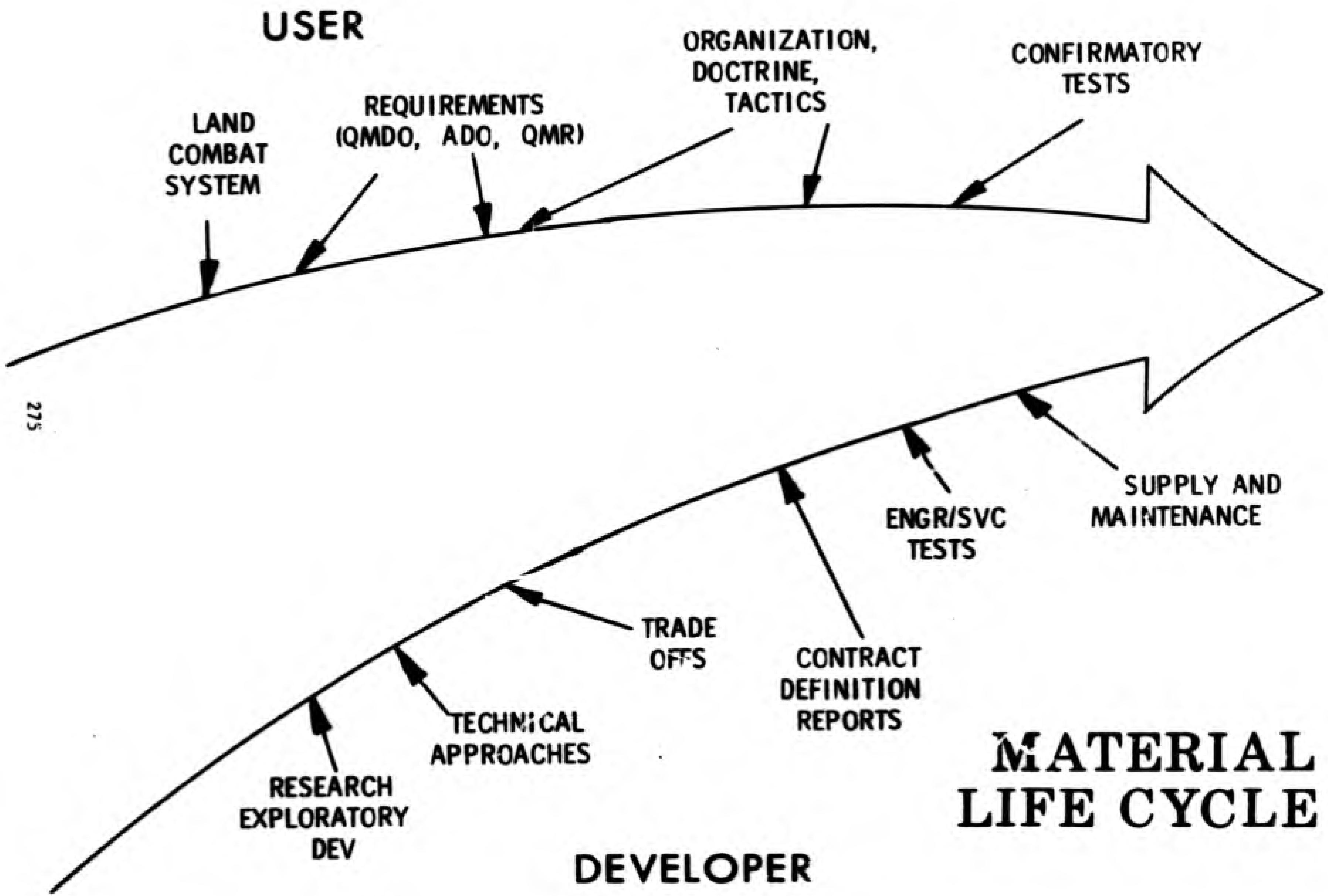
Vugraph 1


CONCEPTS
CONCEPT FORMULATION
CONTRACT DEFINITION
DEV AND PROD
OPN AND DISP
TRAINED
UNITS

Vugraph 2


ORGANIZATION,
PERSONNEL
DOCTRINE,
TRAINING
LOGISTICS
EVALUATION

FLIP 1


USER
LAND COMBAT SYSTEM
REQUIREMENTS (QMDO, ADO, QMR)
ORGANIZATION, DOCTRINE, TACTICS
CONFIRMATORY TESTS
SUPPLY AND MAINTENANCE
ENGR/SVC TESTS
CONTRACT DEFINITION REPORTS
TRADE OFFS
TECHNICAL APPROACHES
RESEARCH EXPLORATORY DEV
DEVELOPER
MATERIAL LIFE CYCLE

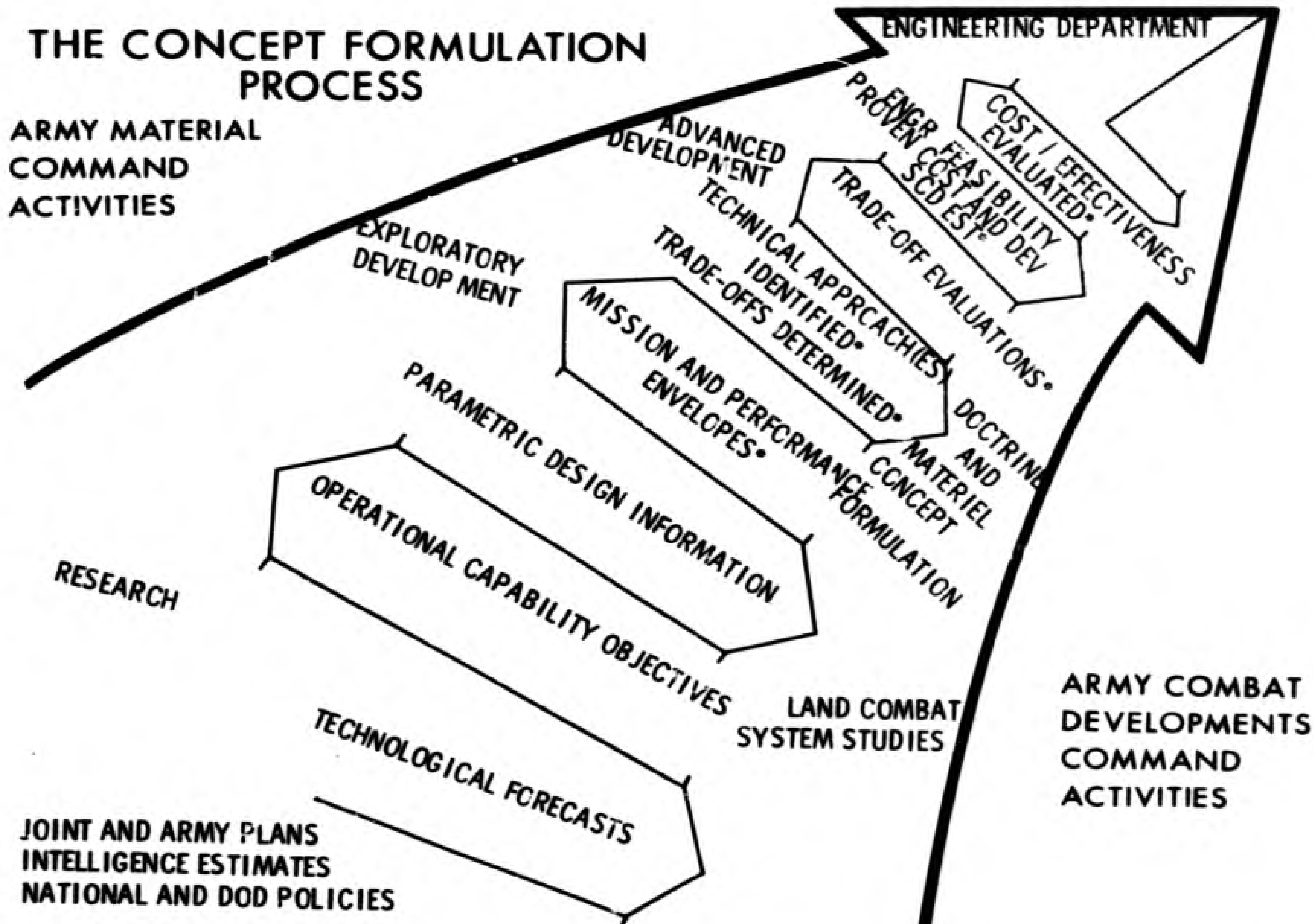
FLIP 2

PREREQUISITES FOR CONTRACT DEFINITION

1. ENGINEERING RATHER THAN EXPERIMENTAL EFFORT REQUIRED
2. MISSION AND PERFORMANCE ENVELOPES DEFINED
3. BEST TECHNICAL APPROACHES SELECTED
4. THOROUGH TRADE-OFF ANALYSES COMPLETED
5. COST EFFECTIVENESS DETERMINED
6. COST AND SCHEDULE ESTIMATES CREDIBLE AND ACCEPTABLE

Vugraph 3

THE CONCEPT FORMULATION PROCESS

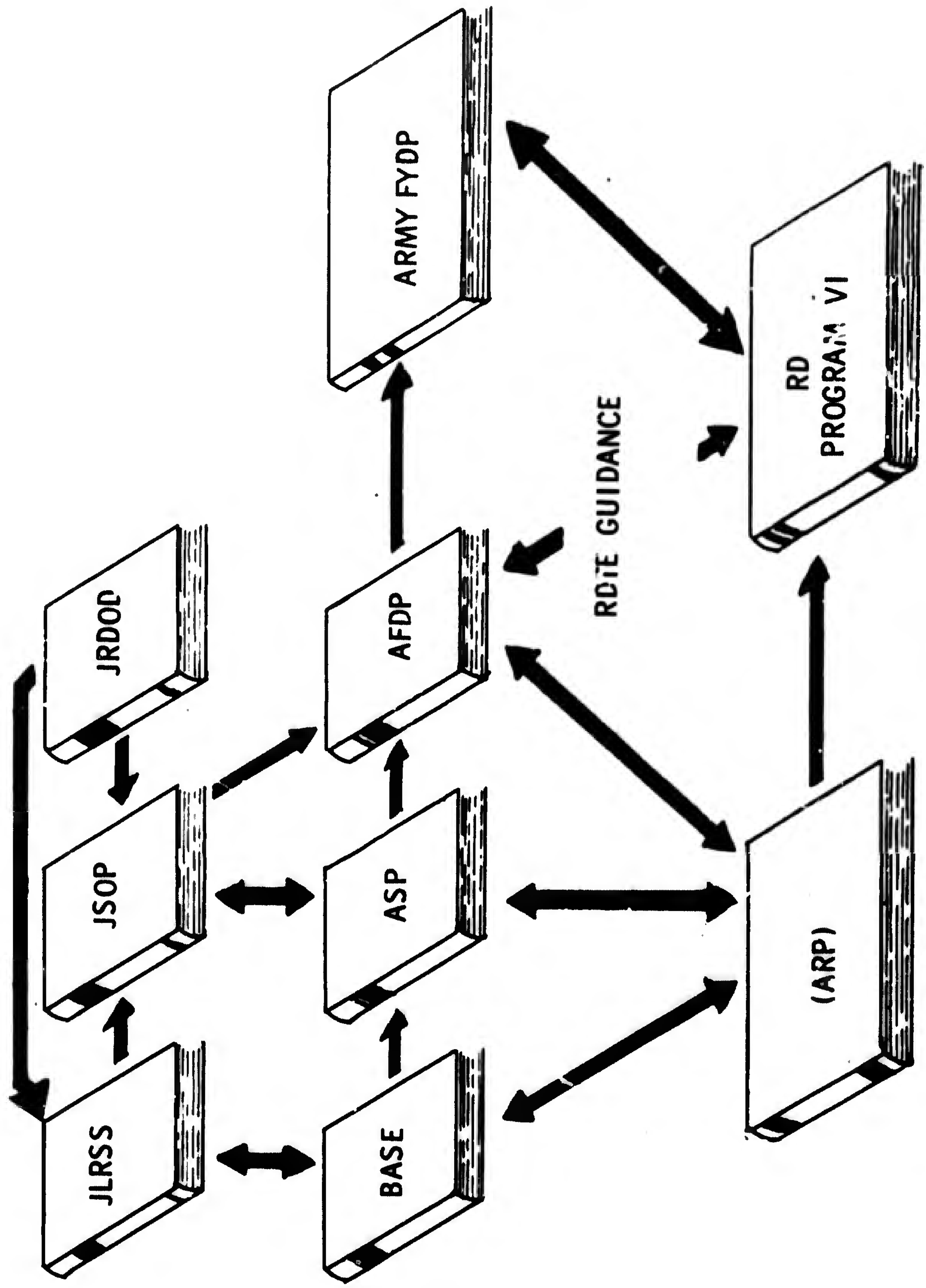


Vugraph 4

JOINT AND ARMY PLANS

- JOINT LONG RANGE STRATEGIC STUDY (JLRSS)
- JOINT STRATEGIC OBJECTIVES PLAN (JSOP)
- JOINT RESEARCH AND DEVELOPMENT OBJECTIVES DOCUMENT (JRDOD)
- BASIC ARMY STRATEGIC ESTIMATE (BASE)
- ARMY STRATEGIC PLAN (ASP)
- ARMY FORCE DEVELOPMENT PLAN (AFDP)
- ARMY RESEARCH PLAN (ARP)

Vugraph 5


JRDOD
JSOP
JLRSS
AFDP
ASP
BASE
ARMY FYDP
RDTE GUIDANCE
RD PROGRAM VI
(ARP)

Vugraph 6

CONCEPT FORMULATION STUDIES OF MECHANIZED INFANTRY COMBAT VEHICLES

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The Mechanized Infantry Combat Vehicle, 1970, Parametric Design - Cost Effectiveness study was conducted by Cornell Aeronautical Laboratory, Incorporated, for the U. S. Army Materiel Command during the 9-month period from 1 October 1965 to 30 June 1966.

The purpose of the study was to provide an information base which would help the Army select the most promising MICV-70 design concept or concepts for further development.

To this end, we attempted to develop and apply means of systematic discrimination among alternative concept designs on the basis of design trade-offs, combat effectiveness, and cost-effectiveness.

Study Structure

(CHART 1)

This chart shows the overall structure of the study. The areas of major endeavor are color coded -- red encompassing the effectiveness evaluations; blue the vehicle design studies; green the costing effort; and yellow the analyses of cost effectiveness and vehicle design results, which constitute the final bridge to the study conclusions and recommendations. The study proceeded concurrently in the red, blue, and green areas and then culminated with the yellow colored effort.

In the effectiveness evaluation studies - red area - the design of the effectiveness evaluation method included computer simulations of battalion-level battles and direct mathematical analyses of combat situations that did not have to be examined by simulation. The computer simulations began with a pilot program to test and de-bug the effectiveness evaluation structure and to learn enough about the simulation program to permit us to proceed logically and systematically. Information from these games, plus vulnerability data on each MICV concept provided by the U.S. Army Ballistics Research Laboratories, and data from our vehicle design studies, permitted us to conduct a second series of games in which actual candidate MICV concepts were played in the combat simulations.

The vehicle design studies - blue area - examined in separate sub-studies the parametric and non-parametric features of MICV designs, and made a comparative analysis of the characteristics of the 49 candidate MICV-70 concepts that had been designed by industry and the Army - and of the 5 existing "reference" vehicles - against the specifications of vehicle design and performance which were contained in the Army Tentative Operational Characteristics for the MICV-70. The Cost studies - green area - proceeded in close association with the vehicle design efforts to collect cost data, devise the costing method, and to estimate the costs of the candidate concepts. Finally, outputs of the red, blue and green efforts were combined in the analyses to determine cost-effectiveness results, and to arrive at the study's conclusions and recommendations.

Vehicle Design

The vehicle design studies attempted to illuminate the basic design relationships among the major physical characteristics of MICV type vehicles. They had a dual orientation -- the vehicle design investigations and the parametric design studies.

In the vehicle design investigations our intent was to identify the non-parametric features of MICV designs and to define the merits and demerits of each so as to highlight the implications of various design choices. This particular effort encompassed semi-quantitative and qualitative considerations that were important to MICV design but could not be dealt with by either the effectiveness evaluation or the parametric studies. As an example, the effectiveness evaluation and parametric studies could indicate how much power a MICV should have, however, that power could be provided by any of a number of different types of power sources. A most appropriate choice among these would involve weighing the advantages and disadvantages of each. The vehicle design investigations assembled and analyzed a considerable amount of information on such sub-systems and components as engines, transmissions, suspensions, ballistic armor, armament and accessories.

The parametric design studies were directed at the parametric features of MICV designs, such as armor thickness, power-to-weight ratio, and primary armament types. Their purpose was to define and quantify the basic relations among such features, and to use these relations to examine the implications of parametric design changes on resultant vehicle characteristics such as weight, cost, and swimming ability.

An indispensable source of data for these studies was the set of 49 candidate designs that were furnished to us. Although not a deliberately varied parametric set they represented well the spectrum of potentially useful MICV-70 designs, and provided a broad base of alternatives. Five existing vehicles augmented the body of information contained in the concept designs with data of a "harder" variety; they were the two versions of the M-113 APC, both MICV-65 configurations, and the Federal Republic of Germany's RU-6 Schuetzenpanzer.

The initial effort of the parametric design studies was to develop mathematical equations defining the main aspects of a MICV design in terms of vehicle design parameters. Three sets of such equations were developed. One set defines vehicle gross weight and major sub-system weights in terms of such parameters as power-to-weight ratio, vehicle volume, mean armor thickness, and crew capacity. A second set similarly defines the principal components of the vehicle volume, and the third set defines the principal vehicle dimensions in terms of each other and of weights and volumes. These equations permit the manipulation of vehicle design parameters to examine quantitatively the design implications of various parametric choices. They were used to synthesize a number of different MICV designs, in order to illuminate the impact on design of varying certain key vehicle characteristics. First we synthesized a family of vehicles that incorporated all possible combinations of two levels of main armament firepower, power to weight ratio, and mean armor thickness, in each of the three sizes (crew capacities) specified by the Army; this family was also used to examine different types of armor materials and the effects of requiring a design to swim. Later, as the first results of the effectiveness evaluations became available, we used them to focus our attention on the most promising design concepts, and we then made more detailed parametric examinations of similar concepts.

The results of the parametric design studies indicate the effects of selecting various combinations of performance parameters on such derivative characteristics as size and weight (and thus cost).

I mentioned earlier that the concepts were compared with a set of tentative operational characteristics. These were of the Qualitative Material Requirement variety, and were quite detailed. Our comparison dealt with 31 characteristics relating to the five combat functions and to vulnerability, and were presented in matrix form indicating the degree to which each concept met or failed to meet the tentative specification for each characteristic.

Effectiveness

The purpose of the combat effectiveness evaluations was to compare the relative contributions of various MICV designs to the using infantry unit's success potential in each of a spectrum of representative combat missions. MICV concepts were evaluated in two basic roles: armored mobility for attacking and withdrawing infantry units, and providing supporting direct fire for assaulting and defending dismounted units. Two types of evaluation methods were used, computer simulated battles and mathematical analysis.

(CHART 2)

Environments in which effectiveness was analyzed by separate mathematical sub-studies are listed on this chart. These environments were not included in the computer simulations because it was felt that there would not be enough interaction between their effects (on relative effectiveness) and the effects of other influences represented in the simulations to warrant the attendant complexity.

The nuclear sub-study was concerned with the question of designing protection against the effects of nuclear weapons into a MICV. It did not attempt an appraisal of each candidate's contribution to success in a nuclear battle environment, primarily because adequate data were not available for assessing the differences between individual candidate vulnerabilities to radiation effects. The sub-study examined box-like hulls made of combinations of radiation attenuating materials similar to those examined in earlier work on the MBT-70, and indicated the trade-offs between radiation protection and gross weight. Both initial weapons effects and residual effects were examined; for example, calculations were made of the added "stay time" in fallout areas that could be achieved with increased radiation protection.

The chemical and biological sub-study was restricted to analysis of advantages and disadvantages of the various available means of protecting MICV occupants against the effects of these environments.

The aircraft attack sub-study examined the question of MICV vulnerability to low-level fighter attacks of various types and quantified the variations in candidate vulnerability that could be expected.

The area defense sub-study was concerned with those aspects of the use of MICV in area defense situations that could affect their relative contributions to the success of their units. A major portion of this sub-study dealt with the anti-personnel effectiveness of various types of main armament weapons.

The artillery and mines sub-study examined the potential gross vulnerabilities to these weapons of the spectrum of the MICV types examined in our study and the amounts of variation that could exist among candidates.

The combat situations that were simulated in computer-played battles included mid and low intensity attacks, with and without tank support, and a delaying action. Soviet, Chinese Communist, and North Vietnamese forces were used as enemies in appropriate terrains. The next chart shows the battle environments selected.

(CHART 3)

More than one type of attack was played in some of these environments. These simulations were conducted on a specially modified version of the PACS II model that the Stanford Research Institute had designed for the Army's Combat Developments Command Experimentation Center; as modified for this study it is now called GLOBAL. It is a time-step Monte Carlo model of a battle between moving elements attacking or withdrawing from opposing stationary elements, and simulates the action of direct fire weapons in considerable detail.

(CHART 4)

This chart shows the terrain variations included in the simulation. Actual intervisibilities between each enemy weapon position and each point on each attacking vehicle's path were determined from map and aerial photo study and used in the simulation.

Four distinctly different levels of intervisibility were played:

- Terrain in Central Korea which had very restricted visibility at all ranges.
- Terrain in S. Germany (in Grafenwohr) which was very open at short ranges, partially restricted at medium ranges and did not permit much visibility beyond 2000 meters.
- Terrain in Vietnam which had few restrictions to visibility at short and medium ranges but considerable restriction at longer ranges.
- Terrain in N. Germany which provided very few restrictions to visibility up to about 3000 meters.

Three levels of surface conditions were employed: Dry, meaning normal mobility conditions for the area concerned; Wet, meaning reduced mobility conditions for that area; and Rough, meaning a terrain surface primarily affecting vehicle vibration and thus the accuracy of weapons fired while moving. These three levels of surface conditions were represented in the simulation by changes in vehicle speed and weapon accuracy, as appropriate.

The effectiveness measures used in such an evaluation as this one are critically important to the study's usefulness. Our primary consideration in selecting and recommending to the Army the measures that were used was that they must indicate the size of the contribution made by each MICV design to the potential success of the infantry unit, at least in relative terms. The effectiveness measures employed in tha battle simulations are shown on the next chart.

(CHART 5)

The basic measure was the force ratio, which indicated the relation between: the number of friendly infantry who were delivered in fighting condition to a point "a" from which they could assault an objective, and the number of enemy personnel who survived to resist that assault when the infantry reached point "a". The number of men remaining on each side at any point in a particular simulated battle is influenced by the characteristics of the MICV design used in that battle. Its firepower both reduces the number of enemy defenders who survive and inhibits the enemy's fire against MICV; its mobility determines the amount of time the enemy has available to fire at the MICV; and its vulnerability determines the amount of damage to MICV which results from enemy fire. Its crew capacity determines the number of MICV in an infantry unit, and thus the amount of MICV firepower employed in the battle, i.e., the number of friendly infantry who are immobilized by a MICV kill (and thus left out of battle) and the number of MICV that the enemy weapons must try to kill in the time they have available to fire. Thus "force ratio" derives from the major factors in a MICV design which can influence the combat effectiveness of the unit equipped with that vehicle, and is a direct indicator of the success potential of a unit equipped with one type of MICV relative to its potential when equipped with another type.

Force ratios were calculated at four points in the MICV advance: at 500, 300, and 100 meters from the enemy position and at the forward edge of that position, so that force ratio comparisons between MICV types could be made at any of these points which might be considered a suitable location for the initiation of a dismounted assault.

The number of personnel casualties sustained at any point is smaller than the number of men who were not delivered to that point, because some of the latter would be unwounded but simply left behind. This expected number of real casualties was furnished as an indicator of relative attrition of the force because of the impact of such attrition on further operations. These numbers of casualties were quite small, and about equal, in the case of all vehicle concepts whose force ratios were competitive, so they did not prove to be a useful measure of relative effectiveness.

The forces employed on both sides, and the force ratios that existed at the beginning of the battles are shown on the next chart.

(CHART 6)

U.S. attacking forces were of mechanized infantry battalion size, in some cases reinforced by a company of MBT-70 tanks. The U.S. force withdrawing in the delaying action was a mechanized infantry company. The enemy forces defending against the U.S. attacks were of approximately infantry company size; they were organized and equipped as estimated by U.S. Army intelligence for the 1970 time frame. The Soviet forces were of motorized rifle type and were reinforced by tanks.

The initial force ratios were, as stated earlier, ratios between the men on each side who would be opposed to each other in the final assault on the enemy position. The differences in these man-ratios of course reflect the differences in the weapons with which the various hostile forces were equipped. Only the men who would normally dismount to fight were counted in the U.S. Force, driver and gunner being assumed to remain with the vehicle. Thus a 6-man MICV transported 4-men who would dismount to fight and a 12-man MICV 10, and it took 2 1/2 times as many 6-man MICV to transport the same assault force. The overall strength of an infantry unit equipped with 6-man MICV would therefore be larger than that of a unit equipped with 12-man MICV, but their starting force ratios were the same.

These battle simulations were conducted in two phases, the first of which, called the Pilot Phase, was exploratory in nature. It was conducted prior to the availability of vulnerability data on the candidate designs, so we used hypothetical vehicles whose vulnerabilities could be readily calculated by BRL (the vulnerability data required by the model had to be derived from a BRL output of over 10[illegible] different probability values per candidate, and production of these data required very large expenditures of BRL effort). A set of 1[illegible] vehicles was synthesized by the parametric design team incorporating variations in firepower, mobility, vulnerability, and crew capacity. These designs were played through the situations both to test the situations and to get a first general picture of the way effectiveness varied as these vehicle parameters varied in each situation.

The second phase of the computer simulations examined the actual MICV candidates and produced the effectiveness data used in cost-effectiveness calculations. The first portion of this phase was the examination of a large number of candidates in a limited number of situations - a screening operation. Results of the analysis of these games permitted selection of a group of six candidates and three reference vehicles for more thorough evaluation in a selected set of eight different battle situations. The 72 games contained in this final portion (each of which was replicated five times and the results averaged) consumed more than 100 hours of running time on a Burroughs 5500 computer. The complexity of these simulations can also be indicated by the fact that a large number of computer runs utilizing three different programs were used in producing input data for the simulation model, and the total number of computer punch cards used in the evaluation was over 300,000.

Although the set of MICV candidates used in the evaluation - 49 concept designs and 5 existing vehicles, as mentioned earlier - did not constitute a parametric set, they did represent a more than adequate spectrum of combinations of vulnerability, mobility, and crew capacity variations. It was possible for us to vary main armament firepower in each of these at three levels. The evaluation could therefore identify the effects on the effectiveness measures of variations in four major parameters: vulnerability, mobility, firepower, and crew capacity. The purposes and procedures of the analysis of the effectiveness output data in these games are summarized briefly on the next chart.

(CHART 7)

The first two steps point up the relative character of the effectiveness evaluation, which compared candidates with each other rather than with some arbitrary standard. The grouping of candidates further reflects the degree of statistical confidence which could be attached to the outputs, in that very small differences could not be considered useful. The third step enabled the fourth to be made; these impacts or effects were of course the primary output of the computer simulations. The comparison of different situations also provided useful information as did the analysis of such special considerations as the effects of MBT use on MICV survival and of different MICV designs on MBT survival.

<u>Cost</u>

Before discussing the cost/effectiveness analyses I shall briefly describe the cost studies. These studies were aimed at the estimation of procurement costs for all candidates and of complete program costs for the set of MICV-70 candidates which was evaluated in the final group of tactical situations. To this end the cost of the total program of vehicle development, procurement, and use was subdivided into the four major functional areas shown on this chart.

(CHART 8)

The cost estimations for all functions of the program are intended to permit a comparison of costs for the various concepts that are inherent in their differing physical characteristics. Cost items included in the RDT&E cost estimates (which this study assumed to be phased over a five year period) were:

Vehicle Development
Construction of 12 Vehicles
Testing and Evaluation
Management, and support from both Army and civilian sources

Advanced Production Engineering was defined to include all effort from engineering of the production model through plant preparation, production planning, and manufacture of the first 10 production models. Our cost estimates for this phase assumed that production would be for five years at the rate of 1000 12-man capacity vehicles a year (or larger numbers of smaller vehicles, so as to provide equal total assault troop carrying capacity). Our Operations and Maintenance cost estimates assumed an average vehicle life expectancy of 7 years and a 1000 miles per year utilization rate for peacetime operations. We attempted to estimate these costs by using detailed cost experience data on generally comparable Army combat vehicles as a basis for estimates of each subordinate cost function and then aggregating these into total costs. The inadequacy of the available data precluded this approach in many areas, and it was necessary to use more approximate methods. However, the overwhelming components of total program cost were procurement and operations and maintenance costs (together amounting to over 90% of the total) and these costs could be estimated with greater accuracy than could those in the other program areas. Combat use costs were also estimated for use in the battle cost portion of the cost-effectiveness evaluations.

Cost-effectiveness

The approach taken by this study in the derivation of cost/effectiveness relationships was to attempt to isolate and relate to each other the combat effectiveness of each MICV-70 concept and its related costs. Two forms of cost-effectiveness figures of merit were derived from the outputs of the computer simulation model; I will discuss the derivation, advantages, and disadvantages of each of them.

(CHART 9)

The Force Ratio-Cost Ratio Figure of Merit, called C_{EM}, equals the Force Ratio (already described to you) divided by the cost ratio. The cost ratio is the cost per battle for a selected candidate divided by the average cost per battle for all candidates that were examined in the same battle situation. Cost per battle is the sum of three significant cost areas: MICV damage, personnel casualties, and main armament ammunition, upon arrival at each of the same points at which effectiveness was calculated. We assumed that the average cost of repairing or replacing a MICV which had been stopped by enemy fire was equal to 25% of its production cost. The estimated cost of a personnel casualty was based on training and survivor benefit costs. This figure of merit is useful for rank ordering candidate cost-effectiveness on the basis of direct attrition (cost per battle), and it is useful for a quick, gross comparison of candidates by use of a single number for each.

A disadvantage is that it would make a candidate having extremely low vulnerability appear to have disproportionately high cost-effectiveness, because its costs would be reduced to the relatively minor cost of main armament ammunition, and thus its cost ratio would approach zero.

Another disadvantage is that C_{EM} does not account for initial investment, and in order to avoid this more serious disadvantage a somewhat more complex figure of merit was derived. Its use required a method of plotting the total of initial investment cost and recurring battle costs so as to produce a gross total cost of using a given type of MICV in a particular type of battle, and while doing so to reflect the relative effectiveness measure attained by that MICV in that battle. The next chart illustrates the plotting procedure used.

(CHART 10)

In this hypothetical case the initial cost of all MICV in this infantry unit is 2 million dollars. The average cost of one battle is 1 million dollars. The force ratio achieved is 2. The line representing the total cost of using this MICV is this unit thus begins at 2 million dollars and increases 1 million dollars while attaining a force ratio of two. Note that the number of battles actually fought is measured along the total cost line rather than along the X axis, which shows total cumulative effectiveness in terms of force ratio times number of battles. The total cost at the end of one battle is 3 million dollars, and in this case will increase 1 million for each succeeding battle of this same type. In order to use this procedure two MICV types must be compared, as in the next chart.

(CHART 11)

Here two MICV types have been plotted, and the point of interest is the intersection of their total cost lines. At this point they have cost the same amount for an equivalent total amount of effectiveness. N_E, the Initial Cost Amortization Figure of Merit, is the number of these battles that the initially more expensive MICV (B in this case) must fight before its total cost becomes less than that of the other MICV (A in this case). If this number - in this case it is 4 battles - is considered to be fewer than the total that this unit should be expected to fight before its MICV become obsolete and are replaced by a newer type, then MICV B will be a less expensive type to own and use than MICV A. The advantage of this figure of merit is that it considers both initial investment and battle costs, and its disadvantage is that it requires a judgement as to the number of battles of each type that a MICV must be expected to fight - however, it should be recognized that the use of other figures of merit also involves the same sort of judgement, whether explicitly or implicitly.

Summary

This has been a very brief description of the highlights of our methodology in examining the feasible design approaches to a mec'ianized infantry combat vehicle, the trade-offs in vehicle characteristics that are inherent in those types of designs, ( ] the effectiveness, costs, and cost-effectiveness that can be associated with them. The purpose of the study was to provide the Army with information in these areas that could be used in conjunction with other considerations in arriving at a final specification of the desired vehicle characteristics, and we feel that purpose has been achieved. The most difficult and time-consuming part of the effort was the effectiveness evaluations. One result of this effort has been our design, as an extension of the MICV study, of a computer simulation model that will facilitate detailed combat simulations of this type; a report describing this SABER model is being delivered to the U.S. Army Weapons Command this week. We at Cornell feel tha' 'udies of this type have a great potential for assisting the users of combat material to insure that their development efforts are accurately aimed at producing what they need with the greatest economy of resources.

STUDY STRUCTURE
MICV-70 D/CE STUDY

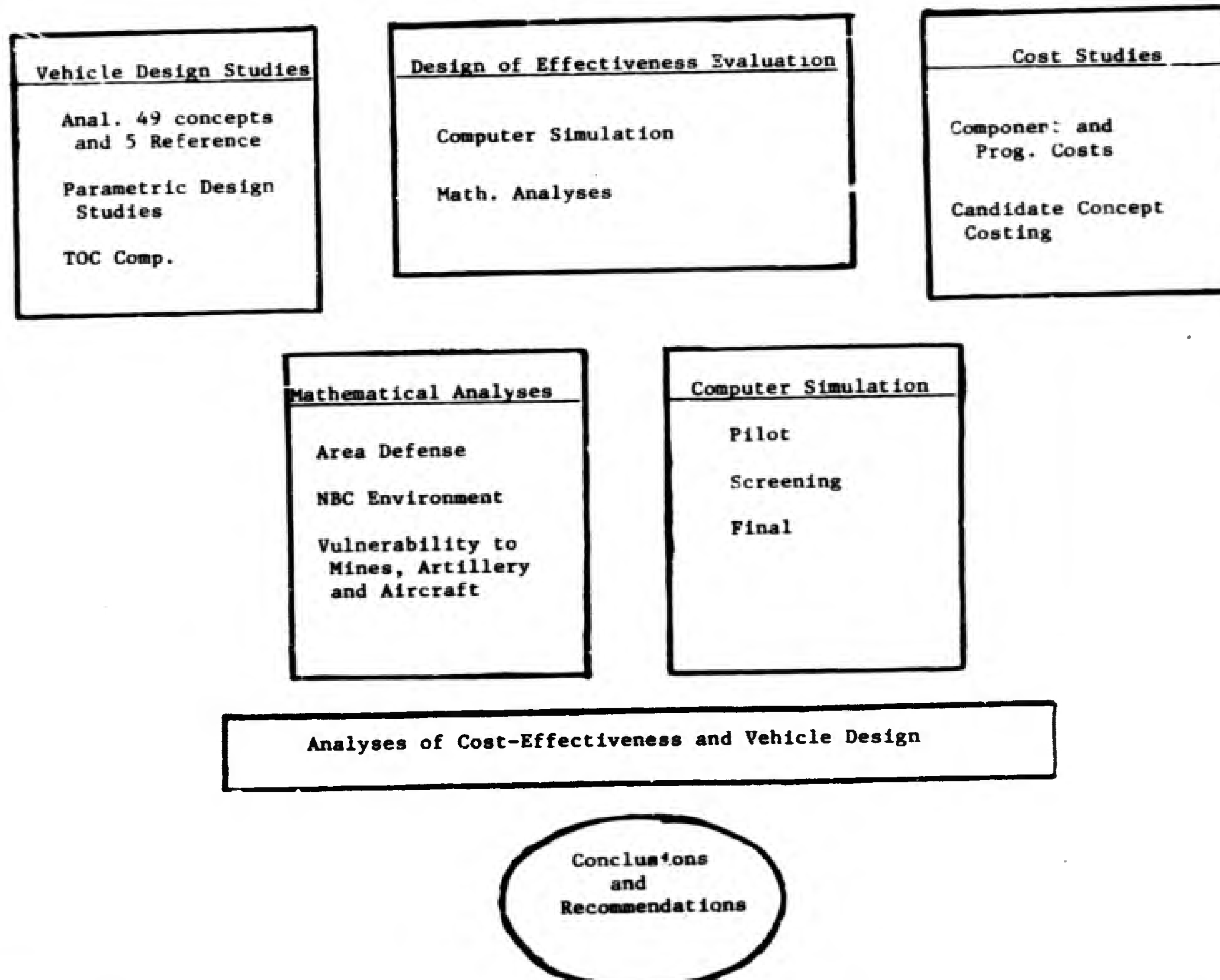


CHART 2

MATHEMATICAL ANALYSES, ENVIRONMENTS, COMBAT EFFECTIVENESS EVALUATIONS

- Nuclear
- Chemical and Biological
- Attack by Aircraft
- Area Defense
- Vulnerability to Artillery and AT Mines

CHART 3

BATTLE SIMULATION ENVIRONMENTS, COMBAT EFFECTIVENESS EVALUATIONS

Conflict Intensity	Geo. Area	Type Enemy	U.S. Force	U.S. Missions
Mid	N. and S. Ger.	Soviet	Inf w/Tk	Attack Delay
Mid	Korea	CCA	Inf w/Tk Inf alone	Attack
Low (Type I)	S. Viet Nam	PAVN	Inf alone	Attack

CHART 4

TERRAIN CHARACTERISTICS
SIMULATED BATTLES

Terrains

4 Levels of Intervisibility

- Restricted at all ranges (Central Korea)
- Few short range restrictions; (S. Germany)
  More at medium ranges;
  Many at long ranges.
- Few short/medium range restrictions; (S. VietNam)
  Some at long ranges
- Few restrictions all ranges (N. Germany)

3 Levels of Surface Conditions

- Dry (Normal Mobility)
- Wet (Reduced Mobility)
- Rough (Reduced Weapon Accuracy)

CHART 5

EFFECTIVENESS MEASURES
FOR BATTLE SIMULATIONS

Force Ratio At Selected Points (FP)

$$FR_a = \frac{\text{No. of US Inf. delivered unwounded at Point a}}{\text{No. of En. defenders unwounded, when MICV reaches "a"}}$$

Vehicle Losses Sustained

Personnel Casualties Sustained

CHART 6

FORCE CHARACTERISTICS
SIMULATED BATTLES

U.S. Force

- Inf. Heavy Battalion Size Task Force } Attack
- Inf. (Only) Battalion Force } Attack
- Inf. (Only) Company Force } Delay

Enemy Force

- Company (-) to Company (+)
- Organization, Equipment, Weapons as Postulated for 1970 Period.
- With and Without Tanks

Initial Force Ratios

- Germany: $\frac{\text{U.S. Force}}{\text{Sov. Force}} = 2$
- Korea: $\frac{\text{U.S. Force}}{\text{CCA Force}} = 1.67$
- Vietnam: $\frac{\text{U.S. Force}}{\text{PAVN Force}} = 1.52$

CHART 7

ANALYSIS STEPS
BATTLE SIMULATION RESULTS

- Rank Order Candidates, Each Situation, by FR.
- Group Candidates, Each Situation, by Approximately Equal FR.
- Correlate Candidate Firepower, Mobility, Vulnerability, Size Class with FR Group.
- Analyze Firepower, Mobility, Vulnerability, Size Impacts on Effectiveness.
- Compare Effectiveness in Different Situations.
- Analyze Special Case Considerations.

CHART 8

MICV-70 COMPLETE PROGRAM COSTS

- Research, Development, Test and Evaluation (RDT & E)
- Advanced Production Engineering (APE)
- Production of Equipment (PEA)
- Peacetime Operation and Maintenance (O & M)

CHART 9

FORCE RATIO/COST RATIO

FIGURE OF MERIT (C_{EM})

$$C_{EM} = \frac{\text{Force Ratio}}{\text{Cost Ratio}}$$

$$= \frac{\text{Force Ratio}}{\frac{\text{Cost per Battle}}{\text{Av. Cost per Battle}}}$$

Where

$$\text{Cost per Battle} = \left[\begin{array}{c}\text{Cost of All MICV Damage} \\ + \\ \text{Cost of All Pers. Casualties} \\ + \\ \text{Cost VRFWS Ammo Exp.}\end{array}\right]$$

And

Av Cost Each Damaged MICV = 25% of that MICV's Proc. Cost

Av Cost Each Pers. Cas. = $3500

CHART 10

METHOD OF PLOTTING TOTAL COST
FOR A NUMBER OF BATTLES WHICH ALSO
REFLECTS EFFECTIVENESS

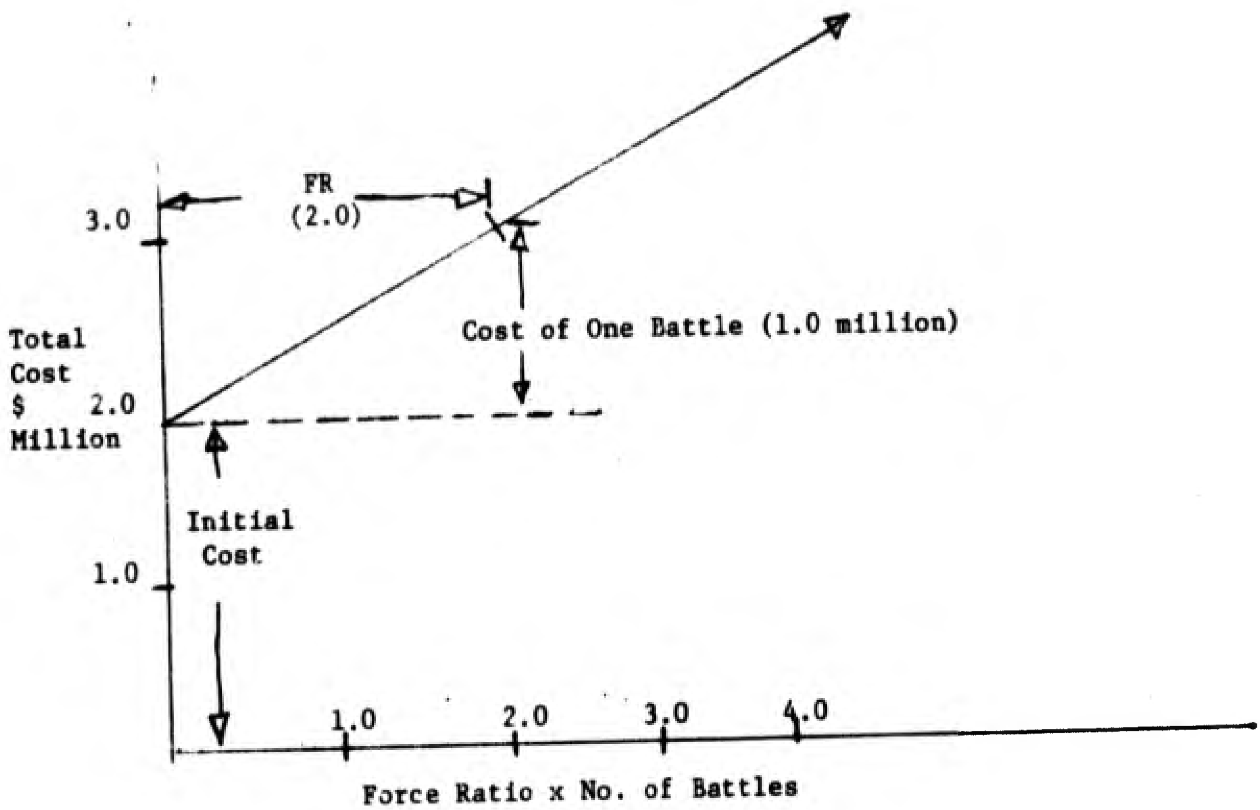
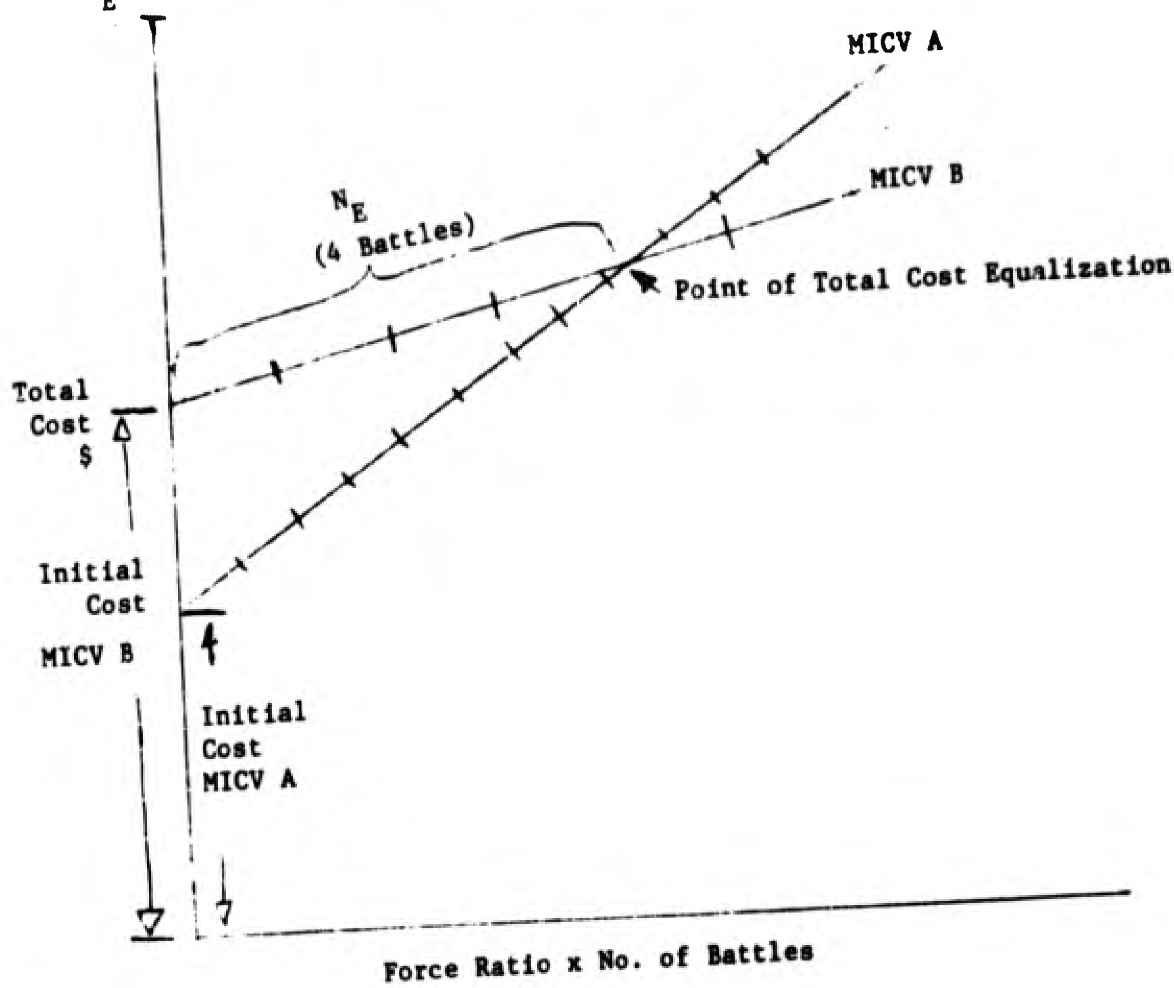


CHART 11

INITIAL COST AMORTIZATION
FIGURE OF MERIT (N_E)

N_E = Number of Battles for Cost Equalization



DIGITAL SIMULATION FOR REAL TIME COMMAND CONTROL OF ARMY LOGISTICS IN THE FIELD

by

MAJOR DANIEL K. MALONE

A large scale digital simulation is proposed which by use of proven OR techniques recreates the logistical real world as a model for real time command and control. The model's feasibility is supported by comparison with successful civilian applications and its viability is supported by echelonment to allow for local command perrogatives.

DIGITAL SIMULATION FOR REAL TIME
COMMAND CONTROL OF ARMY LOGISTICS IN THE FIELD

by

MAJOR DANIEL K. MALONE
US ARMY COMBAT DEVELOPMENTS COMMAND ARTILLERY AGENCY

While Operations Research has won quotidianal recognition in Army research and development, one of the relative newcomers to the OR practitioner's catalogue of methodologies has somewhat lagged the others in its practical application. That methodology is digital simulation.

While we find this technique used in civilian industry for management and control of a variety of processes, its use in the military has been largely to study the potential of various hypothetical organizations, weapons, weapon mixes, and so on, for some future time. These war gamings and such must necessarily sum over many perturbations due (rightly so) to a tactical commander's personal judgment strategies. Yet the world of the logistician, by contrast, is full of boxes and shipbottoms which are readily measurable and of demand and failure rates which, by appropriate statistical methodologies, are at least estimable.

This paper will attempt to show that we have the tools today to establish and use a digital simulation of logistical operations as a tool to facilitate their real time command and control.

SYSTEMS MANAGEMENT AND SYSTEMS SIMULATION

The most subtle, yet perhaps the most crucial, facet supporting this hypothesis has been the on-going evolution of organization theory and its probable extrapolation. Commanders exert control through organizations. If the organization is not modeled on some quantifiable and coherent structure, there can be no coherent simulation.

Today's conceptualization of an organization is, in fact, coherent so far as a computer depiction is concerned. Under the aegis of the systems concept, we have come to accept an organization as a balanced set of inputs and outputs, whose balance is determined by the process which the organization performs and which is kept in balance by some feedback-based control.

This paper solely reflects the views of the author and does not purport to be a position of the represented Army Agency.

Prior to the industrial revolution, before man began to be organized around machines, there was no quantifiable model which would support the kind of simulation we have in mind. Organizations were conceptualized as structures of authority in the ordinary organization chart to which we are accustomed. While these serve the purposes of conceptualizing the archtypical Weberian structure, they are of minimal value for the conceptualization of a simulation of a logistics flow. In fact, this prior philosophy was so singularly people-oriented, that Professor McLuhan might tell us that due solely to our Judeo-Christian tradition, we even blessed the media with putting the boss at the top.

Inevitably, with the evolution of technology, Norbert Weiner's cybernetics in World War II and the writings of such people as Talcott Parsons,[1] Kenneth Boulding,[2] and C. P. Snow[3] caused the traditional model to give way and the systems philosophy to achieve the ascendancy of the times.

But while the pre-industrial theory may be too naive for the problems at hand, the apparent simplicity of the systems concept often makes it too Narcissian. Even though inventory fluctuations have, for example been directly solved by the mathematics of servo-mechanisms,[4] not too much of the real world is expressible as a single set of input, output, processor, and control.

By extrapolation, though, we can see the evolving conceptualization of an organization as a more realistic depiction of a hierarchy of variegated systems, each interrelated to the other, each subject to a hierarchy of controls. We might envision a fleet of trucks and helicopters supplying various deployed units, the fleet in turn supported by a petroleum supply system, maintenance units, more trucks and helicopters bringing spares and repair parts, and so on back to the manufacturing and extractive processes themselves.

Thus, under older conceptualizations of organization, OR applications frequently were limited to a small nodal point of the total process at hand because the process itself was hidden in the media of expression of what an organization was. Today our organizational conceptualization is more aligned to the work process flow itself. Conversely, as we extend our efforts to manage real world circumstances, we find real world organizations themselves being designed towards the theoretical model.

The significance of these organizational perigrinations to digital simulation is that when the technology of computer-based information systems is injected into a real world organization based on the hierarchial conception of systems, a digital model of the real world can be constructed, to any level of detail we choose to measure it.

Further, by the addition of the arithmetic relationships that unite, for example, weight and cube measures of boxes to be shipped with weight and cube capacities of transportation resources, the model can be made dynamic.

Finally, if we use the computer model itself within the control loop, the Commander can easily extend it by furnishing the model hypothesized loads to determine what his related resource requirements would be. At this point, the information system becomes a digital simulation for command and control.

COMING TO GRIPS WITH THE STOCHASTIC ENVIRONMENT OF LOGISTICAL SUPPORT OPERATIONS

True, when we pose the use of a complex information system for the rather pedestrian application of modeling arithmetically related portions of a logistics system, we may be accused of driving a tack with a pile driver. However, this application does have its place and we in the Army should recognize its proven value.

General Electric applied it to a radio receiver production line and reduced the time required to balance the line from three weeks to five minutes.[5] Extended to several feeder lines, their use of digital simulation enabled an increase in stockturn from only six times per year to a full 44 times per year.[6] Even though limited to directly coupled inputs and outputs, such a simulation is not something to be given short shrift.

This is not to say that for logistics management digital simulation is or should be limited to arithemetically related subelements. The logistical realm is populated by stochastically failing equipments, stochastic patterns of demand, and, of course, stochastically occurring combat losses. However, each of the typical examples of, for instance demand patterns, have been identified and solved, individually at least, in civilian OR applications. We have inventory models of Poisson demand with fixed lead times,[7] Poisson demand with gamma lead times,[8] and even models which in the determination of Economic Order Quantities (EOQ) consider the interaction of the various item orders involved, through the use of simulation trials.[9]

Other approaches, such as exponential smoothing, have also proven their worth in typical demand experiences strongly influenced by the sinusoidal meanderings of the economic and business cycle. As shown in Figure 1, these typical situations are demands that fluctuate about a fairly constant average, demands that show an up-trend (or, conversely, a downtrend), that have seasonal or cyclical patterns, and even cyclical with random noise.[10]

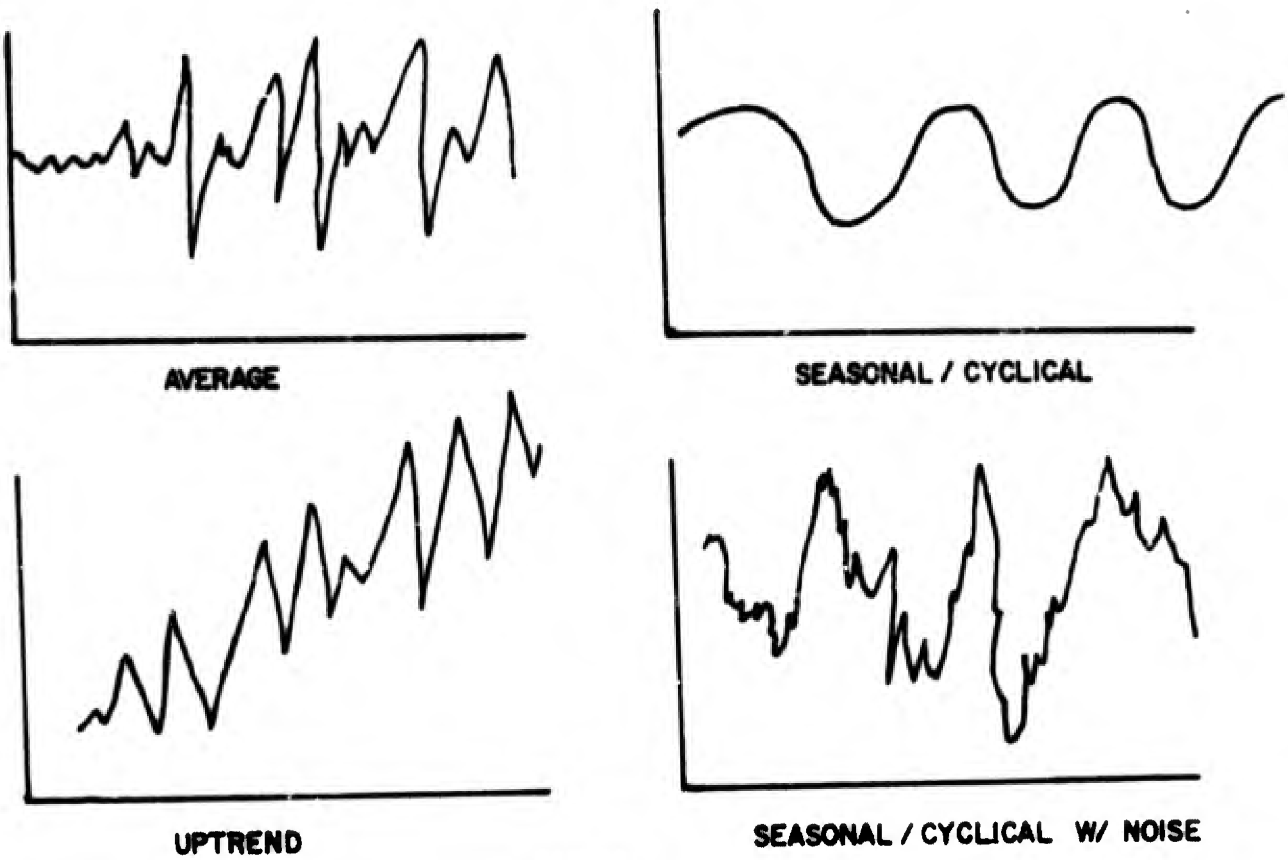


FIGURE 1

These patterns are identical to those encountered in a typical military logistics situation. The up-trend would typify demand during a rapid build-up of forces viewed at any level of organization. The cyclical pattern with noise might be indicative of a long series of limited war/internal stability operations of brief and see-sawing tactical successes, when viewing the economic/logistic operation at the national level. Even secular trends are duplicated in the military in the life cycle of development, fielding, and obsolescence of weapon systems and other assets.

Not only are there existing and proven techniques for measuring, for example, repair parts inventory effects due to end item secular trend, but also military equipment retirement policies are based on a rigidly controlled program rather than the whims of the market place. In short, in inventory theory at least, the preparation of a digital simulation of logistical operations is made feasible by prior successful applications in civilian industry and is made easier because of the increased visibility of possible demand perturbations in what is in essence a controlled military market place.

There is, though, one facet of inventory management emerging which is not usually addressed in inventory management discussions (a result, in fact, of successfully applied OR techniques) which bears careful consideration in the construction of a digital simulation for use in the field.

It is that reliability and maintainability are more and more frequently being treated parametrically in equipment design. First, we establish the

Mean Time Between Failure (MTBF) and the Mean Time To Repair (MTTR) that we want to have, then we design to it. In the past, we would build something, then test it to see how long it would last.

While this approach has been applied largely in missiles and electronics, we find wear-out more and more planned in the tank-automotive and armament areas, too, in such ubiquitous items as batteries, tires, bearings, and the general class of things that have surfaces which fail by friction wear. We meet this phenomenon ourselves whenever we buy tires for our own automobiles, with a guaranteed wear-out period.

What does this cause in the demand pattern? It will appear as in Figure 2, wherein the failures over time are clustered around the planned wear-out date. When viewed in macros, in an inventory model used for management and control at, say, theater level, the relative homogeniety of end item stocks as viewed from that level conceals the pattern in micros. But in a buildup situation such as has recently existed, units are organized and deployed as units, and are equipped with items coming off the production line at relatively the same time. Hence, they may experience a debilitating failure rate at unit level because that unit's equipment will tend to fail at the same time.

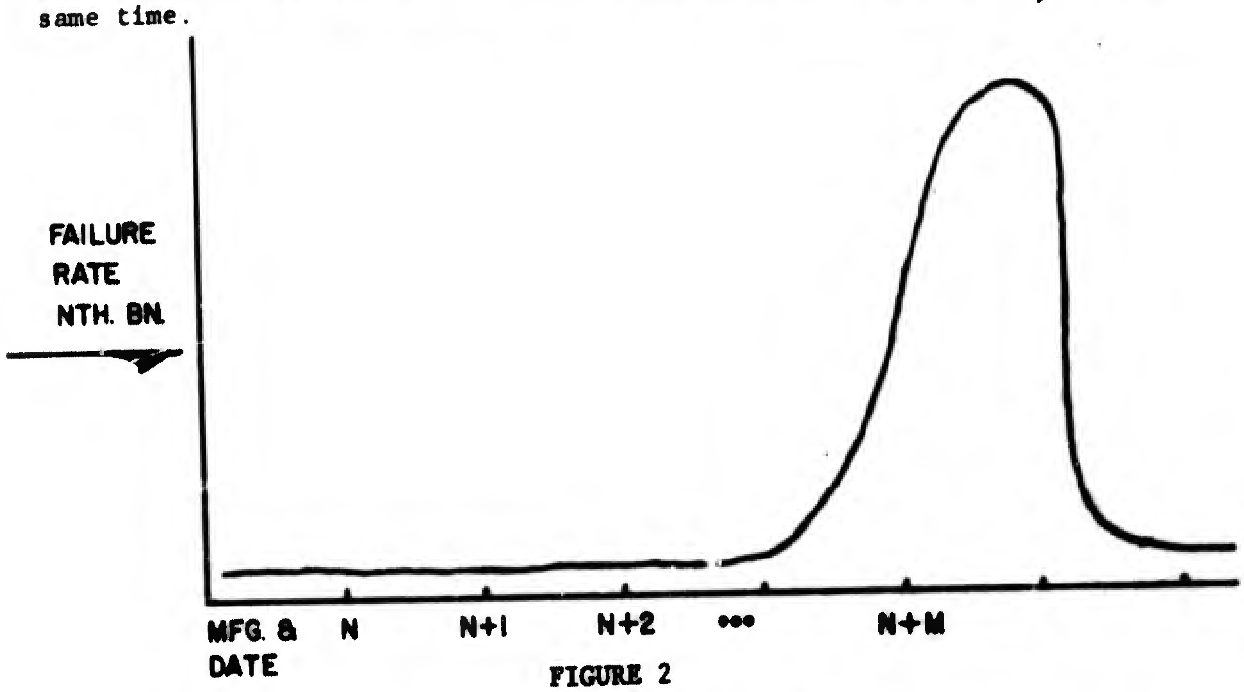


FIGURE 2

We have two options here; viz., to change the model to fit the real world, or, conversely, change the real world to fit the model, which in this case is the general class of OR demand models which assume an underlying homogeniety in the population.

We could perhaps reshuffle equipment among units to obtain the homogeniety usually assumed. In this case, however, we are constrained by the availability of equipment in a rapid build-up situation and the need, for example to have tube artillery of similar age grouped in each battery to eliminate the gunnery computations for severe tube-to-tube variances.

Alternatively, then, we would desire to use our simulation model to:

a. Keep track of the unit and unit location of class-life items such as we have;

b. Alter the appropriate algorithms to sense a rapid change in failure rates or demand (such as is done in some higher order exponential smoothing techniques);

c. Compare the instant experience with a priori predicted behavior;

d. Apply the a posteriori knowledge to update the model; and,

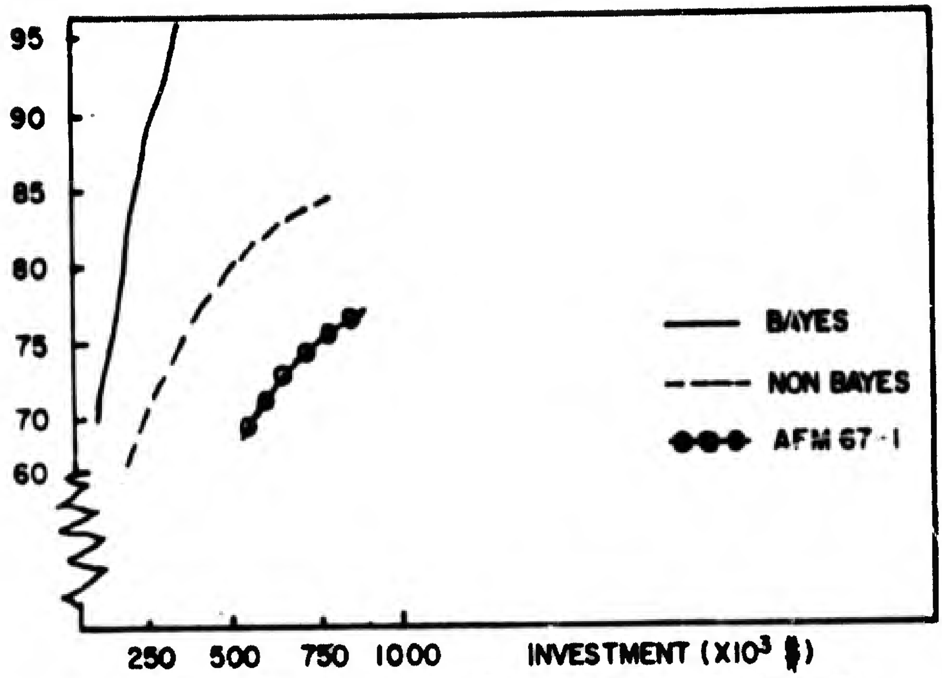
e. Afford translation points to reflect homogeniety at some preselected high echelon to enable orderly procurement.

Needless to say, there is slim chance of providing either the level of accurate detail at unit level or the scope of expansiveness at national levels without the use of computers.

Aside from some short range difficulties in modeling such a demand situation, carefully planned design-to/build-to failure rates specifications offer some interesting possibilities. We once reached a point where we were willing to pay for minimum machining tolerances to buy interchangeability of parts in manufacturing and maintenance. Conceivably, considering the known trade-off between physical inventory and better data to manage it, there may come a time when we are willing to pay for predetermined variance in failure expectancies to buy a better ability to manage our assets.

Aside from this latter idiosyncrasy, however, all of the typical demand patterns descriptive of inventory performance have been identified, analyzed, and practically and tractably solved with OR methodologies. All that remains to achieve a viable digital simulator is to put them together en masse, and of course, marry them to a system capable of doing the supporting computation en masse.

In Figure 3 are displayed the results obtained by a sister service in the application of a RAND-developed model for base management of recoverable spares. The model, fairly large in scope, compares an OR scheme using the systems approach and also a Bayes method to an existing stockage policy.



FILL RATE VS INVESTMENT IN INVENTORY

FEENEY & SHERBROOK, A SYSTEM APPROACH TO BASE STOCKAGE OF RECOVERABLE ITEMS RAND '65 P.27

FIGURE 3

The newer methodologies produced the same fill rate for one-half and sometimes one-quarter the cost of the present method.[11] The present method is akin to the Army method of basing requisitions on a posteriori demand experience, assumed order and shipping times, and retention of empirically determined safety levels.

While these savings are measured here in dollars, these dollars, in the field, measure men, manhours, and other materiel made available for other missions. What is needed is the construction of similar models using fieldable computation equipment, which can provide similar functions in Army logistics.

CONSTRUCTING THE MODEL IN THE FIELD

OR techniques to manage these kinds of problems have been successfully applied for a good number of years. Much effort has likewise been expended to apply classic OR techniques to the specific problems encountered by a Logistical Commander. One Operations Research Group has, for example, prepared a collection of models to be used to assist in logistical planning.[12] Their models include:

a. Dry cargo computation with phased populations;

b. POL computation and apportionment;

c. Casualty and hospitalization programming;

d. Dry cargo apportionment;

e. Network analysis;

f. Airfield construction;

g. Combat roads, tactical bridging, and tactical airfield construction;

h. COMMZ roads;

i. COMMZ railraods.

Department of the Army also uses a simulatbn model, called PROMO, to project procurement requirements for some 700 major end items and their repair parts under various mobilization projections, incorporating as well suboptimization policies between early inventory accumulation and captial investment.[13]

In sum, so far as OR techniques are concerned, enough applicatory work has been done to carve a viable approach to constructing a simulation model for use in the field. The remaining items for consideration are the use of the model after its completion, which reflexively determines much of its specific methodology, and the availability of a data base in the field to support such a model.

The use of the model would be in two general categories; planning and real time control.

For planning, the Commander would want to input such things as anticipated requirements for various classes of supply. In some cases, the quantities are based on number of people. In other cases, the quantities are based on numbers of items times some factor such as in the case of trucks and anticipated mileage. To be most usable, the model would have to accept the elemental item, and compute requirements from thereup.

Outputs desired would be the number of shipfuls of gasoline or tons of cargo or some other measure usable at the level of action concerned. Or, conversely, the process might be the input of gross quantities to yield an output of detailed distribution in loading plan form.

The unique advantages of the simulation approach are the level of detail to which or from which computational planning can be performed and the speed at which this sort of thing can be done. In the summer of 1944, while our armies were moving acorss continental Europe, several potentially significant airborne operations had to be cancelled simply because the ground forces were moving faster than the airborne army could plan.[14] Considering the possible on again-off again environment that can characterize limited war/counter insurgency environment and the increased mechanization and technical complexity of the support of our modern army, the speed and detail manageable with digital simulation of this sort holds indeed many advantages.

A critical question at this juncture is the determination of the echelon of command at which such a simulation should be constructed and used. Assuming an adequate data base, the answer is that each echelon concerned with a given set of resources could profitably use a model which would support decisions for the application of that set of resources. At a given echelon possessing, say, 100 trucks and 50 helicopters, a usable model would, given delivery requirements, roadspace availability, and the like, determine an optimum routing and loading schedule and also determine remaining lift requirements for transmission to the next echelon possessing transportation resources. This approach to echelonment evolves from the notion of a hierarchy of systems in the basic conceptual approach to model construction and hence is a bridge to the use of the model for its second purpose, real time command and control.

The various echelons of the logistics hierarchy, let's say a Division Corps and Army Support Command, are not rigidly interconnected structures. There are instead definable stochastic functions describing their interfaces which perform analogous to the "decoupling" function of inventory separating supply and demand.[15] Inventory, according to John F. Magee, is necessary because it takes time to complete one operation and move to the next and because different parts of an organization need to schedule their activities somewhat independently.[16]

"Inventories" of either actual stocks or of resources "decouple" one echelon from another in the logistical hierarchy of organizations as well. Depending on the size of these inventories, each echelon has the capacity to react to unusual local requirements at certain rates and to absorb maintenance down time, combat losses, and the like. Given this "slack" and an echelonment of models at operations centers in each modeled echelon, a Commander can first plan, then control the conduct of operations.

Most staff work consists of gathering data on available resources and projected demand and then computing its best application. Here the computer provides the data, and with the model, derives the optimum solution. With communications between echelons, requests for support are passed to higher echelons where more resources are available, computation of the best allocation or reallocation is performed, and instructions then issued to the subordinate units involved. In this way, the model projects itself into real time command and control.The hypothesis somewhat evolves, then, from construction of a model using existing OR techniques of inventory theory to estimate demand, queuing theory to assist in routing selection or wharf construction, and so on. Once such a model is constructed, a Commander can use it as an aid in planning.

But once experience factors are obrained for, e.g., demand, and the process is underway, he can use the same model for real time command and control simply by providing real time inputs of, e.g, demand experience, transportation requirement and the like, and using the model as he would a human staff.

APPLICABILITY TO LIMITED WAR/COUNTERINSURGENCY

Two factors intimate the advantages of applying digital simulation in limited war/counterinsurgency:

a. The limited scope of limited war so far as resources are concerned.

b. The advantage of training people to use the technique on a limited basis.

Klauss Knorr, a leading political economist, notes that:

"A technologically superior nation with higher labor productivity will end up fighting on or near a lesser's soil and be forced to transport combat power thereto and use lesser communications therein."[17]

So far as constructing a digital simulation is concerned, this means that the alternative choices of seaports, forward depots, and transportation means are limited, thus simplifying their modeling. Also, just the sheer size of effort in a war such as Vietnam, taking ten percent of our GNP versus about forty percent plus during WW II, results in a lesser confusion in going about it logistically. In WW II, the phrenetic efforts to mobilize and get on with the war led to such things as revising the aircraft production schedule some 212 times in 1944 alone.[18] The materials set aside and subsidiary allocations resulting from such intense change would fantastically complicate the original construction of a digital simulation and strongly hinder its use. This is not to say, of course, there are not severe allocation problems at all, but rather, to intimate that from the raw resources forward there is less confusion and hence more possibility for successful construction and use of a digital simulation in a limited war.

Further, this should not imply that we must begin logistics management with simulation models on an all or nothing basis, even though this discussion of the lesser complications would perhaps invite such a course of action. It is even hard to say what is "all" when it comes to preparing such a simulation. Considering the gold flow problem, for example, we know that due to retention of traditional economic ties with former colonial powers, some of our expenditures in the Orient get back to occidental claimants on our reserves.[19] But we must also ship in some amount of consumer products to, for example Vietnam, in order to offset increased disposable income caused by our in-country dealings. Should we even try to model this to predict the wharfage and lighterage requirements to be set aside? Actually, we can do just as well by judgment, judging what the space set aside should be and basing our model on the remaining capacity.

The second factor, that of training people in the use of simulation, and, for that matter, in the need of accurate data, further indicates the need to start small. True, the injection of computers leads to the accurizing of data, but in situations wherein indigenous personnel are used, problems of handling, e.g., inventory data reading 12 USENOHOOKS and 64 FRAGILES are going to have to be met and bested.

Further, are our people themselves trainable in the use of the technique? OCS, our prime source of officers under mobilization, presently requires only a high school level of education and a GT score of 110.[20] Under a higher level of mobilization, we could expect no increase in requirements.

However, in our professional corps we have a rather large proportion of officers with graduate degrees. The Haines Board, which recently conducted a thoroughgoing study of the Army schooling system, proposed that an Operations Research/Systems Analysis program be formally organized such that captains and majors would be given the opportunity to obtain graduate degrees in OR, and subsequently be assigned in positions where OR might be usable. The Board also proposed that OR be included as an elective area of study at the three upper levels of officer career schooling. This would also afford at least a general exposure to all attendees. Finally, the Board recommended that TD and TO&E spaces be identified as billets requiring advanced degrees in various disciplines, including Operations Research.[21]

Initially at least, the officers involved in these latter programs will be about the only ones capable of really using digital simulation techniques and, especially, of making it usable to a commander in the field. Again, in limited war it will be easier to identify and properly assign such people.

But, limited war or no, both the efficiency of the elemental models and the acceptance of the OR techniques themselves will be measurably enhanced by using small scale applications at first and growing to more inclusive situations later on. Most importantly, considering that several years would be required to establish a really useful model, it would again appear to offer advantages of scale to work to complete a digital simulation of the support of a complete fielded Army force in limited war, so that the skeleton of a simulator for use in a more extended conflict would be available. Extrapolating today's technological complexity into tomorrow, the detail and speed afforded by digital simulation may be a prerequisite to success in another all-out conflict.

In summary, it can be said that since we have in the military logistics environment in the field a set of circumstances that match civilian circumstances in which OR methodologies have been successfully applied we should, with little modification, be able to inject these same methodologies to obtain military solutions. Second, with the data system which will become available to support logistics command and control we have the unique opportunity of building an echeloned simulation model matched to the level of resources of each hierarchical command, and to tie them together. These properties of the environment enable the digital simulation to be used for real time command and control as well as for future planning. Finally, considering the anticipated capability of the personnel concerned, we can profitably begin the undertaking in the relatively limited complexity of limited war.

True, the successful conclusion of such an undertaking is not just around the corner. There are some serious problems in the path, but we should consider the task in the light of these words by Jenkin Lloyd Jones:

"The vision of things to be done may come a long time before the way of doing them becomes clear, but woe to him who distrusts the vision."

FOOTNOTES

1. Talcott Parsons, "The General Nature and Functions of Systematic Theory," Readings in Management, ed. Koonty and O'Donnel (New York: Mc-Graw Hill Book Co., Inc., 1959).

2. Kenneth Boulding, General Systems Theory, "The Skeleton of Science," Management Science, (April 1956), p. 197.

3. C. P. Snow, the Two Cultures and the Scientific Revolution, (London: Cambridge University Press, 1959).

4. Daniel Orr, "A Random Walk Production - Inventory Policy: Rationale and Implementations," Management Science (October 1962) p. 108.

5. Melvin Salveson, "Computers for Decision Making," AMA Management Bulletin No. 30, 1963, p. 39.

6. Ibid.

7. Hadley and Whiton, "A Family of Inventory Models," Management Science (July 1963).

8. Ibid.

9. Dzielinski et. al., "Simulation Tests for Lot Size Programming, Management Science (January 1963), p. 229.

10. Brown, Harvard Business Review, July 1959, p. 105ff.

11. Feeney and Sherbrook, A System Approach to Base Stockage of Recoverable Items, RAND Corporation, Memorandum RM 4720-PR, December 1966, p. 31.

12. Research Analysis Corp., "Computer Assisted Logistic Planning Program Descritpion, TM RAC-T-431, McLean, Va., January 1965.

13. Letter, Hq DA, AGAM-P(M), 22 January 1964, subject: Procurement Mobilization Model.

14. James A. Huston, The Sinews of War: Army Logistics 1775-1953, p. 528.

15. John F. Magee, Production Planning and Inventory Control, McGraw Hill Book Co., Inc., New York: 1958, p. 17.

16. Ibid.

17. Robbins and Murphy, "Economics of Scheduling for Industrial Mobilization, Journal of Political Economy, LVII (1949) as quoted in Klauss Knorr, The War Potential of Nations, Princeton University Press, Princeton, N.J. 1956, p. 36.

18. Klauss Knorr, the War Potential of Nations, Princeton University Press, Princeton, N. J., 1956, p. 106.

19. James A. Huston, The Sinews of War: Army Logistics 1775-1953, p. 456.

20. AR 350-50, Army Officer Candidate Schools, October 1966.

21. Report of DA Board to Review Army Officer Schools, February 1966, Hq Department of the Army (Haines Board), Vol I, Section VI.

Analysis Method
for
Command, Control and Communications

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It is a never ending problem for military planners to anticipate electrical communication requirements and to manage the communication resources necessary to support tactical operations. The communications requirements derive from information transfer among the participants during operations and it is this transfer that requires identification and quantification in advance. Information transfer in this case pertains to the management of the military operation and is transported over electrical communication systems. Information transfer in this context will generate electrical communication traffic and these terms will be used interchangeably throughout the paper.

The flow of electrical traffic through a communication network, resulting from tactical operations, is a difficult subject to order or rationalize. One of the difficulties stems from the characterization of traffic since the transfer of information may assume many forms and be treated in many ways. For example, consider the forms of information as presented to the electrical communication system, i.e., as written, spoken or viewed material. The electrical communication system must accept these inputs and transfer the operational information from the originator to the user. All such information can be placed in digital form and transferred over the electrical communication system through the employment of digital techniques. The modern trend is toward all digital systems, however, extensive analog systems are in being and will be in evidence for a long while. The present day traffic analyst and circuit engineer must deal with both analog and discrete or digital traffic. Next consider a priority system if particular voice calls or written messages should have preferential treatment throughout the system. This gives rise to pre-emption or interruption schemes and to a choice of priority levels. Any choice presents difficulty because pre-empted traffic must be initiated following traffic of higher priority or precedence and the interrupted traffic must be joined at the receive terminal or re-transmitted. Next, consider the routing traffic must follow to get through a network. The traffic must follow specified doctrine each time it encounters a node or relay point. For example, the traffic may be stored and forwarded or switched through a node in real time. If a particular link in a net is not operating, then an alternate route is sought through the net or the traffic is delayed until the link is again operational. The above discussion is not intended to be a discourse on communication traffic flow through a network but is intended to show that a description of traffic through a network is complicated and very difficult to analyze.

One of the commonly employed techniques for testing traffic or information flow, is through the analysis of military exercises or the examination of real operations. These approaches are good ones but suffer from the fact that in each case the analyst is studying history and the situation may never be repeated. This is especially true if contingency planning is the primary concern. Contingencies rarely duplicate. Another drawback to the military exercise is cost. The exercise of forces is indeed necessary to prove many facets of military operations but the communication traffic necessary to support tactical operations cannot be exercised or rehearsed for each operation.

Another timely approach to the problem of anticipating traffic is the Command Post Exercise or CPX. This type of test, exercises the communication system by entering traffic at selected points and in controlled types and amounts. The problem in this case is to admit realistic amounts and kinds of traffic to measure the system effectiveness in the real world.

Extrapolation is another commonly employed technique for anticipating future needs. This is an excellent technique for those situations where population or industrial growth is reflected in increased communication requirements. The requirements to satisfy tactical operations, however, usually change abruptly according to the operation so this technique is less attractive in the tactical case.

Analytical treatment of traffic flow through a network is not tractable except in the most simple cases. The treatment of many nodes in the real world system has been overwhelming.

Many investigators have turned to simulation to analyze traffic flow through real world networks. Simulation techniques have proven to be very powerful tests, however, the problem of loading a simulator to describe the traffic in support of tactical operation persists. A key to the solution of this problem would be the relationships between operational events and the generation of traffic. It is postulated this can be done by employing experienced planners and operations specialists to identify communication traffic associated with operational events. This leads to an orderly and logical step-by-step method for generating traffic, imposing it on a defined or real communication network and simulating the flow to determine if command and control functions are satisfied. The following discussion outlines the step-by-step method.

The first step is to establish the tactical situation. This can be done through scenarios, operations plans or contingency plans. The scenario approach has several advantages. The main advantage is the ability to choose the environment, both political and physical, the level of conflict, and the kind of weapons, both conventional or nuclear and the disposition of resources. The scenario can be made realistic and selected parameters of the situation can be changed at will. This is a very economical way to exercise forces in a variety of situations and environments. The operation plan describes a real world situation and is also ideal for identifying traffic to support a tactical operation. Indeed, this step-by-step method could become a part of operational planning to determine the extent of communication resources necessary to satisfy command and control needs. The contingency plan is very similar to the operation plan but is generally far more sensitive. The employment of a contingency plan to provide a tactical situation for analysis would require extensive and strict security measures.

The next step in the method is the resolution of operational events into a PERT type chart. This step requires the planner to exercise discipline by identifying each organizational and functional unit participating in the operation. It should be noted that organizational units represent known entities during tactical operations. The planner, employing a PERT type chart can trace the participants through the operation and identify operation events. The resulting chart not only serves as a base for generating communication traffic but also provides an excellent means for displaying the operation.

The third step relates the generation of communication traffic and tactical operational events. This step is the very heart of the method and warrants detailed attention. The first fundamental point concerns traffic generation at the source. This is in contrast to sampling traffic at message centers or relay points. In this case, traffic generation is identified at the lowest combat element and carried up through ascending echelons of command. Discrete messages or calls and distributed traffic are related to each organizational unit as a consequence of operational events. Higher levels of command generate high density traffic and it becomes impractical to identify discrete traffic so established sampling methods prevail. Higher levels of command are generally served by strategic communication systems which have been analyzed through established techniques. The interface between tactical and strategic communication systems can be accomplished if the traffic characterization and the utilization factors of the interfacing channels are known. Utilization factor in this case is defined as the ratio of traffic arrival rate to service rate.

The planners or operations specialists, as they examine the operational events, identify the generated traffic and determine the recipients. This action identifies the traffic sources and sinks and provides a means for constructing need lines or establishing a matrix to show information flow among the participants. This is accomplished without consideration for an existing or defined communication network.

The next step includes the imposition of information flow on a real or defined communication system. This requires the identification of a path for each discrete message or call and paths for distributed traffic. In addition, the routing doctrine, relay instructions and priority schemes must be accommodated by the communication system.

The next step includes the simulation which calculates the average transmission time between any two terminals for hourly traffic during a twenty-four hour period. The simulator, as presently written, will calculate the resources necessary to provide a grade of service for given traffic loads or will calculate average transmission times from known resources and traffic loads. The end result is a record of queue locations within a net resulting from generated traffic, length of queues, and average times of transmission.

The measure of performance is chosen to be the time of transmission. Time of transmission includes accessibility to the network and other activities such as off line encryption, that delay information transfer. The analyst, after studying the location, and extent of queues and average transmission time can make appropriate adjustments in the resource allocations. He can also make parametric changes to study the effect on network behavior.

An example will be given using figures to show the steps of the method:

Figure 1 shows a matrix of scenarios that have previously been prepared by Bendix Aerospace Systems Division. These scenarios provide a variety of environments and situations for depicting tactical operations.

Figure 2 shows a sample operation flow diagram depicting events that identify reasons for traffic generation. The operation flow diagram provides operational planning advantage as well as a basis for generating electrical traffic.

Figure 3 shows information flow lines for a small operation on D +3. This identifies the traffic sources and sinks.

Figure 4 shows a defined communication system to carry the traffic generated from the operation. Note the information line numbers shown on previous figures. An example is line 17 that connects terminals 20 and 04. This is a devious route for a simple line shown on Figure 3.

Figure 5 shows computer results between two terminals during a small scenario generated operation. The No. 2500 on the first line is a channel designation and the No. 1008 represents the transmit and receive terminals respectively. The penciled numbers 13 and 14 represent 1300 to 1400 hours of the day. The adjacent number 5 is the number of messages between 10 and 08 during this hour and the messages experienced a 4.1 minute transmission delay. During the next hour 10 messages experienced an average delay of 9.26 minutes.

In summary, it is postulated that tactical operations can be divided into events and communication traffic related to the events. The traffic can be simulated through a communication system to determine transmission time or the resources necessary to provide a desired grade of service. This step-by-step method may provide a basis for managing or procuring resources to meet future tactical operations.

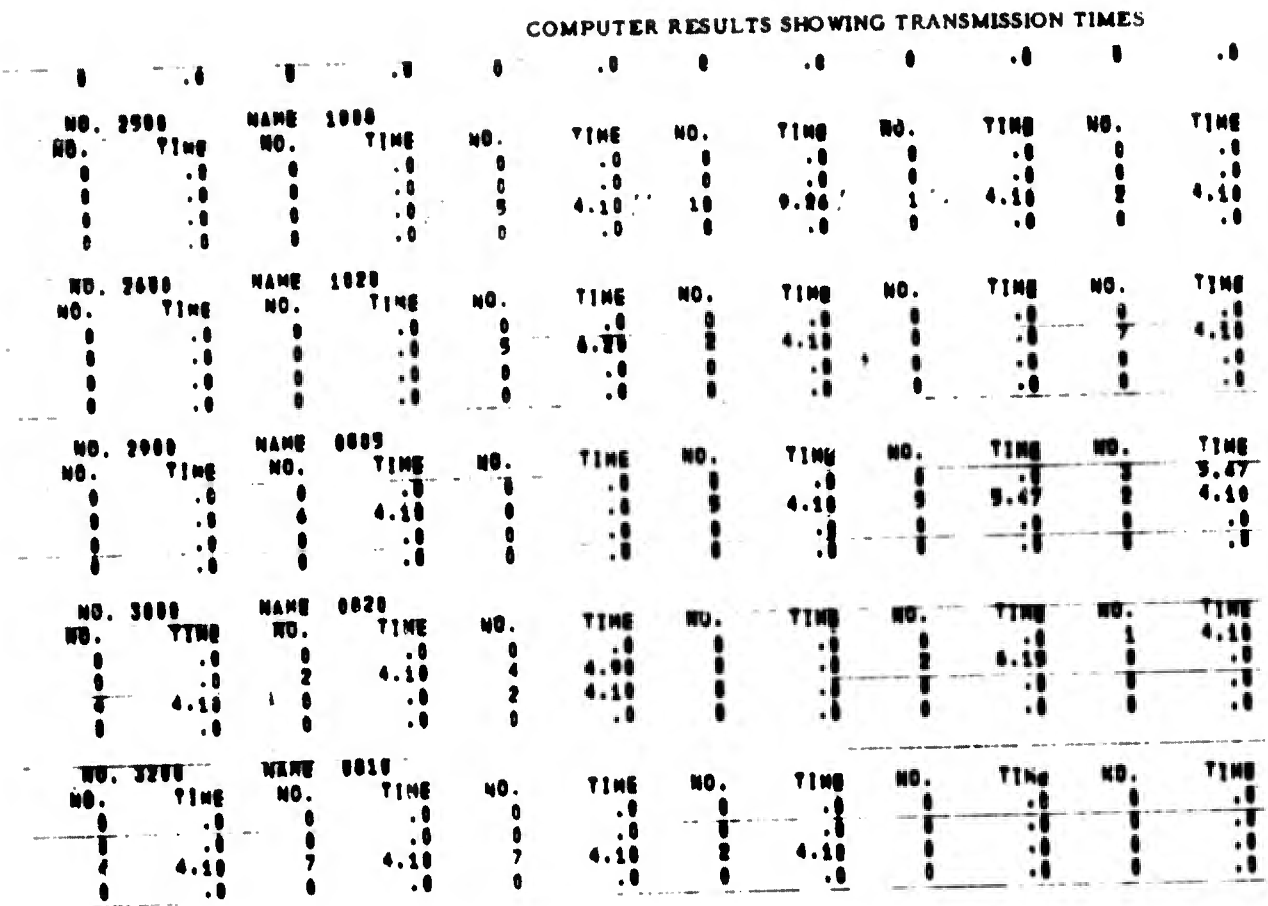


Figure 5 Computer Results Showing Transmission Times

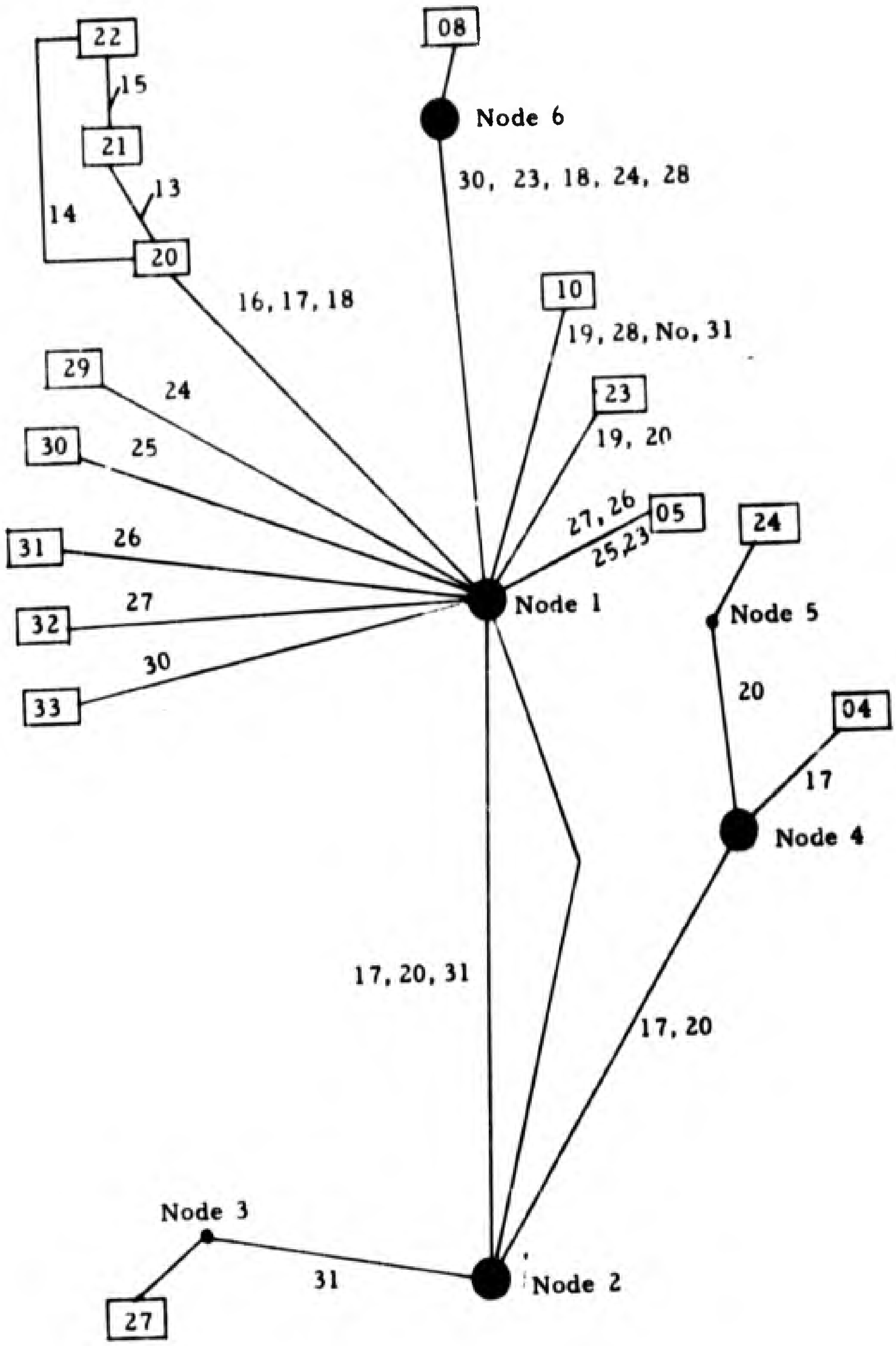


Figure 4. D + 3 Communications Channels

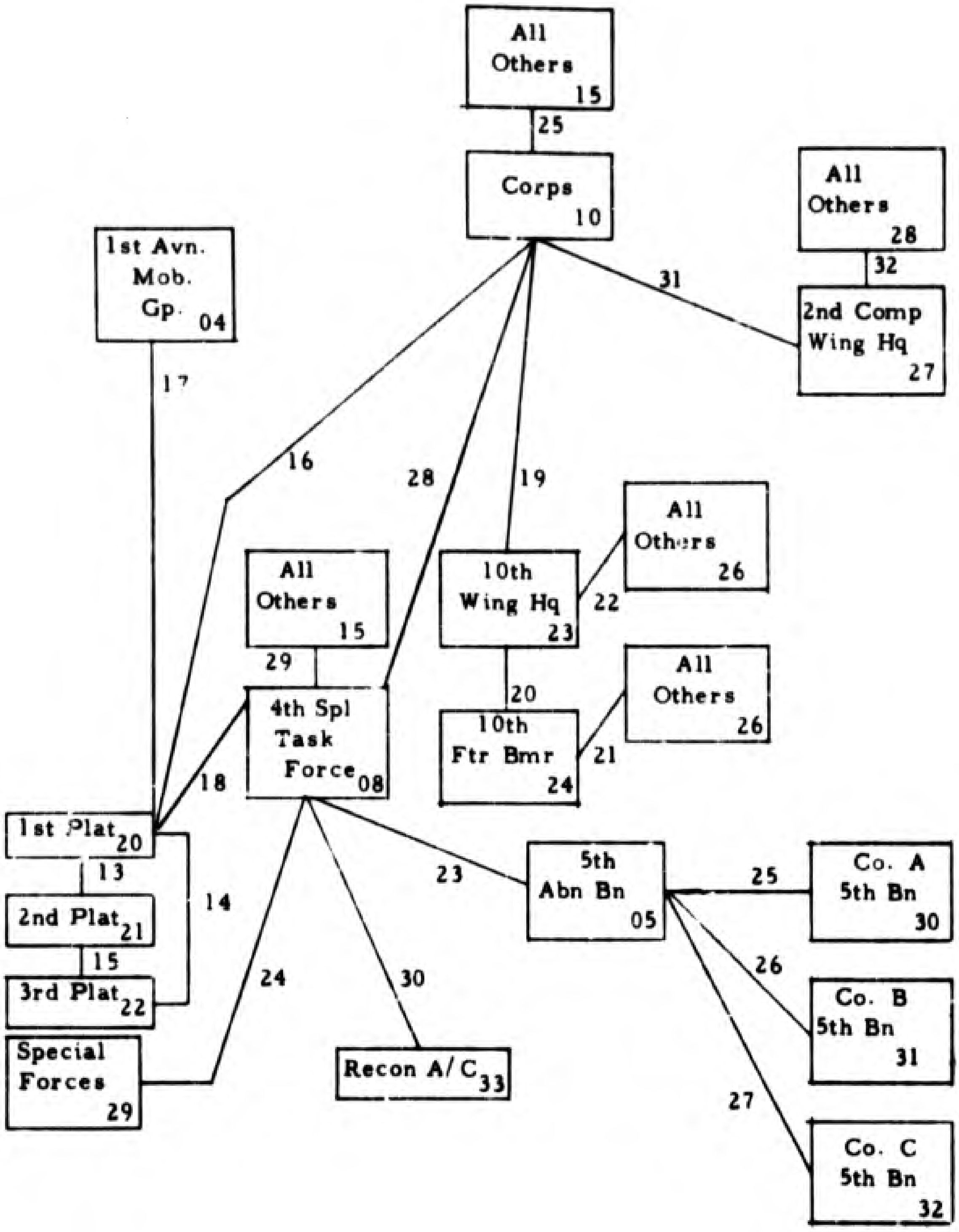


Figure 3. D + 3 Information Flow Lines

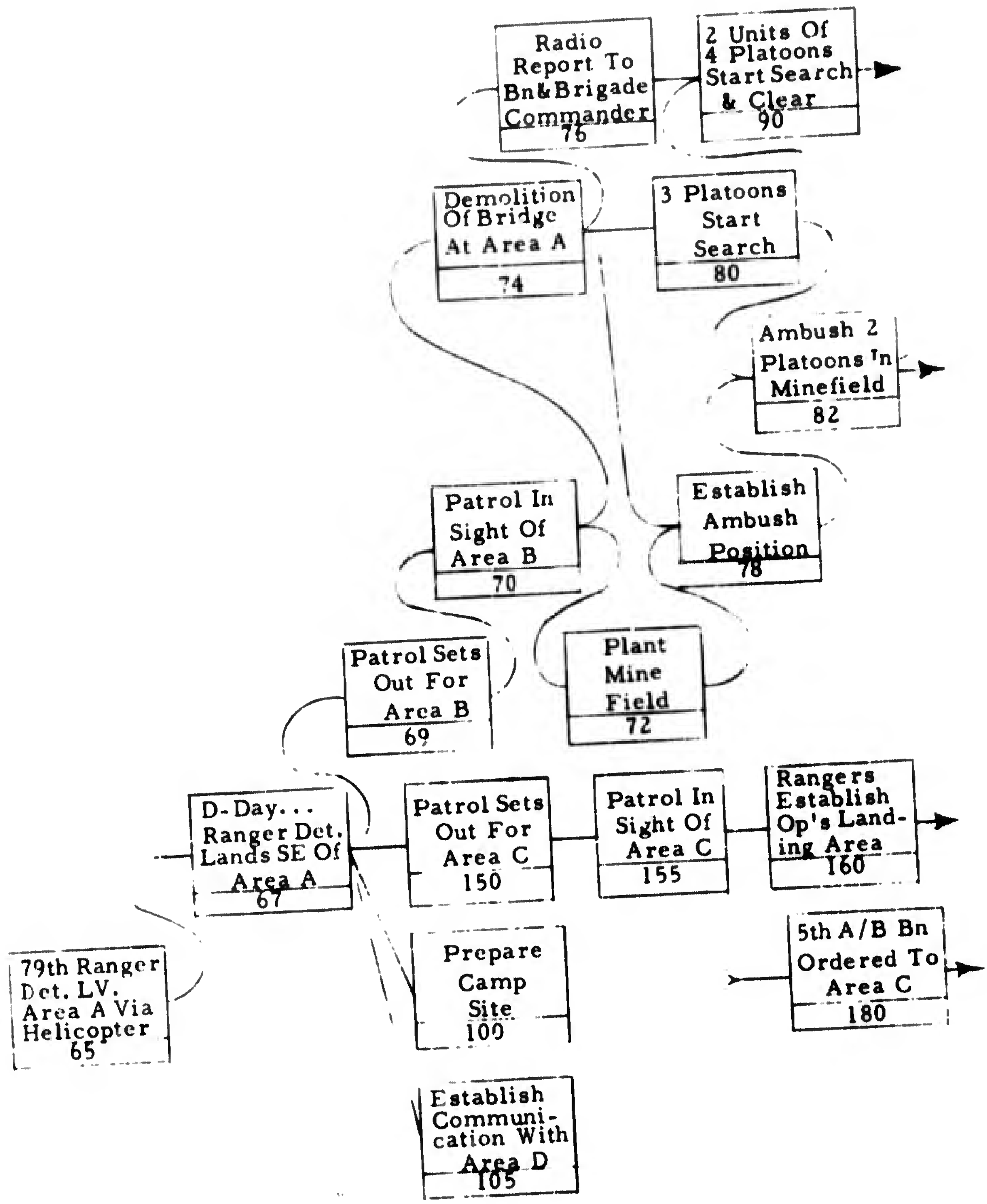
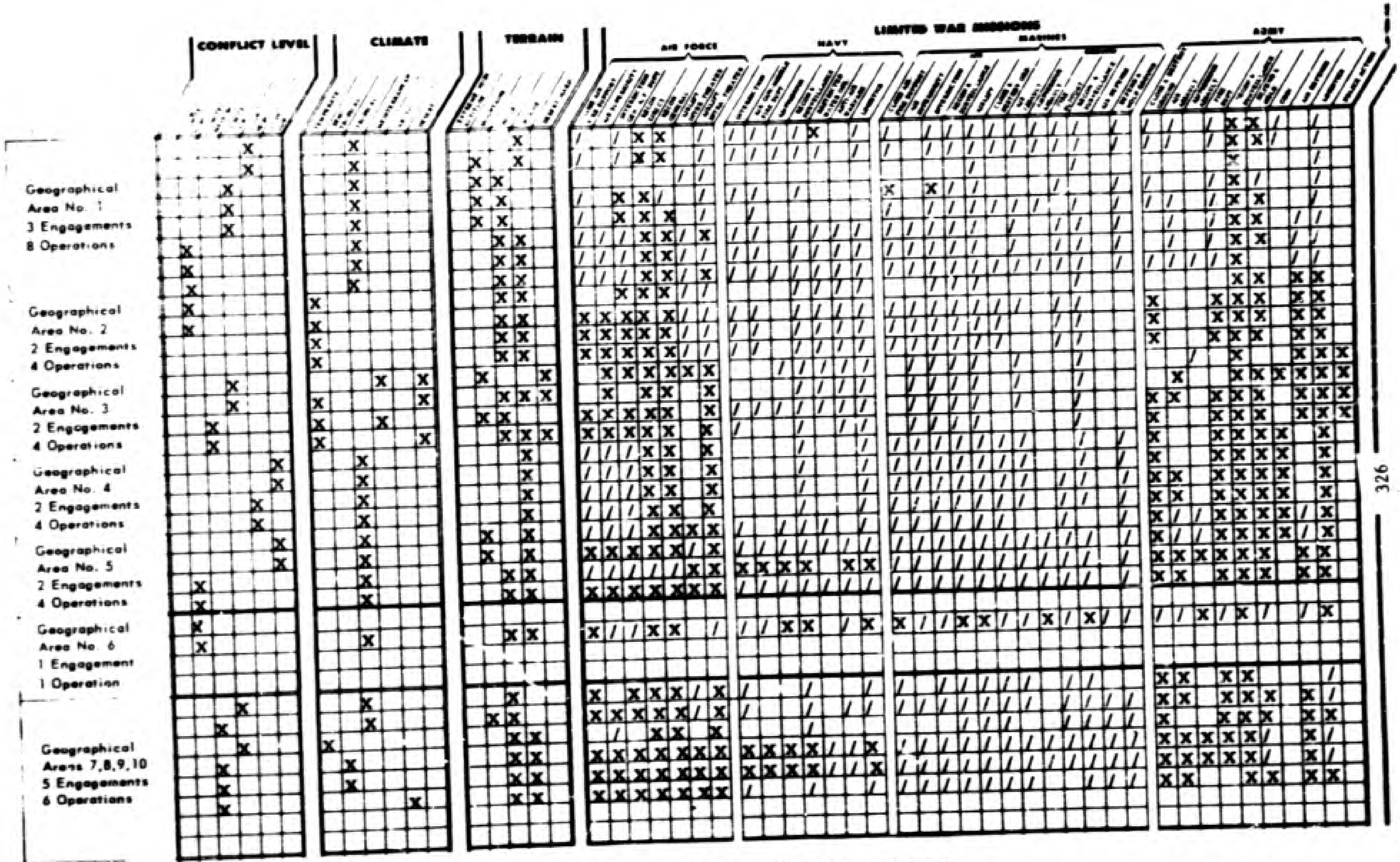


Figure 2. Operation Flow Diagram



LIMITED WAR MISSIONS COLUMNS ONLY

X – Friendly (U.S. & Allies) and or Unfriendly Scenario Forces Engaged in this Mission

/ – Forces not Engaged but Scenario has Potential for involvement

Figure 1 Bendix Scenario Development Program

A Computer Model for Determination of Impact of Certain Personnel System Policies and Procedures

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I. PERSONNEL SYSTEM PROBLEMS

It is the purpose of this paper to describe a generalized simulation model successfully installed and tested on the computer system of the U. S. Army Behavioral Science Research Laboratory. This model will be described in the context of the management research requirements for which it was designed and the research design considerations which influenced its development.

It has become evident that many questions arise in the course of military manpower planning which await objective investigation. Experimental studies involving the real manpower system are expensive both in cost of data collection and in reduced efficiency of the manpower system while an inadequate policy is tested operationally. Evaluation of alternative procedures can be relatively inexpensive, however, if the personnel system can be modeled and experimental results based on a computerized simulation of the system. Relationships between requirements, assignment procedures, input from outside the system (e.g., from external procurement or from training facilities), quantity and quality of personnel information made available to the system, attrition to the system, and measures of system effectiveness have all been studied through the use of computer simulations.

These problems included as a major subgroup those related to assignment of personnel to jobs or job categories. The interests of manpower management offices often center on the comparison of alternative policies for assigning enlisted men to meet prescribed minimum qualification standards. Additional objectives may be to sequentially minimize transportation costs, increase the number assigned to their preferred occupational area, and optimize expected performance on the job (as predicted from scores on paper and pencil tests or other information recorded in the personnel folder). The various policies may change the order in which pertinent variables are optimized or may provide for varying degrees of partial optimization at each stage. Related areas may involve 1) designing testing programs for manpower assignment, 2) formulating policies which change standards for enlistment and induction, and 3) estimating the impact of increased mobilization on the quality of assigned men. Analytic approaches which would handle problems of this level of complexity have been proposed (see, for example, Boldt, 1962) but have not proved economical. Results which can serve as actual solutions to these problems have been heavily based on simulation techniqves.

The simulation approach is particularly necessary when some use is made of optimization techniques within the system to be evaluated. Expected output for a modeled system is often examined, for example, after each of a sample of simulated individuals is assigned to a job in such a way as to maximize the average expected performance for the sample. These assignments are usually based on linear programming algorithms. The beneficial application of such optimization methods has been demonstrated even when the metrics which characterize a personnel system are not of the interval type assumed in the derivation of the techniques involved (Sorenson, 1966).

Before describing a generalized computer model which has been developed at the U. S. Army Behavioral Science Research Laboratory (BESRL), it is of interest to discuss the problems which require special attention in designing and using system models for simulation experiments, notably the choice of suitable research designs and the use of appropriate criterion variables. First, let us consider a more general issue: the type of model to be developed. The experimenter must first ascertain whether a deterministic model is adequate for his purpose. A deterministic model is built to yield results by analytical methods or by a single simulation experiment; output is exactly determined by input, with no random variation in the input or within the model to affect results. In contrast, a stocastic model yields results which vary in accordance with a well-defined probability distribution chosen to represent random fluctuation characteristic of a given system and thus makes possible the solution of multivariate problems which are out of reach with deterministic models. The latter approach was thought to be generally more appropriate for simulations involving the personnel system. The random variation characteristic of the real system can be easily simulated if the population of interest can be represented by a known statistical distribution. Samples are constructed by first generating random numbers and then transforming these numbers to yield observations which can be expected to have the statistical properties of the population. This "model sampling" is performed repeatedly to insure against basing conclusions on a non-typical although random sample. Similarly, replications permit an evaluation of the criticality of the chance input into the system and provide a forecast of output fluctuations which can be expected under operational conditions.

Just as important for the kinds of personnel assignment systems which have thus far been simulated in BESRL, the stochastic approach is necessary in order to achieve a practical solution to the problem posed by management.

For example, when the management problem is to ascertain the consequences of applying a set of rules to selecting, assigning, training, and distributing people, a complex multivariate problem is inevitable. While the distribution of personnel according to policies involving minimum qualifications, quotas, and optimal assignment rules can generally be described as a fairly complicated set of mathematical functions (involving difficult to solve multiple integrals, some with variable limits), the numerical analyst faced with solving such a problem would most likely resort to Monte Carlo or model sampling methods*. Thus, the stochastic approach is indicated. Furthermore, when a simulation requires the flow and/or other manipulation of entities (representing people) according to prescribed policies, either real records must be sampled or artificial people (i.e., entities) generated. It is not generally possible to represent hypothetical policies that have never been implemented by sampling from real data. Furthermore it is not possible to create entities having the exact characteristics (including the prescribed multivariate distribution) of the population of interest. Instead, entities are generated which have the same statistical properties (in all essential respects) as if they were drawn as random samples from a prescribed universe of such entities. This process is of course a stochastic one.

II. RESEARCH DESIGN CONCEPTS

Many of the studies currently envisaged as appropriate for the generalized simulation model described in this paper would use an optimal assignment model as a means of describing the idealized assignment system. Some studies deal with policies for assigning personnel so as to maximize average predicted school or on-the-job performance. In still other studies, a set of policies that utilize optimal assignment procedures at some point in the system may be included only as a standard against which to compare other policies. In any case, a simulation of the input and distribution of enlisted men through individual careers, meeting the Army area and occupational requirements for quantity and quality of personnel, should utilize the wealth of data that relates performance in many different jobs to a wide range of predictor variables. Numerous studies have established the adequacy of linear equations in predicting such performance.

The question might be raised whether linear least square predictions for which the coefficients have been computed to maximize accuracy of performance estimates in a job will also be the appropriate parameter values when it is desired to allocate men to jobs in such a way as to maximize the average predicted performance of all men in the sample. It has been demonstrated that there is no better set of linear functions of the predictor variables

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* In this paper a distinction is made between these two methods by defining the Monte Carlo approach as model sampling using "clever" variance reduction techniques.

than these least square equations for accomplishing this purpose (Brodgen, 1955). That is, a predetermined set of tests yields maximum allocation effectiveness when the predictor variables are given the least square regression weights as computed separately against each performance criterion. Thus, use of these full regression equations to compute predicted performance scores for each job and the use of these scores in an optimized assignment model will assure that the expected average performance of the assigned men has been maximized. On the other hand, while no other set of weights could make this particular set of predictor variables more effective, a particular variable may be contributing so little that its removal would have little effect.

Experiments designed to investigate system output as a function of different policies can utilize the same entities (representing people) for each of the policies. By generating observations for each policy from the same sequence of vectors of random numbers, sampling variability, which is inevitable from person to person, is relatively small from policy to policy. Operations which simulate different policies and/or procedures -- assignment, enlistment, or retirement policies, for example -- are thus performed on the same numerical values. Consequently, a higher component of score differences for any individual can be directly attributed to the effect of policy rather than to other (stochastic) sources of variation.

Difficulties occur with respect to statistical design, however, when observations corresponding to different policies are based on the same sample of subjects. To test the hypothesis that overall job performance is significantly greater under policy j than policy k, an analysis of variance would require that estimates of error variation be independent for each policy, not correlated as when computed from the same set of subjects. A t-test for correlated means is appropriate when there are only two policies, but becomes inappropriate when there are multiple policies or when a more complex factoring of experimental conditions is of interest.

Often, a multivariate analysis of variance is particularly suitable when repeated measurements are made on the same subject. Tests concerning group differences take into account covariation, as well as variation, between the dependent variates, and may lead to conclusions quite different than if a series of univariate analyses had been performed. It is the independent variables, however, which are correlated when allocation policies based on the same individuals are under study; and the random sampling of individuals over treatments required for both multivariate and univariate analyses of variance cannot be claimed.

Wilks (1946) has developed statistical criteria for testing equally of means, equality of variances, and equality of covariances for a multivariate normal population in which the variables are correlated. The test for equality of means would seem appropriate when applied to a sample of observations simulated to characterize different allocation policies which are based on the same individuals. To test the hypothesis that policy related system output (i.e., multivariate criterion measures) means are equal, however, it must be assumed that output variances and covariances are equal across different policies. This would not be a restrictive condition if interest were in establishing that the output variables are parallel measures, a situation for which the Wilks criteria are well suited. It would rarely be anticipated, however, that equality of either variances or covariances would exist when observations are obtained from the complex series of operations which simulate personnel assignment procedures. This happen only when the different policies being compared use exactly the same variables. That is, the variables for the different policies are based on the same functions of the vector of random numbers initially used to represent an entity.

A more subtle difficulty may complicate the choice of appropriate statistical tests for simulated observations. When all observations are independently sampled for an analysis of variance, it is the random fluctuation from treatment to treatment, as well as from individual to individual, which permits, under the null hypothesis, the determination of the two independent estimates of error variance necessary for testing the significance of treatment differences. When multiple observations are obtained from the same individual in the field situation, uncorrelated measurement error still occurs from treatment to treatment, even though estimates of it may not be directly obtainable; the choice of specialized statistical criteria, such as the Wilks criteria when considering parallel tests, amy permit significance tests of treatment differences. When, however, there is no error across treatments, as when observations simulating policy differences are generated from the same random numbers, statistical testing of treatment differences may require different experimental designs than those developed to provide inferences regarding empirical data. It may frequently be possible to take advantage of the fact that the experimenter using a simulation model knows many of the universe values of variables for which he could only make inferences if he were using empirical instead of computer generated data.

When one wishes to use the same research designs as would be used for empirical data, one could sacrifice the direct comparability of policy differences for any individual and simulate only observations which are independent over treatments. Then, the extensive range of statistical designs associated with both multivariate and univariate analyses of variance could be legitimately used in personnel systems investigations using generated data. Once statistical significance of treatment differences was established, the policy differences could be estimated by repeating the simulation, but with entities generated from the same sequence rather than independent sequences of random numbers. Direct comparison in which the individual serves as his own control of treatment effects, is frequently not possible using actual observations. Such comparison may be considered a refinement characteristic of simulation experiments.

The basic design of a simulation experiment in which two policies are being compared can be described by the following sequence of operations:

1) Generate a vector of independent normal deviate scores to represent the i^{th} individual, $X_i = (x_1, x_2 \ldots\ldots x_k)$. This random vector can be thought of as containing the k basic factor scores for the i^{th} individual. All characteristics of the individual can be defined as some function of these independent attributes

2) Create the variables needed to accomplish the i^{th} policy by transforming X_i, e.g.,

$$Y_{i\ell} = X_i T_\ell$$

3) For the ℓ^{th} policy with n_ℓ decisions regarding the disposition of the i^{th} individual, the status of the i^{th} individual (or entity) at the j^{th} decision point can be denoted as $S_{i\ell j}$ and considered a function of the $Y_{i\ell}$ and $S_{i\ell(j-1)}$. Thus we can write

$$S_{i\ell j} = {}_s f_{\ell j} (Y_{i\ell}, S_{i\ell(j-1)}).$$

4) The criterion values for the ℓ^{th} policy and the k^{th} criterion variable can be similarly written as $Z_{\ell k} = {}_c f_{\ell k} (Y_{i\ell}, S_{i\ell n})$.

Note that the elements of the vector Y_{i1} and Y_{i2} represent the same or different measures or char .teristics of the i^{th} individual as required to implement policy 1 and policy 2 respectively. Even if $Y_{i1} = Y_{i2}$ differences in the functions ${}_s f_{1j}$ and ${}_s f_{2j}$ as applied to the random vector Y_i can produce sampling differences that must be evaluated in order to determine whether the sign of the difference $(Z_{1k} - Z_{2k})$ can be estimated with a given level of confidence.

III. CRITERION CONCEPTS

In describing computerized models, it is useful to categorize variables into three types. The first are variables which define the system. Values assigned to these variables are the "givens," the requirements or restraints contained within the system. The second are variables related to the policy or procedure being evaluated; these are modified to simulate different experimental effects. An optimal assignment process can be either of the two types of variable; that is, optimization may be incorporated into the main framework of the system or it may represent one of alternate effects under study.

The third type of variable is the criterion variable. The criterion provides the means for establishing the validity of the model, as well as for evaluating policy or procedural alternatives simulated within the model. Special care should therefore be taken to define indices which are highly similar to criterion indices as they actually exist. Also essential is the correct choice of relevant criteria, as viewed by consultants experienced with the real system.

Any discrepancy between the model criterion index and the criterion variable in the real system may be cause to modify both the criterion index and the model. There is, of course, an alternative point of view. The model may be intended as a simulation of an ideal system. When this is the case, discrepancies among the model and system indices merely indicate that the real system diverges from the ideal. The manner in which this divergence occurs should be understood in interpreting simulated results.

Modeling becomes more complex when there are several variables against which system effectiveness must be evaluated. Even when a model for personnel assignment is designed for very specific military applications, more than one of the following may need to be considered as criterion variables; reenlistment rate, selection ratio for promotion, amount of reassignment turbuleace, quality of fighting force, shortages of particular types of personnel, and reduction in attrition of potential leaders.

Certain criterion indices, which may be called "restrictive criteria," are used only to identify characteristics which are prohibited in the system. Any policy which exhibits these undesirable characteristics is considered to lie outside the class of feasible policies. Multiple criteria such as these present no difficulty, since policies may be examined with regard to any number of restrictions. Other criterion indices, which may be categorized as "maximization criteria," are used to identify optimal policies. When there are multiple criteria of this type, the evaluation of system output may be particularly difficult. One approach to handling multiple criteria may be to investigate the trade-offs among the criteria. Disproportionate increases in one criterion value may be found to accompany small decreases in another. Another approach is that of nesting optimizations. First, a hierarchy of criterion variables would be established. Optimization of the system would then proceed variable by variable, starting at the highest priority. With each optimization, the feasible solution space is reduced, and the point may be reached in which further optimization of the system cannot be accomplished. Results obtained for the higher priority optimization procedures are not affected by the successive solutions, however, and evaluation of the system can be based on the space of feasible solutions or on a function of the value obtained for each of the objective functions.

IV. GENERALIZED MODEL COMPUTER PROGRAM

The Statistical Research and Analysis Division, BESRL, has developed a computer program which serves to model characteristics common to a general class of personnel systems. The model is stochastic, and the basic populations from which simulated individuals are randomly sampled is the multivariate normal, although the non-random sampling which often results in non-normal distributions may also be simulated. The option of optimizing performance of a sample over multiple job categories is built into the model, and criterion indices can be related to the results of optimal allocation. Processing of manpower information may be simulated by use of linear transformations. To expand the model to contain more specific features, the computer program is written so that modifications can be easily incorporated.

Operations of the program are outlined in the flow diagram shown in the Figures 1 and 2. Input of transformation matrices and parameters which determine characteristics of the system are represented in box 1. Defined are the number of samples to be simulated, the number of individuals in each sample, parameters which determine transformations to be performed on individual score vectors before and after allocation, job categories and quotas, and a starting vector for random number generation. Additional input may be read by subroutines written to expand the model (box 2).

Output consists of summary statistics computed over all individuals constituting a given sample (box 4) and also of the multiple replications which are customarily performed for a given experiment (box 5).

The simulation model (box 3) is shown in more detail in Figure 2.

The "general" part of the simulation model begins with the automatic generation of a vector of random normal deviates to represent each entity or individual (box 6 of the flow diagram); on this vector are performed a series of linear transformations of the form $\underline{v} = \underline{u} K + \underline{m}$ (box 7). K may be a matrix of least square regression coefficients for obtaining performance estimates $\underline{v}$ from a set of predictor scores $\underline{u}$; $\underline{m}$ are the additive constants to yield estimates with specified means. A special purpose for which K is used in simulation studies is to transform random normal deviates, which have an expected covariance matrix of identity, into variates with an expected covariance matrix characteristic of the population under investigation. As indicated in Figure 2, the user specifies the series of linear transformations required to generate a particular sample by first inputting the covariance matrices and vectors of mean values, then references these matrices on special transformation cards, which are input in the order of the transformations to be performed. The p cards define LOOP T for computations to be performed before allocation, and the q cards which follow define LOOP T for computations after allocation.

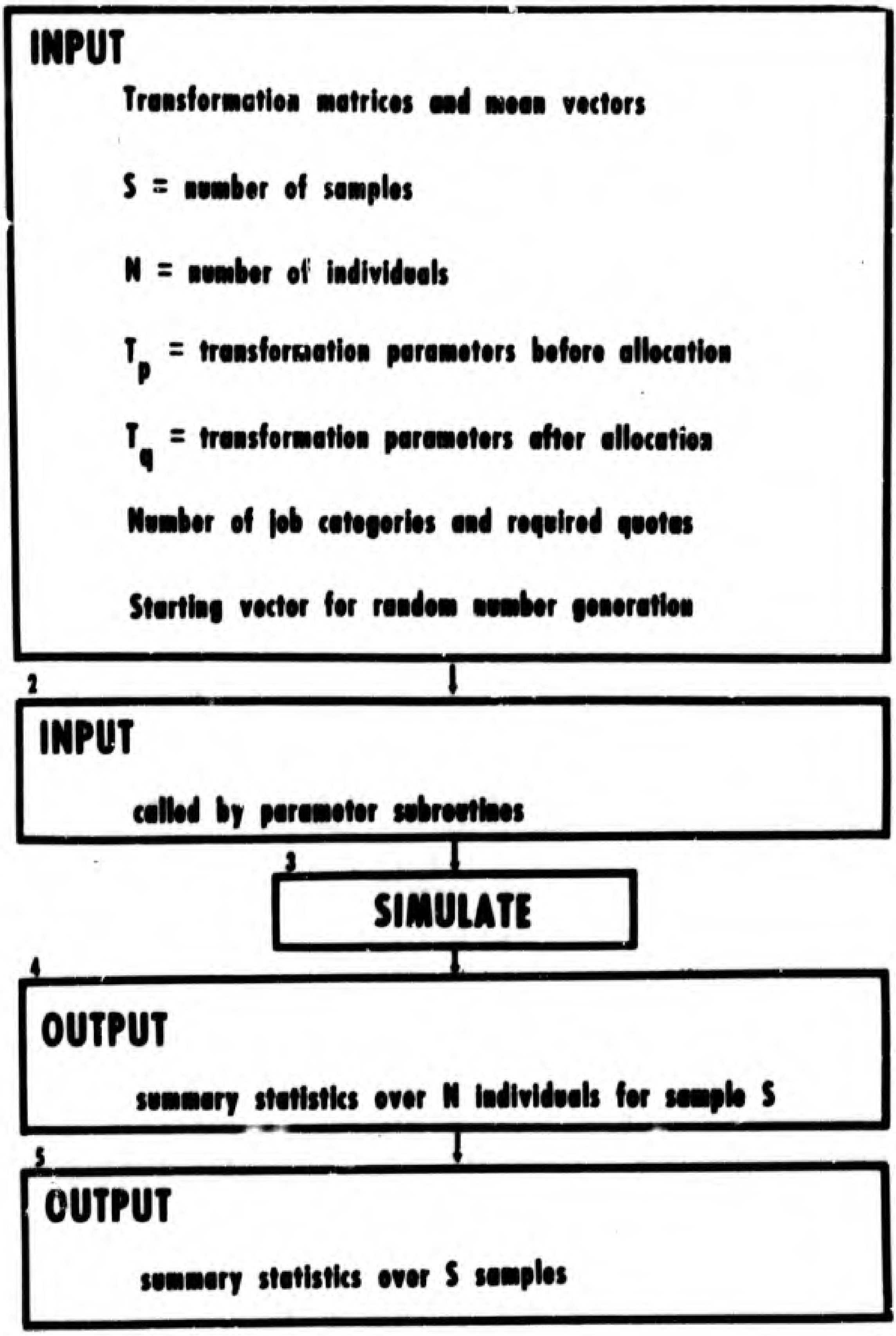

Figure 1. Flow diagram for general computer model.

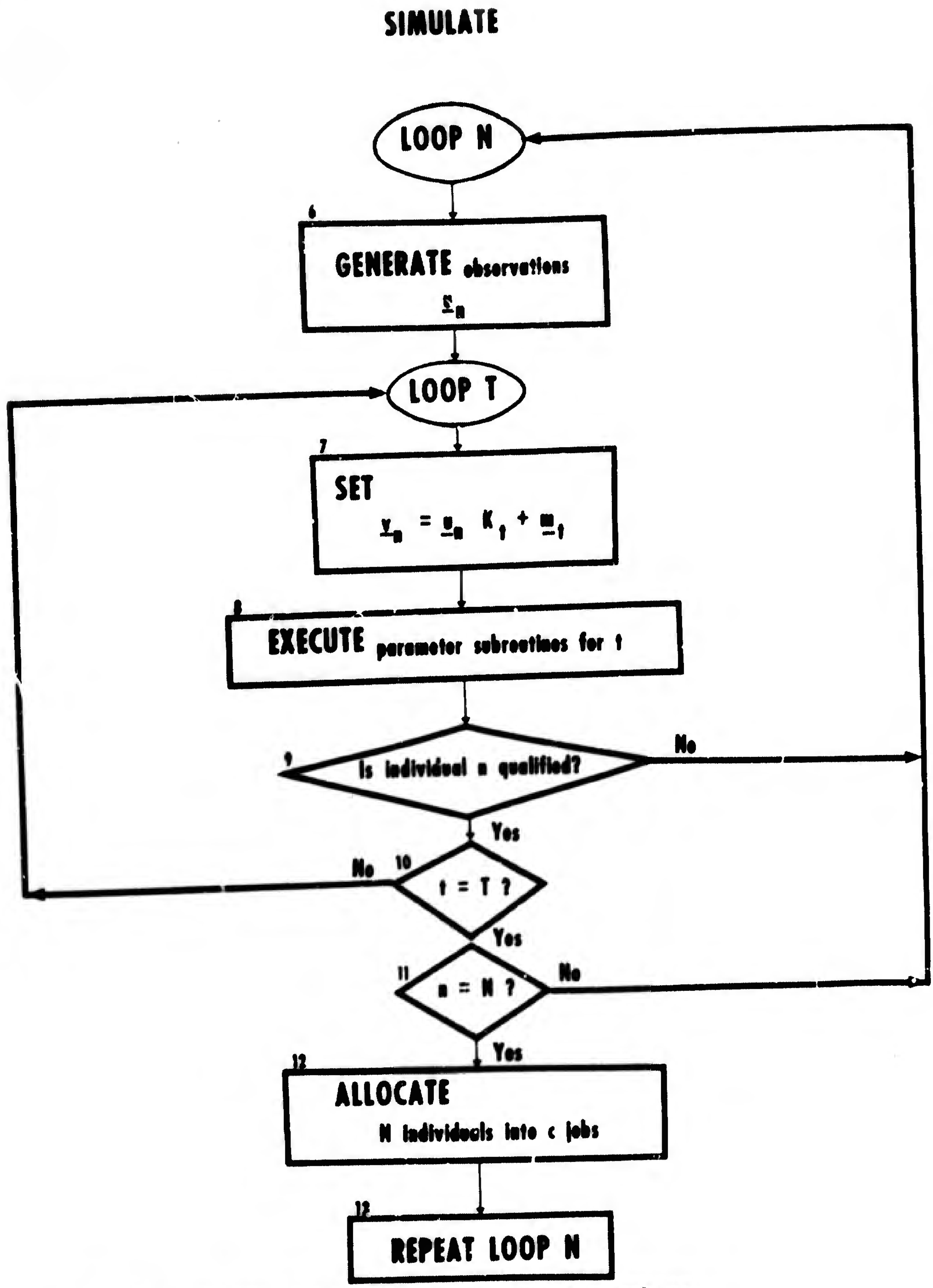

Figure 2. Simulation of personnel policies and procedures.

To perform non-linear transformations on the score vectors generated for each individual, or to perform any other operation to simulate characteristics of a more specialized system, specially written subroutines can be incorporated into operations under control of the main program. Modification and recompilation are required only for a short subprogram, not for the main program. The subroutines are assigned integer names and are called by listing these integers, in the order the subroutines are to be performed, on the same cards which define the sequence of linear transformations. (In other words, execution of the subroutines, box 8, is determined by the transformation parameters within LOOP T.)

The parameter subroutines are also used to determine whether the scores being generated for a given individual are consistent with sample characteristics defined for a particular investigation. As the operations specified on each transformation card are completed, an index, which may have been set to reject a given individual by any of the subroutines, is automatically sensed by the main program (box 9 of the flow diagram). Thus, tests for individual acceptance or rejection may be performed repeatedly and at any stage in the computations.

The result of the sequence of operations specified on the transformation cards is the construction of an N x c matrix of performance measures; the c columns correspond to job categories under investigation, and the N rows represent the individuals in the sample. Based on this matrix, each of the N individuals is optimally assigned to one of the c jobs in such a way that required quotas for the different jobs are met (box 12).

After assignment, the response vectors for the N individuals are regenerated to compute statistics that are functions of the job to which each individual is assigned (box 13). These are the computations specified on the second set of transformation cards previously input and serving to redefine LOOP T. Additional parameter subroutines are included if special computations are required. (Allocation averages and frequency distributions for jobs to which men are assigned are examples of statistics used in summarizing kinds of simulation, and general routines have been prepared for their computation). In order for simulated performance measures to represent the same individuals both before and after optimal allocation, the starting vector of random numbers is re-initialized after allocation.

V. REPRESENTATIVE APPLICATIONS

The purpose here is to describe results typical of the problems for which the program is well suited. Among the series of experiments which motivated development of a general program was a study by Sorenson (1965) on the use of full regression equations versus aptitude area scores for the optimal allocation of enlisted men. The eleven tests of the Army Classification Battery are designed to predict performance in different job areas. However, the operating Army personnel system was basing predictions on computationally simplified composites of only two tests. The purpose of the simulation was to estimate the performance gain using the full set of measures compared with the abbreviated set.

Performance estimates obtained by each of the two methods were used to optimally allocate samples of men into eight job areas such that prescribed quotas were met. The difference between the performance averages over simulated samples after optimal allocation provided a measure of differential effectiveness of the two methods of combining predictors.

Results for the published study were obtained from a specially written program, but re-analysis could now be performed much more simply because of the availability of the general program. The two kinds of performance estimate would be constructed automatically and simply within the program by performing an appropriate sequence of linear transformations on the vector of random numbers generated for each individual. The user would need only to input the necessary transformation matrices as data and to specify on parameter cards the order in which they are to be used.

An example of the type of simulation which would require the use of specially written parameter subroutines, as well as the automatic features of the general program, was reported by Sorenson at the 1966 Operations Research Symposium. The purpose of the simulation was to examine the effect of metric changes on the results of optimal allocation.

To reproduce the 1966 results using the general program, performance estimates for each individual on different job categories would be first constructed by linear operations similar to those used for the study just described. Each set of observations would then be modified to represent eight different metrics. For example, criterion estimates with an expected mean of 100 and standard deviation of twenty would be converted to two-digit integer scores ranging from 0 to 99 by subtracting 50 and truncating. One-digit scores from 0 to 9 would be formed by subtracting 50, dividing by 10, and truncating. Ordinal scales would be constructed by ranking jobs within individuals or by ranking individuals within jobs. These modifications would be performed by specially prepared parameter subroutines. Returning control to the main program, and optimal allocation would be performed for each type of metric, along with the computation of measures of overall performance from which the effect of the various metrics could be evaluated.

The parameter subroutines are especially useful when information is needed concerning the effect on optimal assignment of a change in the minimum requirements for entry into the service. For example, scores on predictor tests (AFQT and ACB tests) can be generated to characterize samples from the mobilization population. These scores can in turn be sampled with respect to the AFQT variable, so that a portion of the generated sample is omitted from subsequent analysis. Simulation is repeated until a specified number meet the AFQT requirement. An example of one such policy is to simulate a probability of omitting 60 per cent who score 91-100 on the AFQT variable, 45 per cent with scores from 71-90, and 30 per cent for scores from 30-70. The selection could be continued by computing performance estimates from the predictor scores and further restricting the sample to men who score higher than 90, say, for two or more job categories. Studies of this kind have been used to recommend policies to the Army concerning changes in input requirements for enlisted men.

In one particular application, interest is in obtaining estimates of overall job performance as a function of various restrictions on the incoming population at a fixed point in time. For a different type of study, interest might be in overall performance when various restrictions are made on personnel as they operate within the system over an extended period of time. In other words, performance at different stages of experience is simulated. In the field situation, samples constructed on the basis of training experience will usually be composed of different sets of individuals because of difficulty of doing follow-up studies on the same men. In a simulation study, however, performance for the same individual can be followed through the complete time cycle. This is accomplished by first inputting transformation matrices which yield expected means, variances, and covariances for men who have the t_1 months of experience, t_2 months of experience, up to t_k months of experience. The vectors of random numbers generated for each individual are then post multiplied by these matrices, maintaining the same random numbers each time a given individual is represented over time.

At the start of the simulation, individuals in a sample are optimally assigned over c jobs on the basis of criterion performance. During the first t_1 months, each of the N individuals is examined for possible loss from the system. This loss may be a function of an individual's estimated job performance, simulated events occurring within the system, a random process which determines that near to p per cent of the sample will be lost, or some combination of these variables. Functions which determine loss are added to the program as parameter subroutines and may differ for the different job categories and for the number of months an individual has served.

For each individual remaining in the system, new performance measures appropriate to his job assignment and the length of time he has spent in the system are simulated. To replace men lost to the system, new random numbers are generated and transformed to expected values for an inexperienced population. Assignment to different job categories is performed such that expected performance of the new sample is optimal and such that job quotas reduced by loss are restored to their original values.

At the end of each point in time, t_i, the effectiveness of the system is evaluated. This may be as simple as computing the average measure of job performance for the different job categories or could involve a fairly complex function of the performance of crew members where a weapon system is involved. Simulation then proceeds from time t_i to time t_{i+1} by again testing observations for the N individuals for loss or retention in the system and by generating new observations to represent enough inexperienced personnel to fill the losses. At the end of the k-th simulation, representing the passage of t_k months, simulated observations will represent individuals with time in service ranging from zero months to full lenght of the tour.

With this type of simulation, quality of performance in the system can be examined as the proportion of experienced personnel in the system increases. In addition, the rate, or change in rate, at which men are lost from the system can be related to system performance. Experiments which investigate constant loss rates over all jobs may be specialized to examine varying patterns of loss rates for different jobs. Research of a more technical nature might involve comparison between different approaches to optimal allocation. Optimal assignment of the incoming sample can be based only on performance estimates of men in that sample. A different approach would take into account performance measures of the total sample, including the experienced personnel, when determining initial assignment of incoming personnel.

VI. REFERENCES

1. Boldt, Robert F. A multivariate function useful in personnel management models. Proceedings of the U. S. Army Operations Research Symposium, 1962.

2. Brogden, Hubert Least squares estimates and optimal classification. Psychometrika, 20:3, 1955.

3. Sorenson, Richard C. Optimal allocation of enlisted men -- full regression equations vs Aptitude Area scores. Technical Research Note 163, U. S. Army Behavioral Science Research Laboratory, OCRD, Washington, D. C., 1965.

4. Sorenson, Richard C. The effect of metric changes on resource allocation decisions. Proceedings of the U. S. Army Operations Research Symposium, 1966.

5. Wilks, S. S. Sample criteria for testing equality of means, equality of variances, and equality of covariances in a normal multivariate distribution. Ann. Math. Stat. Vol. 17, p. 257, 1946.

Sixth US Army Operations Research Symposium, Durham, North Carolina
24, 25, 26 May 1967

AN EXPERIMENTAL AND LOGICAL DESIGN PLAN FOR SYNCHRONIZING TIMING SYSTEMS

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CONCURRENT EXPERIMENTS

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2. ATMOSPHERIC RADIO WAVE PROPAGATION STUDY
3. MULTIPATH PROPAGATION TESTS

FIGURE 1

I. INTRODUCTION

This paper owes its origin to studies and experiments being undertaken in the Electronics Command to investigate the feasibility of using high precision frequency standards in an Avionics system. The objective of the proposed series of experiments is to determine the feasibility of synchronizing clocks by means of radio transmissions between different aircraft and between aircraft and ground stations (radio-frequency links, i. e. RF Links). It involves problems dealing with one of the fundamental parameters of physics, namely, time.

We are concerned with experimentally measuring time to an accuracy of the order of nanoseconds(10^{-9} second). What quantities in the timing system, e. g. phase, frequency, should be measured, and to what accuracies can they be recorded?

It is planned to carry out the following three experiments concurrently:

1. A basic experiment to determine the characteristics such as stability, etc. of the clocks under laboratory conditions, and to establish the type of basic instrumentation required to make the desired measurements.

2. A study and analysis of the errors due to changes in meteorological parameters such as temperature, pressure, and relative humidity along the propagation path in a timing system utilizing an RF Link. These meteorological parameters affect the radio refractive index along the propagation path and therefore can be correlated to observed changes in the received signals.

3. An experiment to determine the effect of RF multipath propagation on the accuracy of the timing system. The multipath effects arise from the reflection of the transmitted energy from terrain and airborne objects along the multiple paths, i. e. "clutter" paths. Such reflections of the transmitted signal may cause distortion of the original signal as well as an increase of its rise-time.

II. OVERALL OBJECTIVES OF EXPERIMENT

The feasibility study and experimentation involved in synchronizing clocks by means of an RF Link has the following objectives:

1. To what order of accuracy can coincidences of time and clock rate synchronism be obtained by clocks under idealized laboratory and actual environmental field conditions? One fundamental objective is addressed to the question: How can synchronization be established between two clocks and what order of accuracy can be attained by this synchronization method?

2. Over what intervals of time can a given degree of synchronization be maintained between clocks without re-synchronization?

3. What are the instrumental constraints involved in both the generation in fast rise-time pulses and measurement of time intervals between such pulses generated by different clocks?

4. To what extent does the environment of an airborne platform affect the precision of the clocks in the system --- i.e., effect of vibration, rotor-blade modulation, etc.?

5. What errors are introduced into one-way line-of-sight time measurement by weather conditions in the atmosphere and multipath propagation effects? What are the characteristics of such errors?

6. What is the spectral region of acceptable carrier frequencies for transmission in a synchronizing RF Link, considering both instrumental and propagation characteristics?

III. DEFINITIONS

In order to discuss an experiment involving the precise measurement of time or time intervals it is first necessary to define the concept of time to be used as a basis in the experiment. In addition to this it is required that the various technical terms to be used in the experiment be clearly defined.

1. TIME: Time is a fundamental physical parameter which well-nigh defies precise definition, and for which it is difficult to establish basic measurement standards. We begin with the intuitive notion of "time" as a continuous or flowing process; the flow of time is considered to be in such a way that the future, as commonly accepted, is in the positive direction. We then define a given rate for the flow of time. This rate must be a constant and known (defined) quantity in order to enable us to relate the flow of time to a fixed reference scale and to make consistent time interval measurements.

A second aspect of time involves a fixed reference scale on which instants of time are posited. For our experiment this scale need be valid not only for the limited environment of the laboratory, but subsequently to include as much of the terrain and atmosphere in which the timing systems are required to operate. On this time reference scale we can define a point T_0 ; at a later time, T_1 , we can define another instant and determine the time difference or interval, $\Delta T = T_1 - T_0$.

2. TIME & FREQUENCY STANDARDS:

A. CLOCKS - In the test or operational systems we will require equipment or a subsystem to establish a time reference scale and to measure time intervals on this time scale.

We establish such a clock in practice by observing some recurring natural phenomenon as exemplified by a quartz crystal oscillator or the electromagnetic radiation resulting from certain atomic and molecular energy level transitions. The mechanical motions and the electromagnetic fields resulting from such natural phenomena can often be described by a sine function. This is the output from our clocks to be utilized in the experiments. Points on the fixed scale are determined by a zero-crossing of the sine function starting at an arbitrary or designated instant. The rate of the clock is measured by the period of the recurring event in completing a cycle.

One device enabling us to determine a time scale is a counter. The counter can be started at a given instant, counting successive cycles of the clock output. At later instants, the counter can be stopped or its reading noted to associate a given event with the time scale established by the counter.

B. STABILITY AND ACCURACY OF A CLOCK - At this juncture it is necessary to introduce the problems of stability and accuracy of the clocks under consideration. The periods of the natural phenomena used for a standard are not all of equal length, but vary slightly, sometimes varying about a fixed mean, sometimes varying about a changing mean --- indicating a "drift" in our clock rate (e.g. due to aging effects in crystals). The mean period for the clock can be defined as:

$$\bar{T} = \sum_{i=1}^{n} T_i / n$$

where the T_i are successive periods for the recurring phenomena.

The mean rate is then given by:

$$\bar{R} = 1 / \bar{T}$$

In a natural process with a stationary mean the distribution of the T_i can be assumed to be normally distributed:

$$f(T) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(T_i - \bar{T})^2 / 2\sigma^2}$$

where σ is the standard deviation of the T_i about the mean $\bar{T}$.

In order for a measurement of time interval or frequency to be experimentally meaningful and usable, the accuracy and stability of the measuring device must be greater than that of the system being measured. Otherwise the measurements will reflect the combination of uncertainties and instabilities of the measuring device and the system under test. For this reason, in working with high precision timing or frequency systems, it is common to compare two or more of the systems in order to evaluate their relative accuracies and stabilities.

$$\text{Stability of clock (time drift)} = \frac{\Delta t}{T}$$

Δt = specification of desired accuracy of clock

Example for atomic clock:

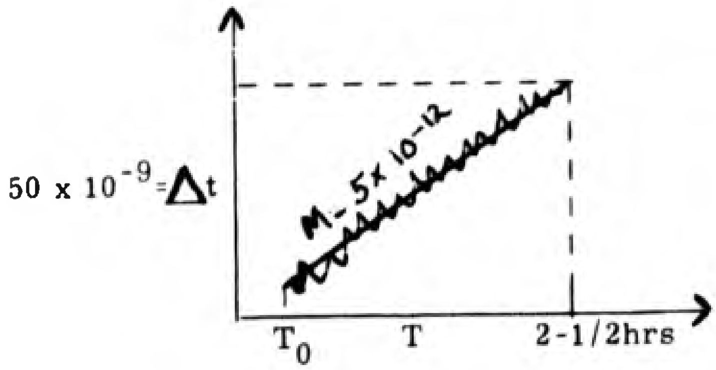
Let stability $= 5 \times 10^{-12}$

Let Δt = specification of desired accuracy

$= 50 \times 10^{-9}$

Then, $\dfrac{\Delta t}{T} = 5 \times 10^{-12}$ or

$$T = \frac{\Delta T}{5 \times 10^{-12}} = \frac{50 \times 10^{-9}}{5 \times 10^{-12}} = 10 \times 10^{3} = 10^{4} \approx 2\text{-}1/2 \text{ hrs}$$



In 2-1/2 hours the specified difference of the desired accuracy will be no greater than 50×10^{-9} seconds (50 nanoseconds) However, the individual pulse differences will be much less.

Examples for crystal clock:

1. Let stabili*y $= 5 \times 10^{-9}$

Let Δt = specification of desired accuracy

$= 50 \times 10^{-9}$

$$\frac{\Delta t}{T} = 5 \times 10^{-9}$$

$$T = \frac{\Delta t}{5 \times 10^{-9}} = \frac{50 \times 10^{-9}}{5 \times 10^{-9}} = 10 \text{ seconds}$$

2. Let stability $= 5 \times 10^{-8}$

Let Δt = specification of desired accuracy

$= 50 \times 10^{-9}$

$$\frac{\Delta t}{T} = 5 \times 10^{-8}$$

$$T = \frac{\Delta t}{5 \times 10^{-8}} = \frac{50 \times 10^{-9}}{50 \times 10^{-8}} = 10 \times 10^{-1} = 1 \text{ second}$$

BENCH TESTS

1. CLOCK ACCURACY AND STABILITY

2. TEST INSTRUMENTATION

3. LIMITED ENVIRONMENTAL TESTS

4. DEVELOP SYSTEM FOR R.F.LINK TESTS

FIGURE 2

MEASUREMENT OF THE TIME INTERVAL BETWEEN LEADING EDGES OF THE PULSES FROM TWO CLOCKS WITHIN SEPARATE CHANNELS:

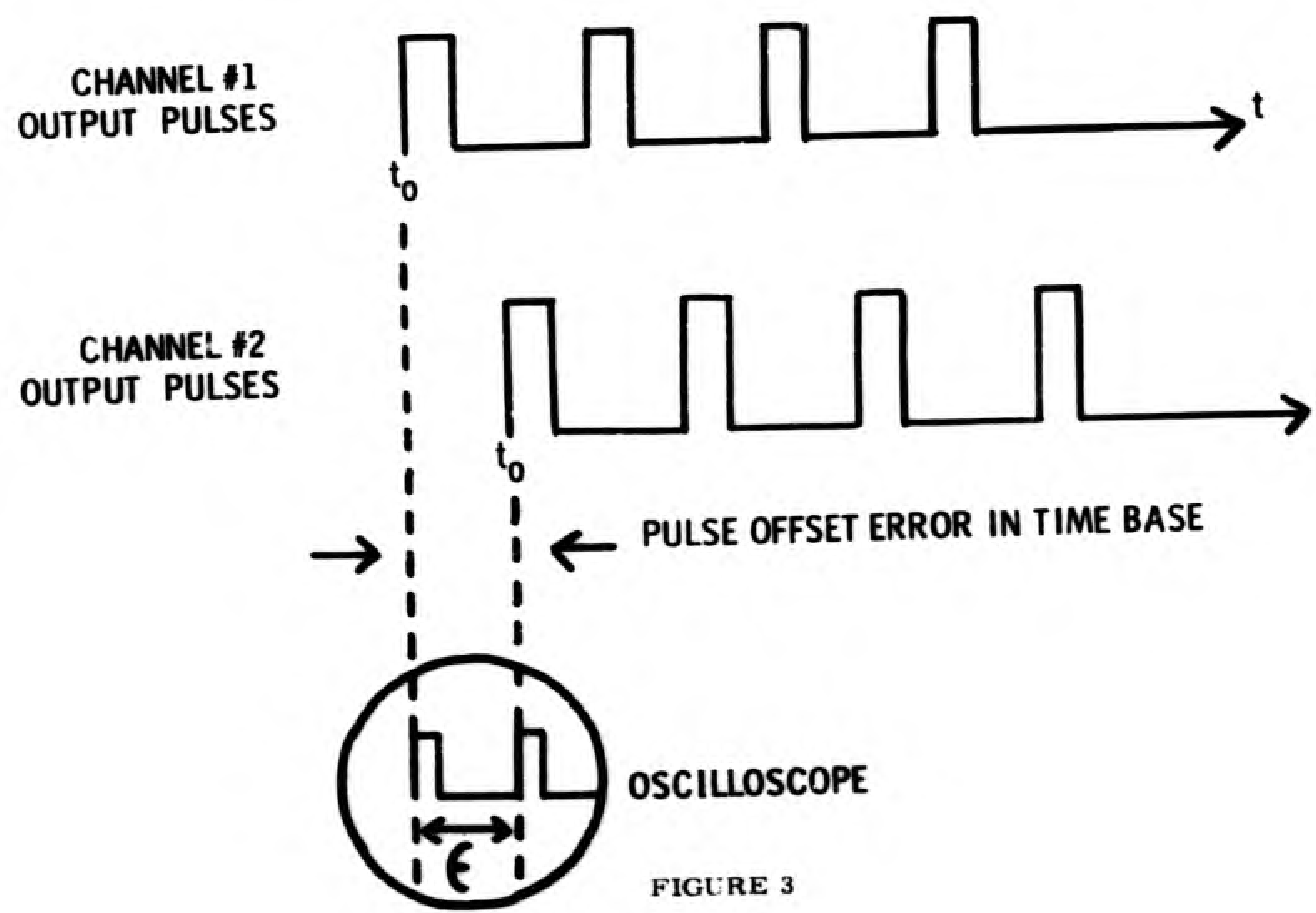


FIGURE 3

IV. EXPERIMENTAL APPROACH

In order to accomplish the experiment in as short a time as possible, it is deemed advisable to separate it into several subtasks which can be undertaken separately and concurrently. We have chosen three such subtasks:

. Bench tests to set up equipment and develop experimental techniques;

. RF Link tests, using equipment developed in bench tests in conjunction with an RF Link to determine the characteristics of the timing signals after transmission through the link;

. Studies of the effects due to the propagation of the RF signal through the atmosphere in the presence of changing meteorological conditions.

1. BENCH TESTS: The first of the three subtasks of the experiment is essentially to provide for familiarization of personnel with the equipment and the development of instrumental and measurement techniques. This subtask deals with ascertaining the accuracy and stability of a clock relative to a frequency standard. The factors to be considered are as follows:

a. To what order of accuracy can we synchronize several clocks under laboratory conditions?

(1) A Phase Comparison to check frequency (r[illegible]) synchronism presents no problem. The RF output from the clocks can be compared by the use of a Phase Comparator. Frequency synchronization can be realized by this method to approximately two or three parts in 10^{12}.

(2) The principle of the pulse comparison technique is as follows: two pulse trains of the same repetition rate (or frequency) are compared to determine the difference, ϵ, in time between the leading edges of the pulses in the two pulse trains. (See figure 3.) Each of the two pulse trains comes from a pulse generator controlled

BLOCK DIAGRAM OF EQUIPMENT REQUIRED FOR BENCH TESTS:

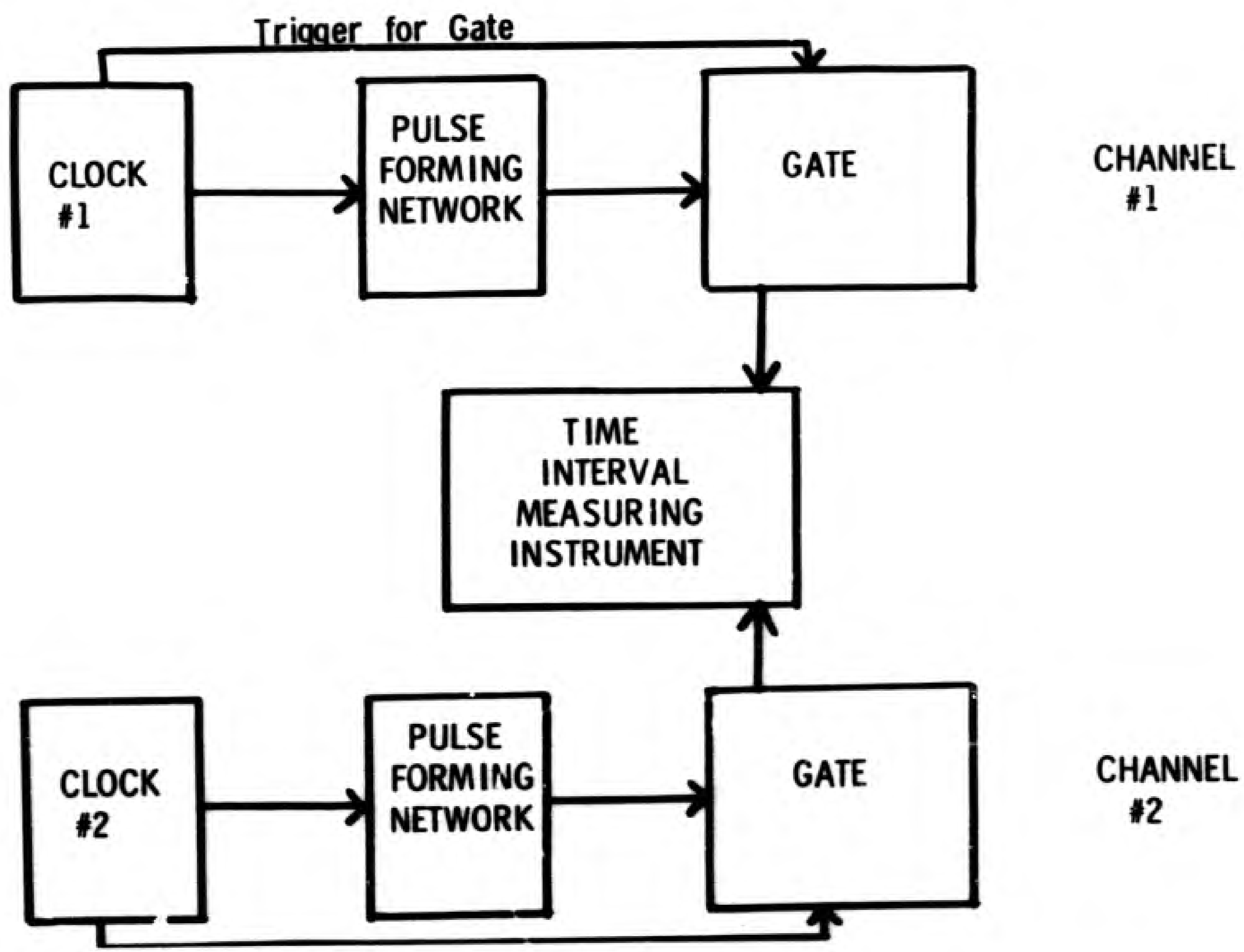
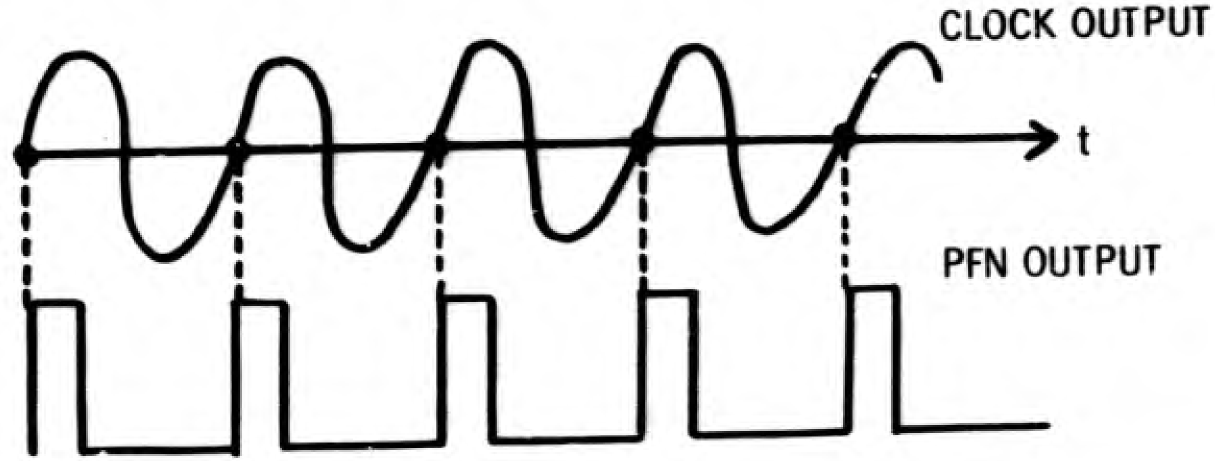


FIGURE 4

OUTPUT OF PULSE FORMING NETWORK:



EVERY TIME CLOCK COMPLETES A CYCLE,
PFN DEVELOPS A PULSE.

FIGURE 5

CLOCK PHASE MEASURED ON EACH CLOCK BEFORE SYSTEM IS ASSEMBLED:

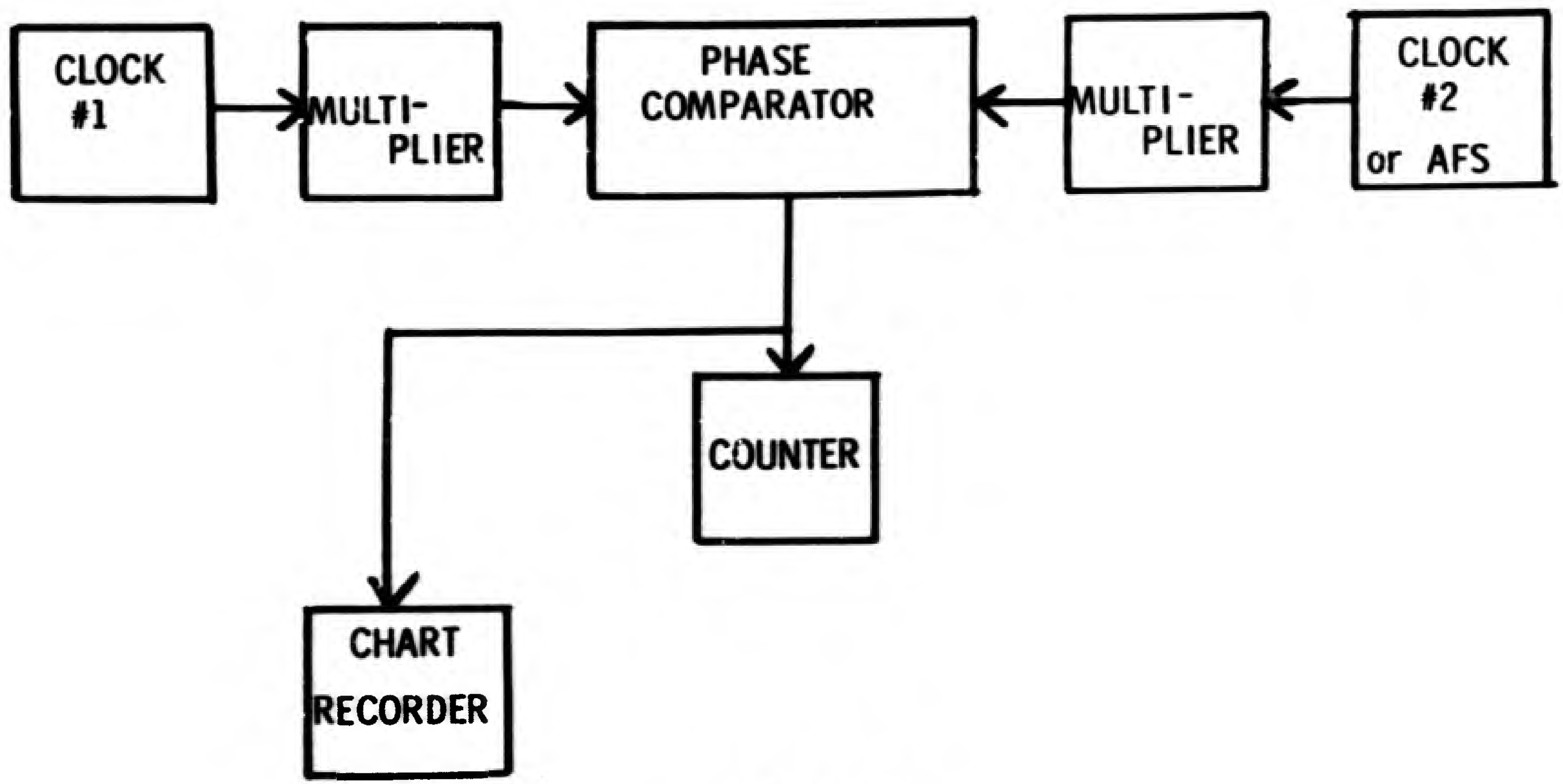


FIGURE 6

by a different clock. A block diagram of the equipment required is shown in figure 4 .

The operation of each channel is straightforward. The sine wave output of a clock is used to control a pulse generator as shown in figure 5 . The output of the pulse generator can then be gated to allow for selection of desired pulse intervals, or pulse train lengths.

The measured ϵ consists of two components: one due to the offset error between the time bases of the two clocks under test, the other due to errors in the pulse-forming network or measuring equipment. The component ϵ due to error in the pulse-forming network would probably appear as "jitter" or instability in the value of ϵ measured.

b. As part of this subtask of the experiment, two clocks are operated in a controlled laboratory environment. The outputs of the clocks are compared to determine the order of the synchronization of the rate that can be achieved under laboratory conditions, and over what time intervals the synchronization can be maintained.

Comparisons are made under varying environmental factors such as temperature, pressure, and humidity. Additional tests can be made under varying mechanical factors, e.g. comparison while one or both clocks are on a vibration bench.

It is during these initial tests that the measurable characteristics of the outputs of the clocks can be determined. Any changes in clock (equipment) performance due to environmental or mechanical factors can be noted at this time. (See figure 6 .)

There are two possible methods of recording the observed quantities: 1) High resolution oscilloscope using photographic and/or visual responses; 2) Magnetic tape (this method is desirable with rapid sampling rates and allows the use of a gated counter technique for direct computer processing of the data obtained).

2. RF LINK TESTS: In the second subtask of the experiment, the synchronization tests are continued, but with the clocks located at some distances from each other. This part of the experiment seeks to determine how the synchronization properties are affected by transmission of the pulses from one channel over an RF Link before comparison. Deterioration of pulse quality due to the characteristics of the transmission equipment and to the propagation of the RF signal between the two terminals of the system will be examined.

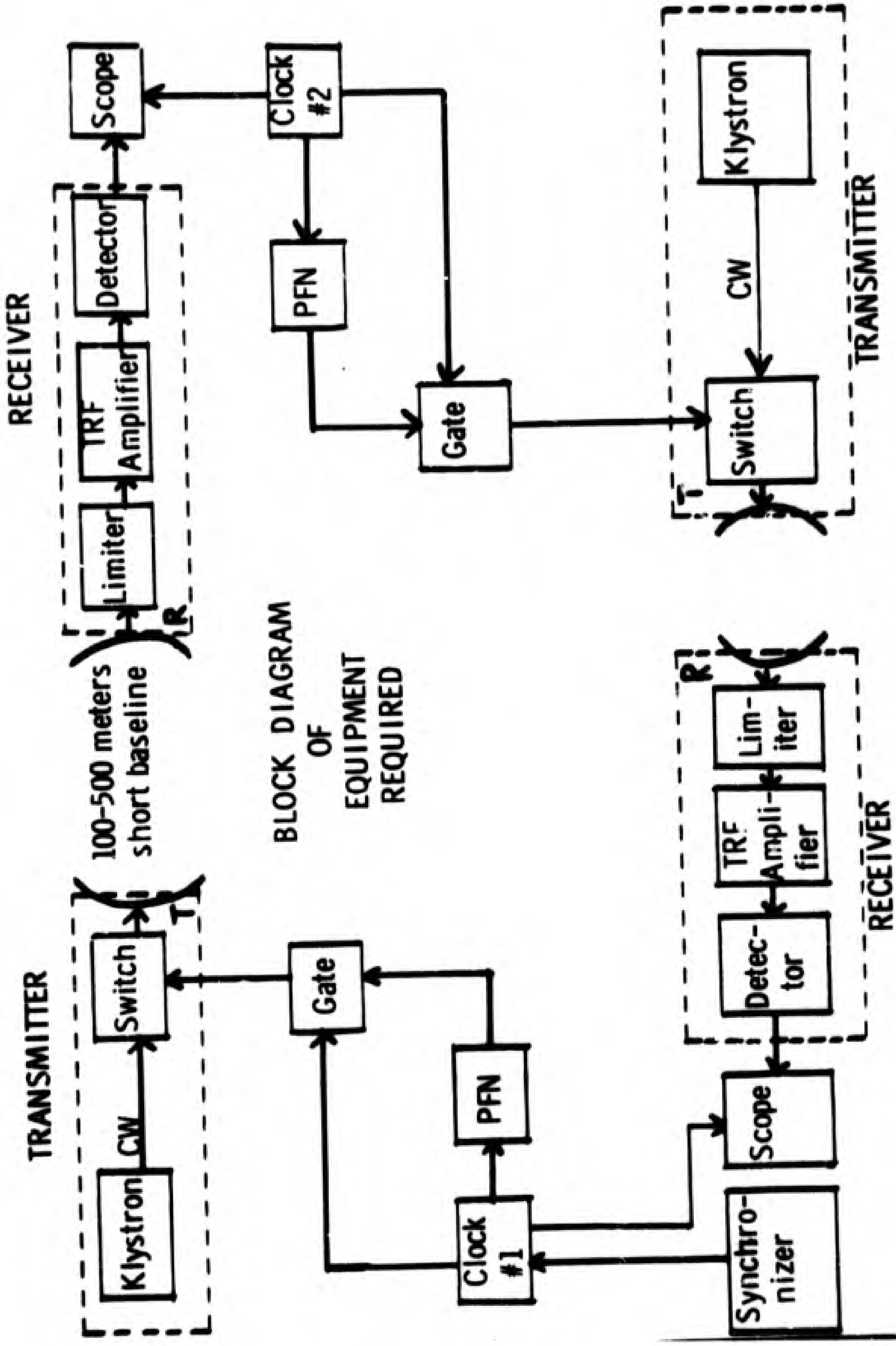

BLOCK DIAGRAM
OF
EQUIPMENT
REQUIRED
100-500 meters
short baseline
TRANSMITTER
Klystron
CW
Switch
T
Gate
PFN
Clock #1
Synchro-nizer
Scope
RECEIVER
Detec-tor
TRF Ampli-fier
Lim-iter
R
RECEIVER
Limiter
TRF Amplifier
Detector
Scope
Clock #2
PFN
Gate
TRANSMITTER
Klystron
CW
Switch

FIGURE 7

ATMOSPHERIC RADIO WAVE PROPAGATION

I

1. LITERATURE SEARCH
2. COORDINATION WITH OTHER ECOM LABS (ATMOS. SCI.)
3. COORDINATION WITH OTHER D.O.D. LABS
4. COORDINATION WITH GOV'T, UNIVERSITIES, INDUSTRY

II

1. SHORT BASELINE R.F. LINK TESTS
2. LONG BASELINE R.F. LINK TESTS
3. TESTS IN AIRBORNE ENVIRONMENT

FIGURE 8

The additional equipment required for this subtask is a transmitter and receiver for each terminal (to allow full duplex operation -- see figure 7). The transmitter can simply be a klystron excited by the pulses controlled by a clock, or whose CW output is switched to the transmitting antenna by a switch operated by the pulses. The receivers must be broadband to preserve the fast rise-times necessary in the system and simple tuned radio frequency amplifiers (using tunnel diode units) are envisioned. Each terminal will then be capable of comparing the signal received from the other clock with the output from its own clock.

We must also consider the carrier frequency requirements for the RF Link. Some of these requirements are as follows:

a. The highest feasible frequency is desired to maintain reasonable scale sizes for antennas to be used on aircraft.

b. Wide bandwidth is easier to obtain at higher frequencies.

c. Frequency should be below 16Ghz to minimize atmospheric absorption effects.

RF pulse transmission tests will be carried out using various carrier frequencies, e.g. 5Ghz, 10Ghz, 15Ghz, and 20Ghz. Results at the various frequencies will be compared for attenuation, multipath, and other induced propagation effects.

The tests in this subtask of the experiment will be carried out with fixed RF Link baselines from several hundred meters up to several tens of kilometers. The effects due to propagation, particularly reflection-induced multipath effects, will be observed in these tests. The measured effects will be analyzed and compared with theoretically expected results, taking into consideration the results of the third section of the experiment.

The final part of this subtask will be the operation of one or more systems in the airborne environment in which the system will ultimately be required to operate. During this stage of the experiment we will attempt to determine:

(1) What equipment modifications and/or special mounting will be required to insure proper operation of the clock-pulse generator sub-system in the aircraft environment,

(2) What additional propagation problems such as time varying multipath propagation effects are to be found in airborne operation, and

(3) Is actual air-air, and air-ground, time synchronization feasible using the planned system.

3. RF PROPAGATION EFFECTS: The third subtask of the experiment involves a study of the effects to be expected due to propagation in the RF Link. These effects will manifest themselves as phase and amplitude variations in the received RF signals and are due to varying meteorological conditions along the propagation path, and the presence of multipath propagation modes. The velocity of a radio wave propagating through the atmosphere is inversely proportional to the radio refractive index of the medium. The radio refractive index is a function of the temperature, pressure, and relative humidity within the volume of the atmosphere under consideration. In most cases the radio refractive index does not have a single value over the entire length of the propagation path. The atmosphere is found to consist of a number of cells or eddies of differing sizes, in which slightly different conditions of temperature, pressure, and relative humidity are present. To accurately predict the effects of propagation on a radio wave, it is necessary to know the range of sizes of the cells, their distribution along the propagation path, and the values of radio refractive index for each cell. As the atmosphere is a dynamic medium, it is necessary also to study how all of the above factors vary with time.

The actual calculations of the distribution of cells and the time variation of the medium becomes basically a problem in atmospheric physics. The major portion of this subtask can be accomplished through a study of the literature and consultation with investigators in

MULTIPATH PROPAGATION STUDIES

1. LITERATURE SEARCH

2. COORDINATE WITH OTHER LABS WORKING ON PROPAGATION

3. REVIEW RESULTS OF OPERATIONAL PULSE R.F.LINKS

4. TESTS USING R.F.LINK DEVELOPED IN BENCH TESTS

FIGURE 9

atmospheric sciences and those actually engaged in the study of atmospheric radio wave propagation.

If it is found that specific questions applicable to our system cannot be answered from outside sources it will be necessary to conduct the experiments in this Laboratory. Such measurements would be accomplished using the clock, pulse, and RF equipment developed under the first two subtasks of the experiment.

V. ASSESSMENT OF EXPERIMENTAL RESULTS

1. After the experimental data have been obtained they will be subjected to various statistical techniques such as covariance analysis, auto-correlation analysis and significance tests. This will be done with a view in mind to ascertain the adequacy, stability and accuracy of the timing system within each of the environmental and physical conditions enumerated. Of particular significance is the power spectrum analysis to be applied to the errors expected due to RF propagation through a turbulent atmosphere.

2. The final operational capability of the system will be determined by a combination of:

   a. The instrumental limitations.

   b. Characteristics of the clock outputs (e.g.: stability, etc.)

   c. Characteristics of the propagation-induced errors.

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COMPARISON OF REFERENCE SCALES FOR SYNCHRONIZATION OF CLOCKS

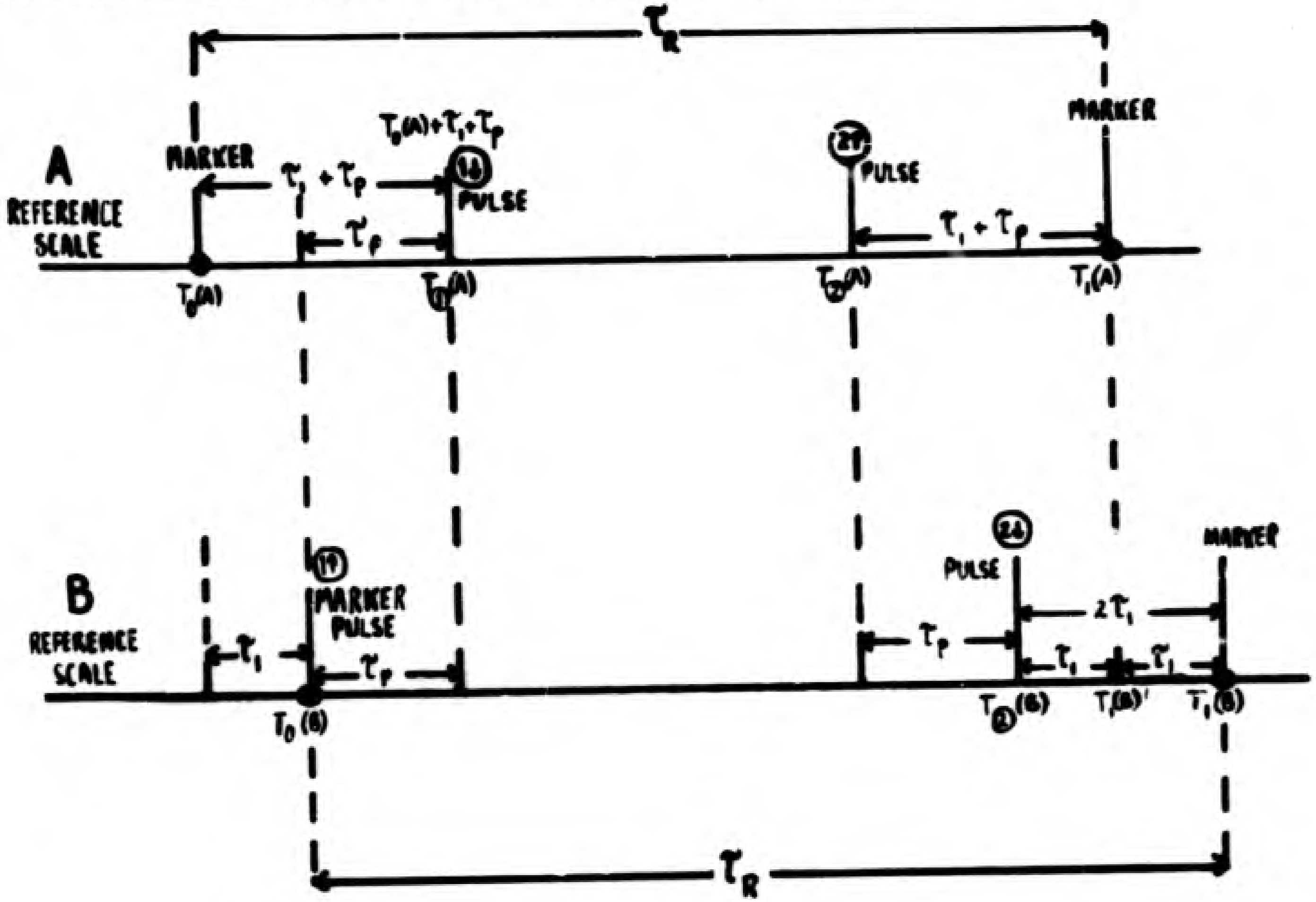

FIGURE 10

APPENDIX

THEORY INVOLVED IN PROCEDURE FOR SYNCHRONIZING CLOCKS USING ONE-WAY PULSE TRANSMISSION

1. The RF LINK subjects two reference scales from different clocks to a direct comparison. It is equivalent to placing both clocks under the same local environment so that the reference scales can be compared.

2. SYMBOLISM

τ_1 = difference of time zero between clock A and clock B .

τ_p = true propagation time between clock A and clock B ; τ_p is independent of the clocks.

$\tau_1 + \tau_p$ = difference of time zero between clock A and clock B plus true propagation time between clock A and clock B ; this is the time which clock A assumes to be the true propagation time between clock A and clock B .

$T_0(A)$ = marker for initial reference time zero on the clock A reference scale.

$T_0(B)$ = marker for initial reference time zero on the clock B reference scale; a pulse is developed at this instant by clock B to be transmitted to clock A.

$T_{①}(A)$ = instant at which clock A receives the pulse from clock B transmitted at time $T_0(B)$.

$T_{②}(A)$ = instant at which clock A transmits a pulse in the expectation clock B will receive the pulse at the instant $T_1(B)'$ on the B reference scale.

$T_1(B)'$ = instant on B reference scale representing image marker synchronized with $T_1(A)$ marker on the A reference scale.

$T_{②}(B)$ = instant at which clock B receives the pulse transmitted by clock A at time $T_{②}(A)$.

$T_1(A)$ = marker indicating the first repetition period after the initial reference time zero $T_0(A)$ on the clock A reference scale.

$T_1(B)$ = marker indicating the first repetition period after the initial reference time zero $T_0(B)$ on the clock B reference scale.

①↑ = pulse transmitted by clock B at time $T_0(B)$.

①↓ = pulse received by clock A at time $T_1(A)$.

②↑ = pulse transmitted by clock A at time $T_2(A)$.

②↓ = pulse received by clock B at time $T_2(B)$.

τ_R = repetition period of markers = $\dfrac{1}{\text{repetition rate}}$;

(repetition rates of both clocks are assumed to be equal)

3. SYNCHRONIZING PROCEDURE

Assumptions:

a. $T_{\textcircled{2}}(A) < \tau_R$

b. $\tau_p + \tau_1 = \tau_R - T_{\textcircled{2}}(A)$

c. Last synchronizing pulse (within a period) is transmitted by clock A at $\tau_R - T_{\textcircled{2}}(A)$ and satisfies the prior equation b .

d. τ_R of clock A = τ_R of clock B .

e. In the event the clocks are not synchronized, clock B will turn back its clock by the offset time to cause the clocks to be re-synchronized.

f. Neither clock is aware of the offset time (τ_1) existing between the two clocks.

$$T_0(B) = T_0(A) + \tau_1$$

τ_R of clock A = τ_R of clock B (repetition rates for both clocks are assumed to be equal).

$$T_1(A) = T_0(A) + \tau_R$$

Clock B transmits a pulse at $T_0(B)$ which is received by clock A at $T_{①}(A) = T_0(A) + (\tau_1 + \tau_p)$.

Clock A counts on its timer from $T_0(A)$ to $T_0(A) + (\tau_1 + \tau_p)$. Since neither clock is aware of the offset time (τ_1) existing between the clocks, clock A assumes that $(\tau_1 + \tau_p)$ is the actual propagation time for the signal transmitted by clock B .

There is no signal transmission by clock A between $T_{①}(A)$ and $T_{②}(A)$.

Clock A knows at which instant the $T_{①}(A)$ marker appears on the A reference scale and is under the assumption that $(\tau_1 + \tau_p)$ is the propagation time for the signal transmitted by clock B . Therefore, at $T_{②}(A)$ clock A determines that pulse (2↑) should be transmitted to clock B, because if the clocks are synchronized, clock B will receive the pulse at $T_1(B)'$ representing the image marker on the B reference scale synchronized with $T_1(A)$ on the A reference scale. In this expectation, clock A transmits a pulse (2↑) at $T_{②}(A)$ which is actually received at $T_{②}(B)$ by clock B.

Since pulse (2↓) fails to coincide with the $T_1(B)$ marker, clock B starts counting on its timer from $T_{②}(B)$ to $T_1(B)$. Clock B determines that pulse (2↓) received at $T_{②}(B)$ is off from the $T_1(B)$ marker by a time interval equivalent to $2\tau_1$.

Making use of the prior agreement under assumption e. , clock B turns back its clock by 1/2 of $2\tau_1 = (\tau_1)$. This is a master-slave situation because clock B (slave) adjusts itself to clock A (master). With a full duplex system, each clock would be corrected for 1/2 of τ_1 to re-synchronize the clocks.

4. MATHEMATICAL FORMULATION (See figure 10)

Objective: To show $T_1(B) = T_{\textcircled{2}}(B) + 2\tau_1$

$$T_0(B) = T_0(A) + \tau_1 \tag{1}$$

$$T_1(B) = T_0(B) + \tau_R \tag{2}$$

$$T_1(A) = T_0(A) + \tau_R = T_{\textcircled{2}}(A) + \tau_1 + \tau_p \tag{3}$$

$$T_{\textcircled{2}}(B) = T_{\textcircled{2}}(A) + \tau_p \tag{4}$$

$$T_1(A) = T_{\textcircled{2}}(A) + \tau_1 + \tau_p = T_{\textcircled{2}}(B) - \tau_p + \tau_1 + \tau_p = T_{\textcircled{2}}(B) + \tau_1 \tag{5}$$

$$T_{\textcircled{2}}(B) = T_1(A) - \tau_1 \tag{6}$$

$$T_1(B) - T_1(A) = T_0(B) - T_0(A) = \tau_1 \tag{7}$$

$$T_1(B) - T_{\textcircled{2}}(B) = T_1(A) + \tau_1 - T_1(A) + \tau_1 = 2\tau_1 \tag{8}$$

(Obtained by subtracting equation (6) from equation (7).)

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STOCK RATIONING

Mr. Alan Kaplan
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We are concerned in this talk with the Army National Inventory Control Point, or NICP, in its role as wholesaler of secondary items to the rest of the Army.

We have looked into how the NICP should use issue policy to help itself out when items it is managing are in short supply, but there is still stock on hand to play with. We investigated the utility of partial shipments to requisitioners, and also the rationing concept, which is what we will be discussing here.

The NICP receives demands of different priorities. Should it backorder low priority requisitions, for items in short supply, to have stock available for future high priority requisitions? The answer depends on the relative importance of high priority demand, and the chances that stock saved by backordering low priority requisitions will be usefully utilized.

There were three parts to our investigation:

a. determine the usefulness of stock rationing

b. determine the type of rationing rule to use

c. apply rationing to the specific Army situation

To investigate the first two aspects of the problem we used a somewhat simplified model. Stock is in short supply, but at some known date in the future, stock levels will be replenished. Two types of demand must be satisfied, low priority and high priority. High priority demands are always satisfied if possible. A low priority demand is satisfied only if stock on hand is above the "scheduled reserve" level. This scheduled reserve level is what is computed, using some rationing rule, to be the amount of stock to reserve for high priority if possible. The reserve level is recomputed periodically (e.g. bi-weekly) as the TTR, or time to stock replenishment, decreases. Something like this might happen: the reserve level is 20 while stock on hand is 19, so all low priority requisitions are backordered. Time passes, and no high priority requisitions are received; the reserve level falls with the passage of time to 15, and four units are freed for issue against low priority backorders.

We programmed this model as a simulation. Different rationing rules would be tested using the same demand history for each rule and comparing results. We kept track of requisitions initially filled and requisitions on backorder, but our basic performance measure was based on average number of units on backorder weighted by priority. A requisition for 10 widgets on backorder for 15 days would represent 150 backorder unit days. If it were a high priority requisition and the weight assigned high priority requisitions was 4, we would have the equivalent of 600 backorder unit days. Backorder unit days are divided by the number of days in the simulation to give us the average number of units on backorder weighted by priority. The weight assigned high priority requisitions was the means of expressing the relative importance of high priority demands. We treated it in most of our work as a parameter. However, it turns out that you need not say too much about what the exact weight is to make reasonable decisions. This is fortunate.

Four rules were tested in this part of our work.

SLIDE 1

Rules 2 and 3 are of the same form. They set the reserve equal to a proportion of expected high priority demand in the TTR. This is the simplest type of time dependent rule, or rule in which the reserve level depends on the length of time remaining before stock replenishment. We determined at the outset that a reasonable rationing rule should be time dependent. Rule 3 happens to be the optimum rule for deterministic demand. Rule 4 uses the results of an algorithm we developed, which actually gives us the mathematically optimum set of reserve levels under a limited set of assumptions. The first and most important assumption is that the distribution of demand for each review period, about the forecast of demand for that period, is known. The appendix gives a detailed derivation of the algorithm. (1)

In the first use of our simulation we ran it with artificial demand data. In using the algorithm to construct rule 4, we assumed the distribution of demand was Stuttering Poisson, with mean equal to the forecast of the mean. The artificial demand data was randomly generated in accordance with the Stuttering Poisson distribution. Thus, in this simulation we were able to compare a simple type of rationing rule with what we knew to be the best rule possible under the circumstances.

We had two cases.

SLIDE TWO

C_h is the "cost of high", or weight assigned high priority requisitions. VMR is the Variance to Mean Ratio. Look at case 2. The slide tells us that for a weight of 10 rule 4 specified reserve levels of 47 for TTR of 8 weeks, 37 for TTR of 6 weeks and so on. Note that these particular levels are quite different than the levels specified by the other rules. For each case there were 324 trials: the initial TTR was 56 days so each trial was 56 days.

SLIDE 3

In this slide average backorders(weighted by priority) for rules 1, 2, and 3 are compared to average backorders for rule 4. For instance, for a weight of 10 for case 2 average backorders weighted by priority for rule 3 were 4.89% larger than for rule 4. Note that rule 4 always gives the best results as we would expect. In a few instances, rule 4 showed a particularly small improvement. As a quick and very dirty measure of the statistical significance of the improvement we calculated "t" statistics as indicated in the slide. These statistics were large. We note that the improvement realized by rule 4 is only marginal. For instance, for case 2 for a weight of 10 while rule 4 gave us much smaller weighted average backorders than rule 1, we could have achieved most of the benefit of rationing by using rule 3, even though the actual reserve levels specified by the simple rule were quite different.

We ran the simulation using actual demand history on 235 items supplied us by U. S. Army Aviation Command. In the actual simulation, we used 336 days of history per item, so that if the initial TTR was 56, we would have 336 divided by 56 or 6 trials per item. In computing penalties for each rule shown, we used the average value of backorders weighted by priority, not just the average number of units on backorder.

SLIDE 4

Note the improvement as the initial TTR increases to 112 days. The explanation is that for stationary or quasi stationary demand processes demand forecasts will be more accurate over longer periods since irregular fluctuations in demand become less signficant.

The conclusions drawn from this part of our study were that:

a. Stock rationing is useful weights above 4 and becomes truly worthwhile as the weight approaches 10.

b. Additional improvement to be realized by using a sophisticated rule will in most cases be small. For large hypothesized weights for high priority it would become more worthwhile to use a sophisticated rule since even marginal improvement could become signficant.

To apply rationing to the Army's situation, we had to determine the exact proportion of expected high priority demand which should be used as the reserve level, and cope with the fact that there are more than two priority groups we wish to distinguish between.

Using our simulation, we graphed the improvement to be expected using proportions of expected high priority demand of .5, .75, 1.0, 1.25, and 1.5 for weights between 1 and 100. Even for weights of 100 a proportion of 1.0 did not do much poorer than a proportion of 1.5. We concluded that if the correct weight is believed to be in the 3 to 10 range, a proportion of .75 is indicated, while if the correct weight is to believed to be at least 5, a proportion of 1.0 should be used. In reaching this conclusion, we looked at several measures of performance.

Suppose now we have 3 priority groups instead of 2. We would then have 2 reserve levels, the first to protect stock for group 1 customers against group 2 customers and the second level to protect stock for group 1 and 2 customers against group 3 customers. If the relative importance of priority group 1 relative to group 2 was in the 3 to 10 range, and similarly for group 2 relative to group 3 we would have

Level 1: = .75 expected group 1 demand in the TTR

Level 2: = expected groups 1 demand + .75 expected group 2 demand in the TTR

If level 1 was 20 and level 2 was 30 at some point in time then: if the stock on hand was above 30, we would issue to all requisitioners, if it was between 20 and 30, we would issue only to groups 1 and 2, and if it were below 20, we would issue only to group 1 requisitioners.

The derivation of the algorithm for computing mathematically optimum reserve levels is given in the Appendix. This is basically a dynamic programming approach, with one twist in setting up the basic recursive equation. For the first reading it is suggested that equation 1 be mastered, then that the two lemmas be just read and the section titled "The Algorithm" be glanced at. Assumption 2 of the algorithm implies that there is no feedback i.e. if you backorder a low priority requisition this will not induce additional high priority demand. For some types of low priority requisitions this will not be true; however, there are good reasons why we have ignored feedback both in the algorithm and the simulation itself.

Note 1: Essentially the same results have been derived independently by Donald M. Topkis, Decision Studies Group, Palo Alto, California. The case where demands are lost rather than backordered is also treated by Mr. Topkis, and he worries about holding costs.

THE OPTIMUM SCHEDULED RESERVE LEVELS

Assumptions

i. High priority demand in any period is independent of demand in any other period, and whether that demand was satisfied. The time between successive opportunities to change the scheduled reserve level is considered a period.

ii. No penalty costs are incurred on a low priority unit backordered from the time it is received until the beginning of the next period. Equivalently, the assumption can be stated: low priority demand always occurs at the beginning of a review period. The beginning period time sequence is: receive low priority demand, recompute scheduled reserve level, issue if warranted against any outstanding low priority demands.

iii. Assumption "a" is that the probability distribution of demand for a period, about the forecast of demand for that period, is known. Assumption "b" is that the distribution and forecasted demand are the same for each period.

iv. High priority demands occur only during the middle of a review period.

Assumptions 3b and 4 are made for ease of exposition only.

The existence proof:

1) $E_{i+1,k,\theta}(x+1) - E_{i+1,k,\theta}(x) =$ (this is the basic equation)

for $k \le x \le \theta-1$: $A(x) + B(x)$

$$A(x) = 1 - (C_h/2) \cdot p(d \ge x+1)$$

$$B(x) = \Sigma_{d=x+1-s_i}^{x} p(d) \cdot [E_{i,k',\theta'}(x+1-d) - E_{i,k',\theta'-1}(x-d)]$$

$$+ \Sigma_{d=x+1}^{\infty} p(d) \cdot i \cdot (1-C_h)$$

for $k > x$ difference is zero

for $x \ge \theta$ difference is undefined

$E_{i+1,k,\theta}(x)$ is: the total expected penalty costs to the system during periods i+1 to 1. (There are i periods after period i+1 before stock replenishment.) This expectation is conditional upon some set $\{S_i\}$ of scheduled reserve levels being used for periods 1 to i .

x is stock to be kept as a reserve in the period.

θ is stock on hand (before any issuing).

$p(d)$ is probability of high priority demands totaling d units in the period.

$p(d \geq x)$ is probability high priority demands total at least x units.

k is net stock, or on hand minus demands outstanding.

C_h is penalty per period per high priority unit backordered. For low priority penalty is 1.

For $k > x$ all outstanding demands are satisfied whether reserve kept is x or $x + 1$. Under assumption 2, this determines all action until the next period. $X \geq \theta$ implies $x + 1 > \theta$ which is impossible by definition.

Otherwise, the difference in expected penalty costs may be broken down into the difference for period $i + 1$, and the difference thereafter. With a reserve of $x + 1$, and $k \leq x$, one more low priority unit is backordered in period $i + 1$ than with a reserve of x, at a penalty cost of 1. On the other hand, one less high priority unit will be backordered if high priority demand totals at least $x + 1$: the saving is then $C_h/2$ using assumption 3b.

The difference in expected penalty in periods 1 to i depends on high priority demand in period $i + 1$. If $d \geq x + 1$: there will be no stock on hand at the beginning of period i. The system is frozen in a sense: 1 more low priority and 1 less high priority unit is backordered with the initial reserve of $X + 1$. If $d < x + 1 - S_i$: on hand at the end of period $i + 1$ will be $\geq S_i$ regardless of whether the initial reserve was x or $x + 1$. By definition of S_i the system will look the same from then on. If $x + 1 - S_i \leq d \leq x$, then the reserve kept for period i will be the reserve kept for period $i + 1$ minus "d", for this quantity will be smaller than S_i.

1') $E_{1,k,\theta}(x+1) - E_{1,k,\theta}(x) = 1 - (C_h/2) \cdot p(d \geq x + 1)$

where it is not zero or undefined. This is the basic equation, as it appears for period 1.

Lemma 1: The difference of equation 1 does not depend on k or θ so long as $X \leq x \leq \theta - 1$.

We use an induction argument. The lemma trivially holds for period 1. The only way the difference for period $i+1$ might then depend on k or θ is if the probability that $k' \le x - d \le \theta' - 1$ depended on k or θ. But $k \le x$ and $k' \le k - d$ implies $k' \le x - d$. And if a reserve of $x+1$ is kept for period $i+1$, on hand at the end of $i+1$ is $x+1-d$. Hence $\theta' - 1 = x - d$.

Lemma 2: The difference of equation 1 - $\Delta E(x)$ - is monotonic increasing as a function of x for the range of x such that the difference is not trivially zero, and for any S_i which is not demonstrably non-optimal.

We again use an induction argument. For period 1 the statement is true as $p(d \ge x+1)$ is monotonically decreasing.[2]

For period $i = 1$ $\Delta E(x+1)$ minus $\Delta E(x)$ $= T_o + T_1 + T_2 + T_3 + T_4$

$$T_o = p(d \le x - S_i) \cdot 0$$

$$T_1 = p(d = x + 1 - S_i) \cdot [-\Delta E_i\ (S_i - 1)]$$

$$T_2 = \Sigma_{d=x+2-S_i}^{x}\ p(d)\ [\Delta E_i\ (x+1-d) - \Delta E_i\ (x-d)]$$

$$T_3 = p(d = x+1)\ [\Delta E_i(0) - i\ (1 - C_h) - (-C_h/2)]$$

$$T_4 = \Sigma_{d=x+2}^{\infty}\ p(d) \cdot 0$$

That T_1 is ≥ 0 will be shown later. This proof will clarify use of the non-optimal clause. Each term of T_2 is ≥ 0 by the induction assumption. T_3 is ≥ 0 as $\Delta E_i(0) \le i \cdot (1-C_h)$ in magnitude.

Proposition 1: Let net stock in beginning of period i be k, on hand be θ. Let S_i^* be an optimum value for the scheduled reserve level, possibly dependent on k and θ. The set of optimum S_i^* for period i, $\{S^*\}_i$, is non-empty.

If we look at all values of x where it is not trivially non-zero, $\Delta E(x)$ must be always non-negative, always non-positive, or there can be at most one change of sign, the change being from negative to positive as x increases. This is a restatement of lemma 2. If $\Delta E(x)$ is always non-negative, a subset of S^*_i is all $S_i \le k$, and if it is always non-positive all $S_i \ge \theta$ form a subset. If there is a change of sign, let x' be the maximum x for which the $\Delta E(x)$ is negative. $S_i = x' + 1$ is in $\{S^*\}_i$.

In the proof of lemma 2, we had to show $\Delta E_i(S_i - 1)$ was non-positive. We now see that if it were positive S_i would be demonstrably non-optimal (for period i monotonicity was assumed by induction).

Proposition 2: There exists at least one optimum scheduled value for the reserve level for period $i + 1$ which is independent of k, θ .

Choose k small, θ large. By proposition 1, there is at least one optimum value, which may depend on k, θ . We show that any optimum value for k, θ is also optimum for net stock = k' , and on hand = θ' , when $k \le k' \le \theta' \le \theta$. Suppose the value is in the interval $(k' + 1, \theta' - 1)$. By lemma 1, $\Delta E(x)$ in this interval is the same for the two cases. Therefore, the same reasoning which proves the value optimum in 1 case, prove it optimum for the other. If there is a value of $S_i^* (k,\theta)$ - notation has obvious interpretations - which is $\le k'$, then $\Delta E(x)$ is non-negative for $x \ge k'$, for both cases, and all values of $S_i \le k'$ are optimum for the (k', θ) case. Similar reasoning takes care of optimum values of $S_i^* (k, \theta) \ge \theta'$.

The Algorithm

The optimum schedule is calculated recursively using equation 1. For each period $\Delta E(x)$ is calculated, beginning with $x = 0$ and incrementing x by 1 until a positive value for the difference is obtained. (θ is taken implicitly to be larger than x, k negative.) This provides the optimum value for that period. At the same time the values for the differences are saved for use in the next period (begin with period 1, then period 2 and so on.)

In doing the calculations, assumption 4 should be relaxed. Hence, an expression is needed for the expected time remaining in a period after the x + 1st high priority unit is demanded, given that at least $x + 1$ high priority units are demanded in one period. For the Stuttering Poisson distribution the desired expression is

$1 - (x + s)/\lambda s - [\Sigma_{d=o}^{x} \; d \cdot p(d)/_{\lambda s} - p(d \le x)]/p(d \ge x + 1)$ where λ is the frequency of demand per review period and s is the average order size.[3] For the Stuttering Poisson distribution there is a nice algorithm available for calculating the necessary probabilities.[4]

Note 2: Without assumption 4 we would have to put things a little differently. Let z be the time remaining in period $i + 1$ after the x + 1st high priority unit is demanded, z being defined as 0 if this event does not occur in the period. Then $E(z)$ is monotonic decreasing with x and $C_h E(z)$ should be put inplace of $(C_h/2) \cdot p(d \; x +1)$ in equation 1. T is no longer exactly zero.

Note 3: This result is based on work done by Edward Bruckner, University of Pennsylvania, and Djoerd Hoekstra, U. S. Army.

Note 4: See Feeney, G.J., and Sherbrooke, C.C., "(S-1,S) Inventory Policy under Compound Poisson Demand,"Management Science, January 1966, p409-411.

Figure 1 (Slide 1): Four Rationing Rules

1) Set reserve level = to 0 i.e. do not ration

2) Set reserve level = to expected high priority demand remaining in the TTR.

3) Set reserve level = to expected high priority demand multiplied by $(C_h - 1)/C_h$ or "cost of high" is the weight assumed for high priority demand.

4) Use results of algorithm.

Figure 2 - Two Artificial Cases

	Case I	Case II
mean demand/pd-hi prior.	2.1	7.0
VMR -hi prior.	5.0	19.0
mean demand/pd-lo prior.	4.2	21.0
VMR -lo prior	11.0	1 (constant order size of 30)

Reserves by period

	Case I				Case II			
Ch = 2								
rule 1	0	0	0	0	0	0	0	0
rule 2	8	6	4	2	28	21	14	7
rule 3	4	3	2	1	14	11	7	4
rule 4	3	2	1	0	11	6	1	0
Ch = 4								
rule 1	0	0	0	0	0	0	0	0
rule 2	8	6	4	2	28	21	14	7
rule 3	6	5	3	2	21	16	11	5
rule 4	8	6	4	1	27	21	13	2
Ch = 10								
rule 1	0	0	0	0	0	0	0	0
rule 2	8	6	4	2	28	21	14	7
rule 3	8	6	4	2	25	19	13	6
rule 4	13	11	8	4	47	37	27	13

Figure 3 - Results from Artificial Trials: relative penalty costs
Rules vs. Rule 4

	Case I	Case II
Rule 1 vs rule 4		
Ch = 2	101.1%	101.0%
Ch = 4	113.2%	112.7%
Ch = 10	145.7%	144.3%
Rule 2 vs rule 4		
Ch = 2	105.1%	105.0%
Ch = 4	100.2% ("t" = 2.42 n = 125)	100.3% ("t" = 2.25 n = 227)
Ch = 10	103.2%	103.3%
Rule 3 vs rule 4		
Ch = 2	100.7%	101.2%
Ch = 4	100.9%	100.8%
Ch = 10	103.2%	104.8%

Figure 4: Results using actual demands

	Ch=2	Ch=4	Ch=10
56 days per trial			
rule 2 vs no reserve	103.0%	100.4%	97.7%
rule 3 vs no reserve	100.9%	99.9%	97.7%
rule 4 vs no reserve	100.0%	99.7%	98.1%
84 days per trial			
rule 2 vs no reserve	103.1%	99.1%	94.6%
rule 3 vs no reserve	100.7%	99.0%	94.7%
rule 4 vs no reserve	100.1%	99.0%	93.4%
112 days per trial			
rule 2 vs no reserve	102.4%	98.4%	94.1%
rule 3 vs no reserve	100.6%	98.2%	94.4%
rule 4 vs no reserve	99.9%	98.4%	93.4%

BANQUET ADDRESS

Mr. Robert Weinberg
Anheuser-Busch, Incorporated

Thank you. General Clark and Colonel Billingsley are two difficult acts to follow.

What I would like to do this evening is discuss senior management's view toward Operations Research and toward management sciences. It is difficult for me to do this, to speak to a group of this sort, without some personal reminiscences, some of which are relevant and some of which are totally irrelevant.

I actually cut my analytical teeth, so to speak, with the Air Force in Project SCOOP; Scientific Computation of Optimum Programs. I enjoyed military Operations Research, and when I left the Air Force I returned to military Operations Research, this time for the Navy with the MIT operations evaluations groups. Having gone through two complete cycles of military Operations Research, I tried IBM and stayed there about 10 years. Then about 8 months ago I joined Anheuser-Busch. I find that I can still start a talk by writing "THINK" on the blackboard, but I immediately change the T to a D and the H to an R.

I think the interesting point in this discourse, this personal reminiscence, is something I would like to put on the table. Can you imagine a Midwestern brewery, a brewery that sells about 650 million dollars worth of beer annually, hiring IBM's chief analytical executive? This, you know, is unheard of. Some of the statisticians will say, "Well, Gossett worked for a brewery." I think this is an indication of something that's happening in American business. Two years ago, I was in Washington attending some lectures. One lecturer was a gentleman with political views as far to the right as Louis XIV. During his lecture, I made a comment to the fellow sitting next to me. The speaker heard me, looked down, and said, "I gather you disagree with me." I said, "Well, yes, I do." He said, "Well, young man, if you thought about it, you would see that it is obvious that I'm right. If I'm wrong, how did we win World War II?" The conclusion that I reached was, and I say this with all due respect, that one of the most instrumental factors in our winning World War II was the fact that Germany and Japan had a counterpart of the Pentagon. This is a harsh thing to say, and I am now going to defend this position with a theory. The theory I am going to offer I will call the "Theory of Mutual Ignorance." I am going to give you the business version of the "Theory of Mutual Ignorance." It works this way: take the dumbest move your company has made in the current planning period, and the odds are extremely high that your competitors have made an equally stupid move in the same time period. If this is true, the errors cancel out. You do get a report card in business, but the people who grade your report card are generally security analysts and bankers who are not too imaginative. It is very similar to a group of students conspiring against a professor who marks on the curve.

Let's develop this notion of mutual ignorance in business. How many companies have 25 year old vice-presidents who are not the sons of 55 year old board chairmen? The answer is "very few, reasonably few." The acquisition of wisdom (and the acquisition of intelligence and the acquisition of insight) is an evolutionary process. But it is a slow process. A bright young man has to graduate from a business school or an engineering school, and he generally has to work his way up in a corporation. This takes time. The change is slow. It is an evolution. And so, traditionally, it has been impossible in business for a company to get much brighter than its competitors quickly. There is a balance of power which provides a basis for this "Theory of Mutual Ignorance." Something has happened since World War II, and this disturbs business men. What has happened is that there has been almost a revolution in management practices. They have been so systematic, so orderly, so obvious, that they are not even being discussed. I think three things have happened.

The first thing that has happened is the availability of data. When I speak of the availability of data, I might classify data into internal data (data that are available within the enterprise), and external data (data provided by the government, data provided by trade associations, and so forth). I think I can further classify these data into data that are available in machineable form and data that are available in non-machineable form.

My wife completed her doctoral work at Columbia in 1962. She took many of the same courses that I had taken 10 years earlier, and she was able to prove all sorts of things that I couldn't prove. She was able to do this by the availability of 10 more years of data. There were things that we were conjecturing about then that an econometrician or a mathematical economist could very well prove today. The quality of data has improved. When I had been with IBM about five years, I ran all of the corporate market research projects. At that time we were using data that were released by the government representing the structure of the economy five years earlier. Today the data we are using are about last year's economy. And so, we have the availability, just the plain old availability, of data.

There is something else that is even more significant from the management's point of view. Several years ago at IBM I wanted to do a quarterly assessment of our competitive position. Everybody agreed that we should do this study producing a set of planning factors or statistics to tell us how successful various marketing strategies were. We decided at IBM, a company that was then a billion and a quarter dollar business, that we couldn't afford these studies. It was just too expensive to collect these data for decision making purposes. About three or four years later, with changes in the accounting system of the company, most of these data became available as <u>part of the administrative system</u>, part of the accounting system. What we were doing for management control and analysis is re-processing data that exist in machineable form for some other administrative purpose. I can cite many examples in business where the company that couldn't afford to prepare the data for extensive analysis now has the data as a by-product of a central administrative system. This is extremely important, the availability of data.

The second thing is the availability of computers. There isn't a company in the United States today, indeed a company in any major country in the free world, that doesn't have virtually complete access to computers. Every larger company has computers, in fact probably too many of them. Smaller companies can use service bureaus, data centers, and so on.

We have the data, we have the computers. We have the basis for doing something. We have the evaluation tools. Since World War II there have been really dramatic developments in the area of methodology. When I started my academic career in mathematics, they used to s y, "If you want to get a mathematician sore as hell, find him some practical use for his output." That branded you in the profession. Principally as a result of World War II, as a result of agreement on the part of the Defense Establishment that war was not only hell and war was not only costly, but was also fairly complicated, you had a strange union between military establishments and scientists. Actually, when you think about it, prior to World War II, with very, very few exceptions (Bell Labs, General Electric, maybe three or four others), really first class scientists would never engage in any kind of applied research. Most certainly not for commercial enterprises; possibly government, but never commercial. As the result of the union between the enterprises, scientists, and policy makers as a result of World War II, an extraordinary body of analytical knowledge has been developed. In fact, in some cases it has been highly overdeveloped. Here I think you have some very interesting communications problems.

Shortly after I joined IBM I was loaned back to Washington to work on some broad defense problems involving Soviet threat capability. We were speculating about possible Soviet submarine based missile systems, we were looking at various aspects of our vulnerability to such a system. I formulated a model and decided I didn't know what to do with it. It was too complicated. I had a friend who was then a professor of mathematics at one of the larger state universities, and who had just completed some work for the Air Force and had the necessary security clearances. I called him and invited him to come to Washington to help me with the problem. He was just delighted to. He came to Washington, I explained the problem, and he wanted to think about it. About three days later I received a call in my hotel about 4:00 o'clock in the morning (which my wife appreciated), and he said, "I've solved the problem." I said, "Good, come over for breakfast tomorrow morning and we'll discuss it." About 6:30 in the morning there was a knock at the door. He was there for breakfast, which my wife appreciated even more than the telephone call. Clutching a sheet of paper, he looked at me and said, "Bob, I've solved the problem if you allow me to make one simplifying assumption." I said, "All right. What's that?" And he looked at me and, in all sincerity said, "The earth is flat!"

We all laugh at this, yet my friend (I'm cautious not to use his name because he is now very much involved in military Operations Research), produced an extremely useful piece of information. He demonstrated conclusively that, taking all the verbal foliage and emotionalism aside, there was no solution to the problem. "Stop wasting your time" was a significant result. We're all willing to laugh at it. But how many times and how much effort have we wasted on problems where some good, heavy, theoretical kind of analysis would say, "Look, you're wasting your time."

I cited this as an example of the communications problem. I think my friend would have lasted maybe 25 minutes in such a presentation to senior management of a corporation. He could have said to me, "Bob, there's no solution to the problem unless the earth is flat." Or more conclusively, "Look, you fool, the only way this would work is if the earth is flat." He chose his words incorrectly. No, he didn't, he acted like a mathematician. We do have this communications problem.

We have the data. We have the computers. We have the tools. Opposing these developments is the inertia of management. Think about it. When you attain senior management heights in industry, where can you go? Only one way: down. I think this is one of the reasons many managers tend to be conservatives. It may be a little harsh saying that, but I think that senior managers say, "We have a bag of tricks, we have rules of thumb which have worked so far. Why not continue to use them?" This management inertia is being acted upon by a stimulating counter-force. What is this counter-force? If you study American business history, I think you will find that with very few exceptions, prior to World War II you can't find a situation where a single erroneous decision wreaked havoc with a large company. Two major erroneous decisions were Chrysler's airflow and Henry Ford's decision on the model change. Look at the post World War II situation. You can start with Lever Brothers' decision not to manufacture detergents. The General Dynamics Company has the dubious distinction of having the largest deficit ever achieved by a non-government agency. The immediate situation at Douglas (they went broke without knowing it) are examples of where major companies have gotten into awful trouble with essentially a single erroneous mistake. From this, can we conclude that management today is dumber than management was before the war? I think, if anything, management is far more professional and far more sophisticated today. What has happened is that business is becoming complicated.

I think there are two factors that have complicated business. One is the long lead time. Let's take the Edsel. It has been argued, and I don't share in this view, that if the day the decision was made to create the Edsel, if they could have had the cars in the show room, they would have been successful. I've heard that argued by people who were involved with the Edsel, and I don't think it is true. But I don't think you can discount it.

We have recently announced the purchase of a brewery site in Greensboro, North Carolina. When are we going to build this brewery? Well, we won't even begin to build the brewery for at least two years. It takes two years to build the brewery. It will be at least four years before it is in operation. You are forced to think ahead.

Here is a second change I think is very significant. If you look at the resources that are available to a company, you might first look at the total resources that are available to get into new ventures. Then if you look at the resources you have to lay on the table to do one new thing, you find that this one-venture requirement has been going up faster than the total resources are going up. This is a preposterously complicated way of saying you have fewer chances at bat. Why do you have the opportunity to make a big mistake? Because you make big decisions.

Is management aware of this? Of course management is aware of it. Let us think about this for a minute. I think it is impossible to read four consecutive issues of "Business Week" without finding an article on some reasonably sophisticated aspect of management. It is almost impossible to read two consecutive issues of "Harvard Business Review" without finding an article that is either reasonably mathematical or has an appendix that is mathematical. Something that is even more startling to the business community: marketing is the last intuitive stronghold of management. Marketing is subjective, it is emotional, it is the last intuitive stronghold of management. Yet every major publisher of technical books in the United States today has either published or has in press a book on mathematics in marketing. This is a measure of the change. Publishers are mercenary; they publish because people buy.

We have data, we have computers, we have a body of analytical knowledge, we have structural changes in the environment of business which create an incentive to change. I submit that the changes affect all of us.

Consider Anheuser-Busch and how we have used management science and Operations Research. Let me give you some statistics which I think are relevant. In 1947, Anheuser-Busch had 4.1% of the beer market. In 1952 they had 6.3% of the beer market. In 1957 they had 7.1%, in 1962 they had slightly less than 10%. Last year we had 13.0%, and the first quarter of this year we had 15%. These are published data. In 1963 Anheuser-Busch earned $1.44 a share. On an adjusted share basis in 1966, the earnings were up to $2.99 a share. Where did this come from? Is the consumer gouged? I don't think so. In fact, the price of beer actually went down. How did we do it?

For the last four years Anheuser-Busch has been using the Operations Research group at Case, and now the management science group at the University of Pennsylvania's Wharton School of Economics. The company has initiated a series of extremely sophisticated marketing experiments. We have broken the market into several marketing areas; we matched areas according to socio-economic characteristics, and we literally ran an experiment in marketing. One practical result of such an experiment (those of you who drink it are aware of this) was a very substantial price cut in Michelob beer. When Michelob was first introduced, it was priced to compete with the foreign beers. It was clear to us that the beer was overpriced. As a result of its being overpriced, the demand was low, and as a result of the demand being low, the cost was high, justifying the high prices. The experiment says, "If we can increase the volume, we can justify a lower price." We decided we could increase the volume by lowering the price, a marvelously simple economic principle. The Company had the courage to do this. Why did we have the courage to do this? Because we used some reasonably sophisticated management science techniques to demonstrate this was the thing to do. Anheuser-Busch is a dynamic company in a static industry, but I don't think our performance is significantly better than that achieved by other companies whose management is interested in the scientific approach.

If I have to generalize and say something that would be common to all senior management groups, I think I would say that management does not like surprises, unless they're pleasant; even then they can cause problems. I could quote this from memory, but I don't trust myself. I like to read this because it is so offensive that I like to credit it to somebody else. "Management doesn't like surprises. And the business environment is changing. In a changing business environment, you can do one of two things: you can either exploit the change or you are going to be victimized by the change." Those are really the only two alternatives. I think management is becoming analytically oriented because the long lead times force it to look ahead. The changes in environment force management to anticipate change. Kenneth Boulding, who is a professor of economics at the University of Michigan, gave the Richard T. Eli lectures in the American Economics Association in 1965. He read a paper which he called "The Economics of Knowledge and the Knowledge of Economics." I thought it was an extraordinarily good paper. There are a couple of paragraphs in that paper I think are extremely important.

"In my book, The Image, I sketch what might be called 'The Theory of Behavior', pointing out that a decision is always a choice among alternative pre-conceived images of the future. The study of decision, therefore, must concentrate on how the images of the future are derived from the information which has come from the past, as this is the only place from which they come. The point is that we have to think of our images of the future as essentially learned out of our inputs from the past, and that the nature of this learning process therefore is overwhelming." Then he goes on to say, "Another profitable line of study lies in economic sociology, the analysis of the way in which organization structure affects the flow of information; hence, affects the information input to the decision maker, hence affects his image of the future in his decisions, even, perhaps, his value judgments. There is a great deal of evidence that almost all organizational structures tend to produce false images in the decision maker, and that the larger and more authoritarian the organization, the better the chance that decision makers will be operating in purely imaginary worlds. This, perhaps, is the most fundamental reason for supposing there are ultimately diminishing returns to scale."

At one time, I think, a computer was an industrial status symbol. You show me your computer, I'll show you mine. Then I think industry went through the battle for PhD's. Your PhD can talk to my PhD. I think that the dismal failures of Operations Research have given way to the reasonable, balanced approach to the use of OR techniques in business. I think it is now up to the Operations Research community to provide the tools necessary for management's use.

A MODULAR APPROACH TO ARMY FORCE PLANNING: AN ADAPTATION OF INPUT-OUTPUT TECHNIQUE

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INTRODUCTION

The work to be described here this morning is being supported by the Directorate of Force Planning Analysis in the Office of the Assistant Vice-Chief of Staff. It is a joint effort involving the Directorate, STAG, and contractor personnel.

Our attention was first turned to force planning problems because of General Brown's belief that some of the most basic logistic and materiel readiness problems are imbedded in, and inseparable from, the force planning process. As we examined this process from the standpoint of logistics analysis and resource management it appeared to us that the force planning guides contained a number of significant limitations. The two principal ones are

1. They are based on a "requirements" approach; i.e., a "blank check" approach, and
2. They provide no rules or logic by which the user can develop alternative force structures for different situations or force levels.

The essential feature of the present force planning process approach is that it "slices" the problem horizontally into two parts. The first step in the process provides consideration of tactical interactions — but in a very limited way because of the gross aggregations used in the tactical gaming models. The results tend therefore to reflect idealized requirements of a tactical operation unrestricted by logistic capabilities. The second step, the logistic analysis, in turn tends to generate an idealized support system that will not constrain tactical operations. Thus, the vertical interactions between tactics and logistics — which in reality are often controlling on tactics — are suppressed in this approach.

These considerations led us to formulate the basic premise that "below-the-line" resource and cost considerations must come into the force planning process initially and integrally — not terminally. It was from this premise that the modular slice concept began to develop. What we sought was an approach that would provide improved ability to —

- Introduce constraints in the initial stages of developing alternative force structures.
- Investigate broader ranges of contingent situations and alternative responses.
- Examine trade-offs between
    a. alternative combat unit mixes,
    b. alternative resource allocations between combat and support.
- Maintain balance of force components in adjusting theatre forces or total force structure to different levels.

The modular force planning system was designed to meet these objectives as well as to overcome some of the limitations of the present process. Essentially the modular force planning concept considers the complete "tail" of support units required for the effective operation of the various combat modules. These "below-the-line" units are considered initially and integrally, that is, whenever the force planner chooses a mix of combat modules the total requirements for the theater are computed. The system offers a rapid means of considering a number of alternatives and trade-offs between different force mixes. The selection of the alternatives and the choice of the mixes are left to the military judgment and experience of the force planner. The modular force planning method is merely a tool which assists the planner in combining his objectives with his constraints.

THE MODULAR FORCE PLANNING METHOD

To understand the modular force planning method a few definitions are required.

A combat module is defined to be an Army force, usually of battalion size, that interacts directly with the enemy. The current list of combat modules is shown in Figure 1. We recognize that traditionally artillery has been considered as combat support of infantry or armor. However, there are cases in military experience where it would be more correct to say that infantry supported the artillery; others in which infantry supported armor, and vice-versa. The emphasis here is on the combined arms concept — the idea that all combat units are mutually supporting. At the present time there are only 22 modules on the list. It is anticipated that this list will be expanded after the prototype system has been demonstrated.

A support unit is an Army unit, usually of company size, that supports a combat module with a logistical capability inherent in the skills and equipment of the support unit. A support unit can also be cast in the role of supporting another support unit or units, that is, supporting the supporters. At the present time there are approximately four hundred support units considered in the prototype system.

The basic concept of the modular force planning method is that the planner develops his plan entirely in terms of the combat modules. The support requirements in terms of support units, dollars and personnel are then computed, based only on his inputs of numbers of combat modules. These are then presented to the planner to compare with his constraints or with alternative mixes of combat modules. There are some exceptions to the principal that the planner deals only with combat modules and these are concerned with units in the theatre base as well as certain other optional units. These exceptions, will not be discussed here.

The approach taken here to the problem of estimating the number and type of support units required to support a force of combat modules consists of separating the problem into two parts. The first part consists of estimating the number and type of support units required to support the combat modules directly. The second part consists of a technique for estimating those additional units required to support the support units. In addition, a mechanism is provided for including the support requirements for aid to Allies.

COMBAT MODULES

1. Infantry Battalion
2. Mechanized Infantry Battalion
3. Tank Battalion
4. Armored Cavalry Squadron
5. Armored Cavalry Regiment
6. Field Artillery Battalion, 105 Towed (Div)
7. Field Artillery Battalion, 155 SP (Div)
8. Field Artillery Battalion, 155/8" (Div)
9. Field Artillery Battalion, Honest John (Div)
10. Field Artillery Battalion, 105 Towed
11. Field Artillery Battalion, 155 Towed
12. Field Artillery Battalion, 155 SP
13. Field Artillery Battalion, 8" SP
14. Field Artillery Battalion, 175 SP
15. Field Artillery Battalion, Honest John
16. Field Artillery Battalion, Lance
17. Field Artillery Battalion, Sergeant
18. Field Artillery Battalion, Pershing
19. Air Defense Artillery Battery, Vulcan
20. Air Defense Artillery Battery, Chaparral
21. Air Defense Artillery Battery, HAWK
22. Air Defense Artillery Battery, Nike Hercules

FIGURE 1

The methods proposed here are not new. They are a variant of the input-output analyses of economic theory that have been known for more than a quarter of a century. All that has been done is to choose those parts of the technique which offer promise as a useful tool for force planning in the Army.

DIRECT SUPPORT MATRIX (A)

The direct support matrix is a table showing the direct support requirements for each combat module in terms of the numbers and types of support units as shown in Figure 2.

The first element in the table, a_{11}, is the number of type 1 support units required to support one module of type 1. The element, a_{12}, is the number of type 1 support units required to support one module of type 2. In general, a_{ij} is the number of type i support units required to support one module of type j. (A computational note: The a_{ij}'s are not generally whole numbers and their fractional parts are to be estimated to an accuracy consistent with the data available. In addition, there will be "rounding rules" developed to cover cases where doctrine or usage dictate requirements other than those that would be estimated by conventional rounding procedures.)

The summary rows at the bottom of the table provide estimates of the amount of dollars and manpower represented in the support column for each module. For example, if the dollar costs of the support units are $C_1, C_2, \ldots, C_s$, then the dollar cost of support units to support one type j module are $a_{1j}C_1 + a_{2j}C_2 + \ldots + a_{sj}C_s$, which we abbreviate as

$$\sum_i a_{ij} C_i .$$

Similarly, if P_i is the number of people (level of manpower) in the i^{th} type support unit, then

$$\sum a_{ij} P_i$$

is the number of support personnel directly attributed to one j^{th} type module.

Now if a plan calls for n_1 type 1 modules, n_2 type 2 modules, and so on, we can calculate the number of support units of the i^{th} type required for direct support as

$$\sum_j a_{ij} n_j .$$

"aij" Primary Support Matrix (A)

Modules	M_1	M_2	.	M_j	M_m
SUPPORT UNITS S_1	a_{11}	a_{12}	.	a_{ij}	a_{1m}
S_2	a_{21}	a_{22}	.	a_{2j}	a_{2m}
⋮	.	.	.	.	.
S_i	a_{i1}	a_{i2}	.	a_{ij}	a_{im}
⋮ S_n	a_{n1}	a_{n2}	.	a_{nj}	a_{nm}
(\$) $\Sigma a_{ij} C_i$	.	.	.	.	.
(M) $\Sigma a_{ij} P_i$	.	.	.	.	.

$\sum_i a_{ij} C_i$

$\sum_i a_{ij} P_i$

$\sum_j a_{ij} n_j$.

FIGURE 2

Thus the direct support matrix provides the information needed to compute the number of support units (by type) required to directly support a force of given numbers of modules. In addition, it provides estimates of the costs in dollars and personnel associated with the support units.

INDIRECT SUPPORT MATRIX (B)

The relationships between the indirect support units, that is, the support required by the support units, can be described by a square matrix. The rows of the matrix correspond to the types of support units, as do the columns. As indicated in Figure 3, the number of types of support units in the indirect support matrix can exceed that of the direct support matrix. This is necessary because some support units do not directly support any module, but support only the supporting units.

The elements b_{ij} in the indirect support matrix are interpreted similarly to the a_{ij}'s. The element b_{11} is the fraction of a type 1 unit required to support a type 1 unit, b_{12} is the fraction of type 1 unit required to support a type 2 unit. In general, b_{ij} is the fraction of a type i unit required to support a type j unit.

The b_{ij} matrix can be used to compute the support required for any given number of support units required in the direct support of either modules or Allied forces. Suppose that the number of type j support units required in direct support is r_j. Then

$$\sum_j b_{ij} r_j$$

is the number of additional support units of type i required to support the supporters. But these additional units in turn require support and the additional increments can be computed as

$$\sum_i \sum_j b_{ki} b_{ij} r_j .$$

These increments in turn require support and the increments can be computed by another summation (the notation is cumbersome). In order to simplify the formulae, introduce the matrix notation where $\underline{B}$ stands for the b_{ij} matrix and $\underline{r}$ is the column vector r_j of numbers of the j^{th} type support units. We then have that the total requirements are

$$r + Br + B^2 r + B^3 r + \ldots + B^k r + \ldots$$

Indirect Support Matrix (B)

	S_1	S_2	...	S_j	...	S_n	...	S_{n+k}
S_1	b_{11}	b_{12}	...	b_{ij}	...	b_{1n}	...	$b_{1,n+k}$
S_2	b_{21}	b_{22}	...	b_{2j}	...	b_{2n}	...	$b_{2,n+k}$
⋮								
S_i	b_{i1}	b_{i2}	...	b_{ij}	...	b_{in}	...	$b_{i,n+k}$
⋮								
S_n	b_{n1}	b_{n2}	...	b_{nj}	...	b_{nn}	...	$b_{n,n+k}$
⋮								
S_{n+k}	$b_{n+k,1}$	$b_{n+k,2}$	...	$b_{n+k,j}$	...	$b_{n+k,n}$	...	$b_{n+k,n+k}$

$\sum_j b_{ij} r_j$

$\sum_i \sum_j b_{ki} b_{ij} r_j$.

$r + Br + B^2 r + B^3 r + \ldots.$

$(I - B)^{-1} r$

FIGURE 3

where each term after the first represents the support increments required by the preceeding term. If this series converges, it converges to the matrix

$$(I - B)^{-1} r$$

(the exponent minus one denotes the inverse operation). The convergence of the series should be assured in any practical case since divergence (non-convergence) would imply that some mix of support units would of itself require an infinite amount of support. Indeed, for any reasonably designed units the convergence should be rapid. In the event of rapid convergence it may be more efficient to compute the terms of the truncated series than to invert the matrix. However, it may still be better to invert the matrix since in that case we can add to the summary rows of the A matrix all of the indirect costs associated with the combat modules. In addition the inverse can be used to give the total system cost (excluding CONUS support) for adding or deleting any type of support unit from the below-the-line troop list.

SUMMARY

The technique described here offers a practical approach to providing a compact, easy to use tool for the force planner. The b_{ij} matrix of coefficients is expected to be practically invariant within a theatre, and consequently the arithmetic (for each theatre) can be done once for all — pending fundamental changes in the technology of the theatre support system, or in the policy for support. Thus, the influence of variation in deployments and in combat environments within a theatre will all be reflected in the a_{ij} matrix coefficients. "Standardized" values of these coefficients will be determined for various combat environments and deployment depths so that the force planner can limit his attention to development of a force structure in terms of the modules, and then obtain a complete theatre troop list by computerized application of the A and B matrix data.

The remarks of Mr. Dalimil Kybal, Lockheed Missiles and Space Company, entitled "1975-1980 World Environment and Related National Security Needs" were not available at the time these Proceedings went to press.

TITLE: The Development of RECAP: A Model to Aid Army Force Planning

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CONTRACTOR: Research Analysis Corporation

COGNIZANT AGENCY: AVC of SA (FPA)

This paper describes progress to date toward the development of an automated model to be used for the simultaneous (joint) analysis of the resource requirements and pre-combat capabilities of Army force units. The current Army force planning process is considered in order to show how such a "REsource-CAPability" model could supplement the present planning process. The model's method of assessing both cost and capability measures will be explained, along with several of its techniques which could aid the rapid comparison of force alternatives. Some of the limitations of the model are also discussed.

Objective

The objective of the model development is shown in Fig. 1. Points to be emphasized are first the joint consideration of both resources and capabilities, and second the rapid analysis objective. In this, a few days or less are the goal, rather than a few weeks or a few months. The idea is to improve back-of-the-envelope force estimates for postulated contingencies, rather than replace more sophisticated research methods.

OBJECTIVE

To CONCEIVE, CONSTRUCT, AND EVALUATE

an AUTOMATED METHOD

for the RAPID ASSESSMENT AND ANALYSIS

of both RESOURCE REQUIREMENTS AND COMBAT CAPABILITIES

of ALTERNATIVE ARMY FORCES

[illegible]

Fig. 1. Objective

Research Plan

The time-phased subtasks of the work are shown in Fig. 2. Currently, prototype construction (the third task) is about to begin, which means computer programming and to a certain extent, finalizing of parts of the model which are now concepts. This paper is essentially a description of these concepts.

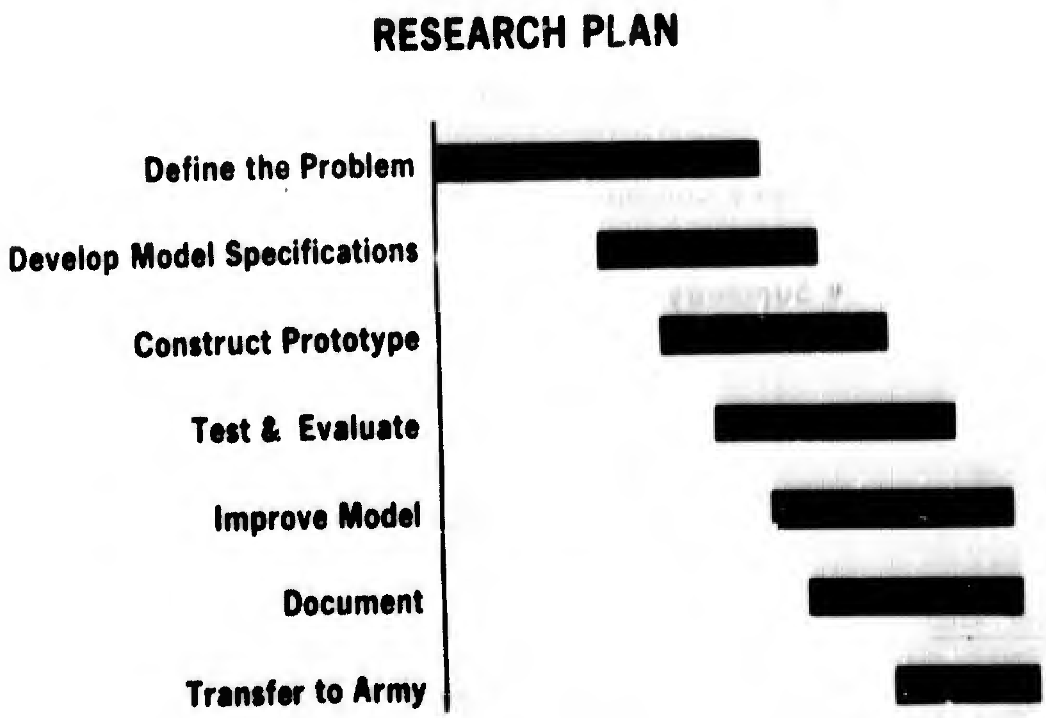

Fig. 2. Research Plan

Topical Outline

The topics to be discussed are shown in Fig. 3. Design requirements are included because part of the development of the model consists of asking what is needed of this type, in addition to current force planning tools. Comments are also made about resource and capability measures, especially the latter. Tabulation, the computer model, and force comparison techniques are important parts of the RECAP model, and are intended to enhance the usefulness of raw data provided as inputs to the model.

OUTLINE

- Introduction
- Design Requirements
- Measures and Their Tabulation
- The Computer Model
- Force Comparison Techniques
- Summary

Fig. 3. Outline

Current Aids

We now turn to the design requirements for the model, and start by asking what methods are currently available to aid force planning. Some of the aids are shown at the top of Fig. 4. The points of comparison are shown on the left-hand side, and have been chosen to highlight features which will later be compared with the RECAP model. All three of the aids are good in providing information about tactical detail. This is especially true of field experiments and war games which can be planned to generate large amounts of accessible information, which results mainly from deliberate experimental control. However, because of this very fact they are relatively time consuming and can examine only a few alternative forces. And with very few exceptions an intrinsic ability to determine costs is not part of the aids. It is true that some equal cost force war games have been played, and there are a number of cost-related weapon-system studies. But Army force planning aids are a rarity with the ability to either control costs with effectiveness-type implications or control effectiveness with cost implications.

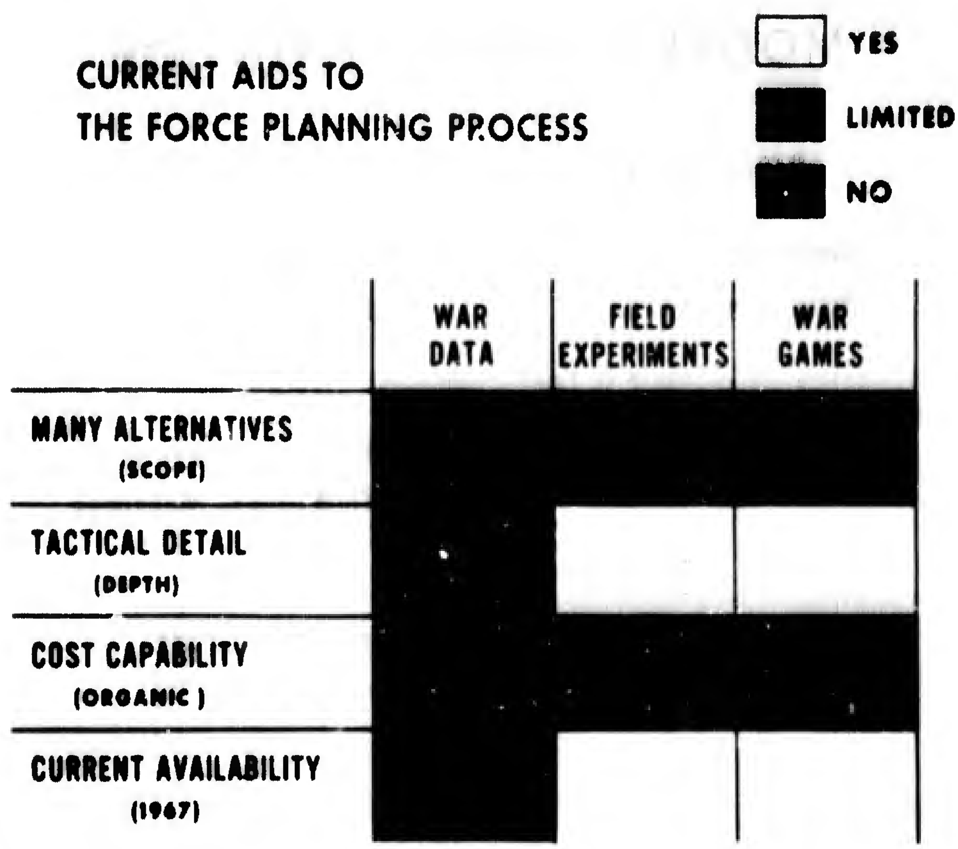

Fig. 4. Current Aids to the
Force Planning Process

Model Characteristics

In Fig. 5 are shown some of the more specific implications for the model design. Rapid use probably requires a computer program along with internal data storage. The latter will have to include both cost, and effectiveness related indicator data in order to deal with both of these aspects of the problem. The last item on the chart is intended to suggest that a really adequate aid to force planning probably will have to do more than provide cost and capability implications of given forces. That is, some applications might well require force adjustment prior to comparison along with analysis of some type, such as partial rankings according to various measures. Especially prominent in this regard is adjustment of forces for equality of costs before comparison on capability measures.

Classification of Measures

Before turning to a final statement as to how a resource-capability model is related to other force planning aids, let us look

MODEL CHARACTERISTICS

DESIGN GOALS	IMPLEMENTING MEANS
Rapid Use & Many Alternatives	Automation & Data Base
Both Cost & Effective-ness Measures	Data Base with Cost & Effectiveness Measures
Cost-Effectiveness Comparison Capability	Force Adjustment, Analysis & Display

Fig. 5. Model Characteristics

at some measures of military worth as a basis for talking about these aids. Fig. 6 is intended to point out the difference between pre-combat capabilities and post-combat outputs. The capabilities shown here are somewhat arbitrary in that they are a selection from a long list of possibilities. However, the combat outputs shown here are probably of chief interest for actual combat or any technique which simulates combat. This points to the advantage of aids which provide combat outputs instead of capabilities. This is just another way of saying that games and field experiments can provide tactical detail that capability measures cannot provide. Fig. 6 also indicates why the term "performance" is not right for this model. In a sense, the post-combat outputs represent the performance of the forces involved, whereas the model deals with precombat capabilities.

We next ask where force effectiveness fits into the picture, and how it is related to capabilities and combat outputs.

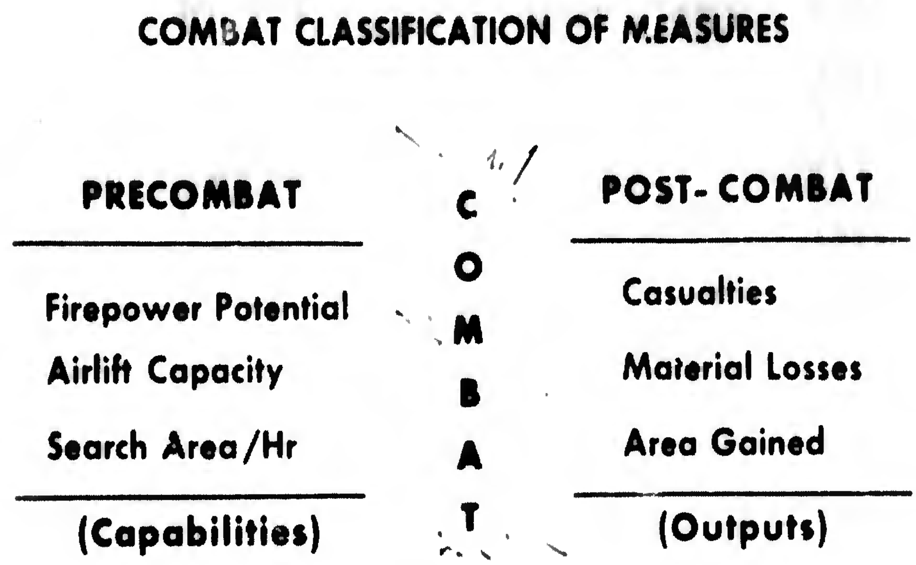

Fig. 6. Combat Classification of Measures

The point of focus of Fig. 7 is the combat process. Prior to combat, there are the friendly forces with their capabilities, during combat a (probably nonlinear) interaction with an enemy, and after combat the outputs for both friendly and enemy forces. The question then is, what about effectiveness? Suppose one adopts an often used definition that an effectiveness measure is a measure of the degree of fulfillment of combat objectives. In this case, the combat outputs may or may not be good measures of effectiveness, depending upon the objectives.

Fig. 8 shows the relationship between capabilities and effectiveness. Capabilities are pre-combat and effectiveness is post-combat, with effectiveness depending upon both combat outputs and combat objectives. From this sort of picture some statements of the following kind can be made.

First, an approach which uses capability measures does not and cannot deal with the specifics of the enemy or combat environment.

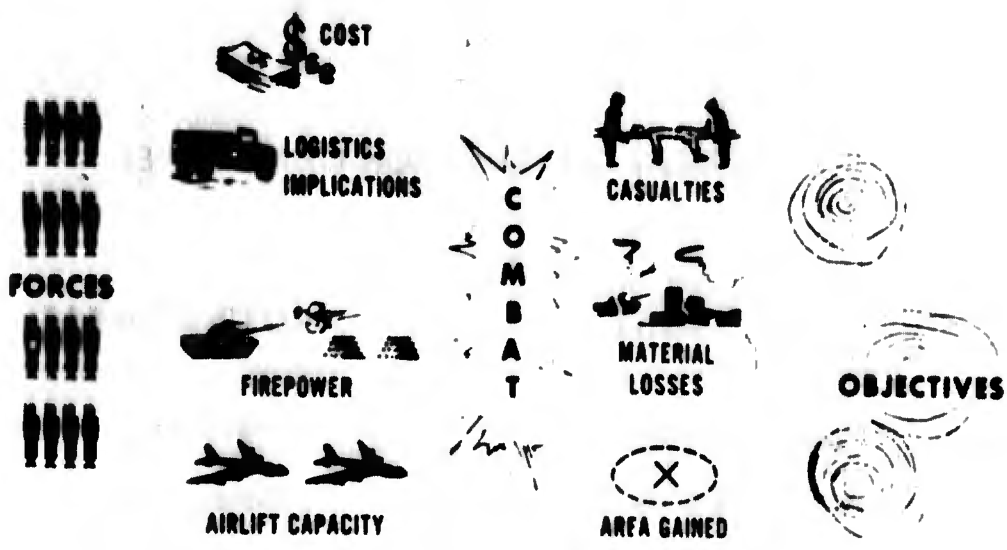

Fig. 7. Precombat-Postcombat Diagram

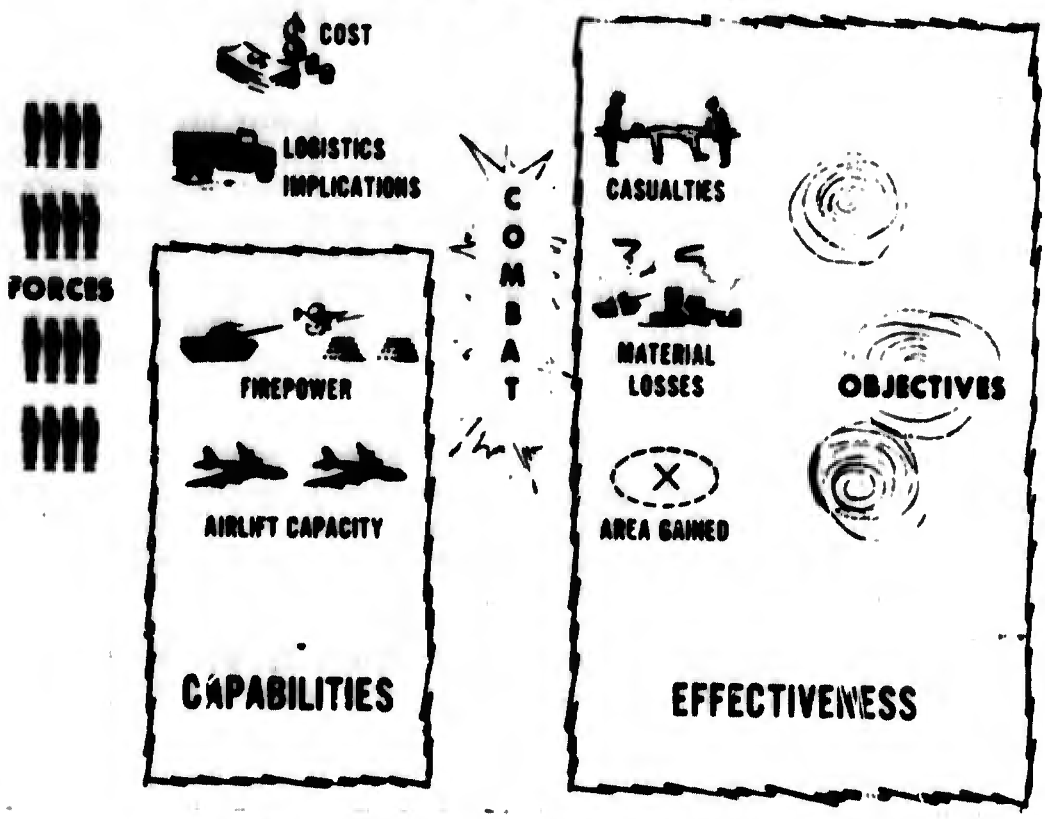

Fig. 8. Capabilities and Effectiveness

Second, such an approach does not and cannot deal with the non-linear effects and interactions of combat.

Finally, since other force planning aids do focus on the tactical situation and its non-linearities, a capability measure approach is a supplement to these other methods, and not a substitute for them.

Some Measures

Fig. 9 illustrates the kind of measures for which data is now being sought. It is an incomplete list. The resource measures are of both the non-dollar and dollar type. The capability measures are being classified according to the widely accepted combat functions, in hopes of affording some amount of completeness and validity for them. Actually, a much better test would be a study of the correlation between these capability measures and combat outputs. Due to the press of time, and probable intrinsic difficulty, this, however, is not likely to be done in this study. As a result, the list will probably be open-ended rather than limited to a few so-called good, or best measures. Currently, we have a list of 92 measures. These include measures for combined functions such as mobile firepower, and in this sense represent interactions among capabilities. These are to be distinguished, of course, from combat interactions which lead to combat outputs.

SOME MEASURES UNDER CONSIDERATION

RESOURCES

Initial peacetime investment cost
Recurring peacetime cost
Recurring wartime cost
No. of C5A's lift required
Wartime consumption, ton/mo
⋮

FIREPOWER (FPP)

Line of Sight
Indirect
Antitank
Antipersonnel
Total
⋮

MOBILITY

Wheeled Veh, ton-km/hr
Tracked Veh, ton-km/hr
Aircraft, ton-km/hr
Aircraft capacity (men)
Bn lift capability
⋮

OBSERVATION

Ground radar area coverage
Observation A/C available flying hours per day
⋮

Fig. 9. Some Measures Under Consideration

Output Concept

The complete output concept for the RECAP model is as shown in Fig. 10. The force alternatives are listed on the left, with a single entry corresponding to the total value of a single measure, for a single force alternative. In order to obtain such a single measure total, it is necessary to combine the measures for the combat modules within the force. This intermediate step is shown in Fig. 11.

This figure shows the basic computational operation planned for the resource and capability measures. A much larger list of measures than these three would be used in an actual application. The main point is that these measures are added, or simply tabulated, over the various modules of a force. This takes advantage of the addition of capability measures, leaving the non-additive combat effects in particular situations to other force planning aids.

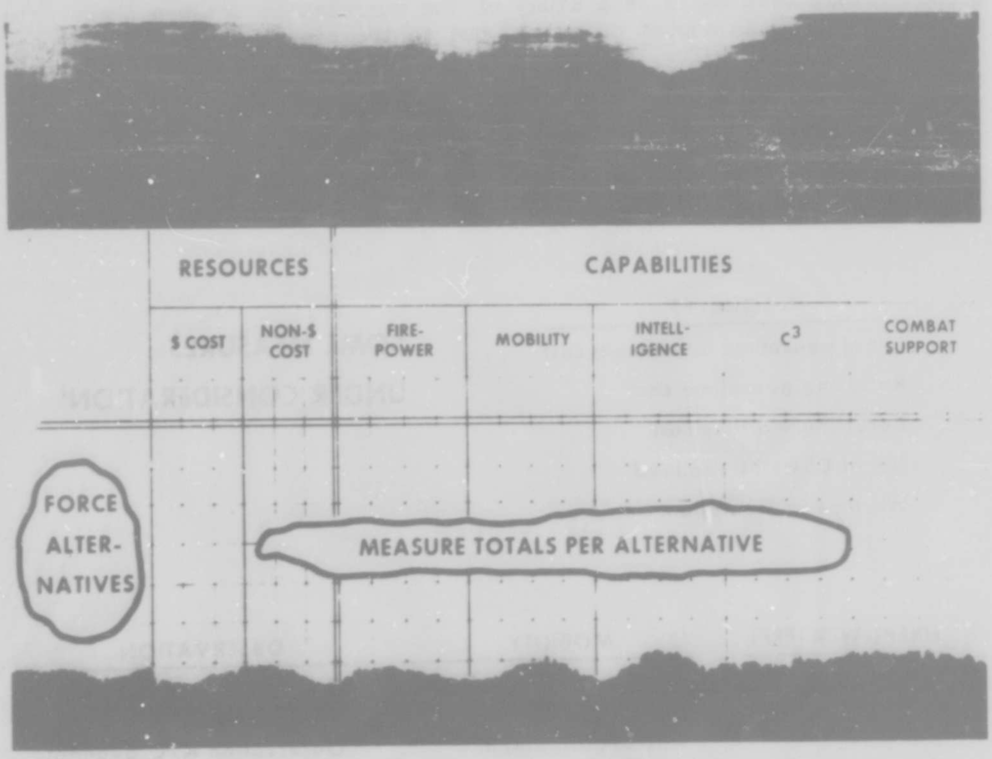

Fig. 10. Output Concept

Additive Measures per Combat Module

Combat Modules	Quant.	5 yr Peacetime Cost ($Mil)		Firepower Potential Line of Sight		Carrying Capacity of Aircraft (Men)	
		UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL
Inf. Bn.	8	41.4	331	4,250	34,000	0	0
Tank Bn.	2	58.5	117	29,650	59,300	0	0
Airmobile Co's	11	25	275	100	1,100	227	2,500
FORCE TOTALS			723		94,400		2500

Fig. 11. Additive Measures per Combat Module

Current Aids versus RECAP

Having reviewed in a rough way the sorts of things that a resources and capabilities model can and cannot do, we now summarize what was said. Fig. 12 indicates that a RECAP model has definite advantages where other aids are weak, and has definite failures where other aids are strong. In commercial terms, a resources-capability model is neither the <u>best</u> mousetrap nor a <u>better</u> mousetrap. It catches mice which are not now being caught but fails to catch other mice that other traps catch regularly.

Prototype RECAP Model

We now turn to some of the features planned for the computer program and for the methods of its use. Fig. 13 shows the major blocks in the information flow. In any particular use of the model, inputs will have to be specified. This task will be facilitated by the use of a data library of factors, some of which may be additive measures, while others

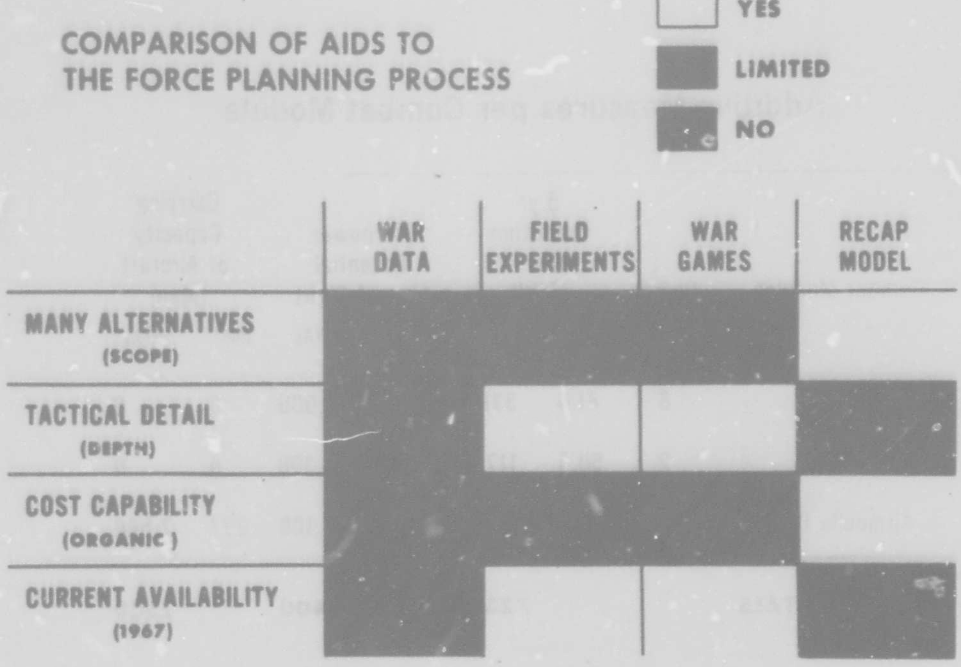

Fig. 12. Comparison of Aids to the Force Planning Process

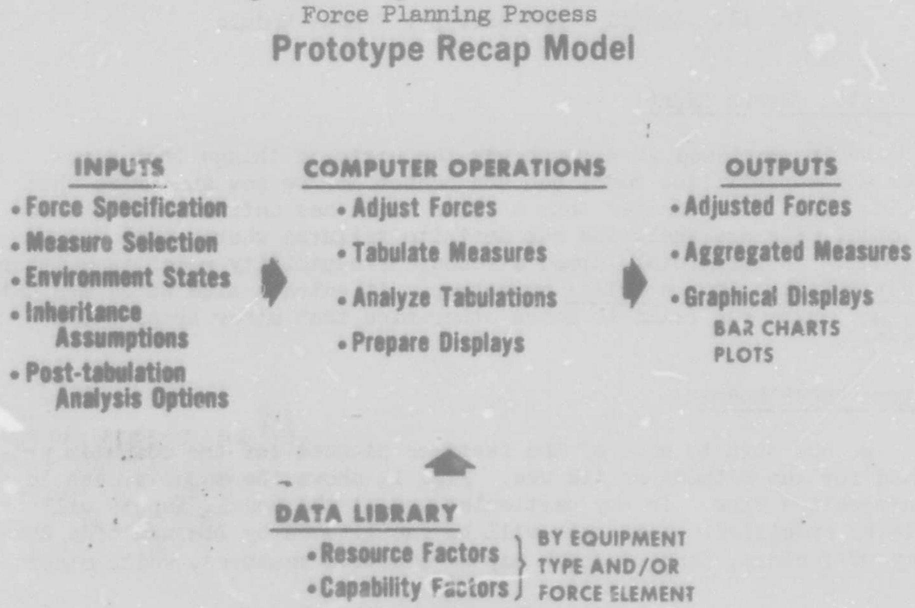

Fig. 13. Prototype RECAP Model

may be factors which go to make up measures only after combining-operations are applied to them. Among the inputs the user will specify, are first and foremost the force, by modules, that he is interested in. This will include for cost purposes, some statement as to the current availability of such modules, i.e., the inheritance assumptions. Measures will be selected by perhaps a checkoff list. Some provision might also be made for selecting combinations of measures by the user, such as products or quotients. Environmental states would be limited to the simplest and most essential ones, such as general terrain types, because this involves measures for each environment. We will leave for later the discussion of the computer operations and the output.

Data Library Table

Fig. 14 shows the arrangement of data in one part of the library. The main point is that numerical measure values are associated with either combat modules or equipment items. The inclusion of equipment items is explained in the following way:

Since RECAP is a force planning tool the primary interest and output is in terms of combat modules and summed measures for forces which contain these modules. One way of obtaining these measures is to have in the library data for individual equipment items along with the table of equipment for each module. The computer will then add up measures, such as firepower potentials or vehicle carrying capacity, for individual items to obtain combat-module totals. These latter totals can then be used in the same way as the measure quantities for the battalions shown in the bottom part of Fig. 14.

Data Library: Factor Table

	SYSTEM TYPE	FIRE-POWER POTEN'L	VEHICLE SPEED TERRAIN A	VEHICLE SPEED TERRAIN B	COST PROCUREMENT	COST ANNUAL OPERATING (PEACETIME)	WEIGHT
TANK SYSTEM	A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
105mm HP HOW, SP	B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
155 mm HOW, TOW	C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
⋮							
RIFLE	D	[illegible]					[illegible]
⋮							
5 TON TRUCK	F		[illegible]	[illegible]			[illegible]
⋮							
INFANTRY BN	G				[illegible]	[illegible]	[illegible]
MECHANIZED BN	G				[illegible]	[illegible]	[illegible]
AIR MOBILE BN	G				[illegible]	[illegible]	[illegible]

Fig. 14. Data Library: Factor Table

Force Structure Specification

Fig. 15 shows the input information required to specify a force in its simplest form. The types of combat modules in the force are on the left. The numerical information can be interpreted in the following way: Consider the top line on the chart. Alternative 1 is seen to contain eight infantry battalions with the assumption that none are on hand for use in this alternative and hence must be newly activated battalions. Alternative 2 contains no infantry battalions and hence makes no direct use of the assumed eight battalions already on hand, although they could be broken up and used in other combat modules of alternative 2. This example is given its full generality. In a specific application, the inheritance assumptions would probably be the same for all alternatives under comparison.

Output Evaluation

The concept for a basic type of output is shown again in Fig. 16. The force alternatives are listed on the left, with a single entry in the table corresponding to the total value of a single measure for a single force alternative. If such information can be provided relatively quickly to a user, the model has paid off as a rapid data assembly aid. However, the problem of selecting the best set or subset of these alternatives for a particular use still remains. To visualize this problem, suppose you were presented with an array of numbers for, say, 10 alternatives and 50 measures. That is 500 numbers and a lot of data. But the matter is

Force Structure Specification

	Alt #1	Inheritance	Alt #2	Inheritance	••••
Inf Bn	8	0	0	8	
Mech Bn	0	0	[illegible]	[illegible]	
Tank Bn	2	0	[illegible]	2	
Airmobile Bn	0	0	[illegible]	[illegible]	
Airborne Bn	0	0	3	0	
⋮					

Fig. 15. Force Structure Specification

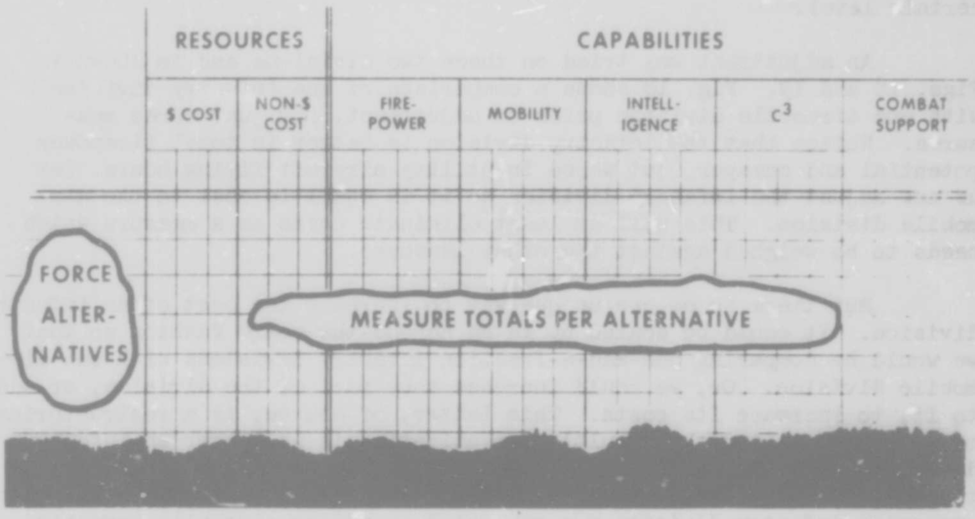

Fig. 16. Output Concept

simplified to a certain extent by focusing on one measure at a time. If for each and every measure, one alternative is best, that alternative is the preferred alternative. However, this is an unlikely situation. The problem will probably always result in a need for the user to choose among conflicting capabilities - conflicting in the sense that some measures will point to one set of alternatives, while other measures will point to another set of alternatives. To see what could happen in this regard, a hand calculated example was tried for two different division-sized forces, using rough data.

Fig. 17 shows a very limited set of measures for these two forces. For the resources, notice that the airmobile division costs more but has less wartime consumption. And for the capabilities, the infantry division has more firepower but less air capability as represented by lift capability and observation aircraft flying hours. Which is preferred? The answer would no doubt depend, at least, upon the contingencies which the user of the RECAP model has in mind. One device that might be of help would be to adjust the forces prior to this comparison so they would be of equal cost, or so they have the same firepower potential for line of sight weapons. This would eliminate the need to make comparisons on these measures. The first adjustment corresponds to a common cost-effectiveness technique, namely equal-cost comparisons. The second adjustment corresponds to something like a requirements approach for which it is desired to compare only those alternatives which have one of its capabilities at a certain level.

An adjustment was tried on these two divisions and is shown in Figs. 18 and 19. Fig. 18 shows a comparison of one infantry division with one airmobile division prior to adjustment, for just three measures. Notice that the infantry division is better in total firepower potential and cheaper, but worse in utility aircraft flying hours. Let us now adjust the infantry division so it is equal in cost to the airmobile division. This will at least eliminate costs as a measure which needs to be weighed against the other measures.

But there is no one unique way to increase the cost of an infantry division. It could be scaled up in an across-the board fashion so that we would be comparing one-and-a-fraction infantry divisions with one airmobile division. Or, we could increase some part of the division, or add to it, to increase its costs. This latter, of course, is a restructuring of the division and the resulting organization is no longer an infantry division in the original sense. The latter method was chosen, in order to test out this more complicated adjustment, and is shown in Fig. 19. An augmented infantry division was generated by adding airmobile companies until the costs of the two divisions were equal. This in turn, we interpreted as some sort of alternative to the airmobile division.

Sample Output: Tabular Display

	RESOURCES				CAPABILITIES							
					FIREPOWER POTENTIAL (THOUS)			CARRYING CAPACITY (MEN)			AVAILABLE FLYING HOURS PER DAY	
	QUANT.	5-YR PEACE-TIME COST ($MIL)	NO. OF C-5As REQ'D	WARTIME CONSUMPTION (TONS/MO)	LINE OF SIGHT	IN-DIRECT	...	ARM'D VEH'L	A/C	...	OBSERV'N A C	...
INF DIV Total	1	1075	200	1200	125	59		684	1075		190	
AIR MOBILE Total	1	1343	98	580	29	39		0	4741		379	

Fig. 17. Sample Output: Tabular Display

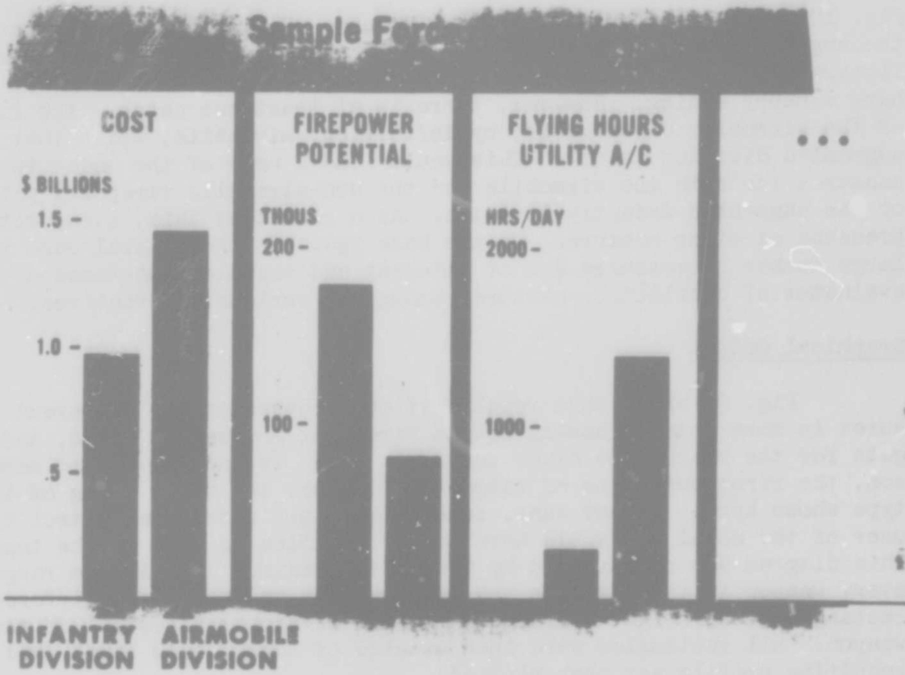

Fig. 18. Sample Force Comparison

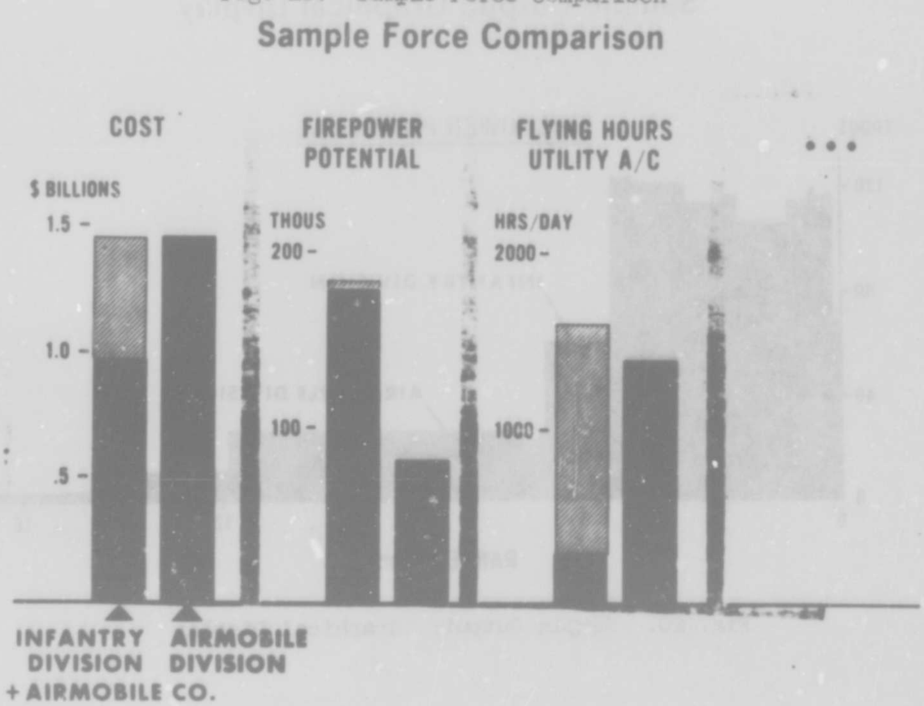

Fig. 19. Sample Force Comparison

Fig. 19 shows the resulting measure values. It is interesting that now the augmented infantry division is equal in cost and better in both total firepower and flying hours. If this were the end of the story, it would have a happy ending. However, there is at least one catch - the firepower of the airmobile division is, by definition, airmobile, while that of the augmented division is not. This would lead a user of the model to want measures for both the airmobile and the non-airmobile firepower potential of the augmented infantry division. As a result of this, along with the presence of other measures, we are back again to the general case where a large number of measures are of interest and the user functions as an evaluator of conflicting measures among the various alternatives.

Graphical Output

Fig. 20 shows what results if one focuses on two different measures in more detail, namely weapon firepower and weapon range, and forgets for the moment the other measures. This is another aid to comparison, the first being the adjustment of forces, the other being of the type shown here. In any case, such options are under the control of the user of the model and would have to be specified as part of the input. This diagram was constructed by taking the maximum and minimum range of every weapon in the division and constructing on this range-difference a rectangle whose height corresponds to the firepower potential of the weapon. All rectangles were then stacked on top of each other, and the resulting profile was then plotted.

Sample Output: Graphical Display

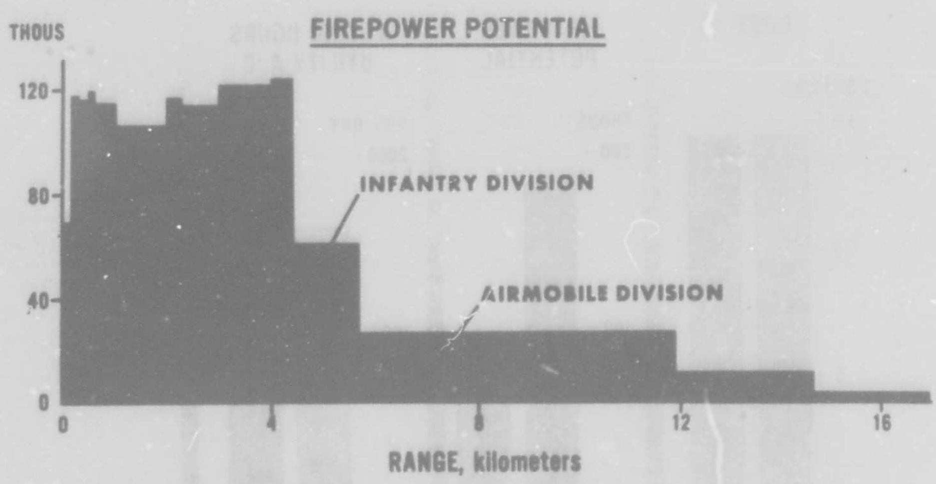

Fig. 20. Sample Output: Graphical Display

Major Model Options

Fig. 21 is intended to point out the basic distinction between the use of the model to simply tabulate resource and capabilities totals for given forces on the one hand, and the use of the model to organize these tabulated totals or adjust the given forces to facilitate comparisons, on the other. In either case, displays and arrays of various types of output will be available.

Major Model Operation Options

Type I **Bookeeping Only**

- OUTPUT TABULATIONS OF MEASURES FOR UNADJUSTED FORCES

Type II **Force Comparison Techniques**

- FORCE ADJUSTMENT
- BOOKEEPING
- OUTPUT DATA ORGANIZATION

Fig. 21. Major Model Operation Options

Force Comparison Techniques

Fig. 22 is simply a list of those comparison techniques which might turn out to be useful. Some have been tried out numerically and others have not. There is a natural classification of these techniques into those that require adjustment, meaning scaling or restructuring of a force alternative, and those that do not. In case of restructuring, the user of the model must specify those modules which will vary during the adjustment and those which will not. One of the tested options along this line has been a constrained maximization of selected capabilities measures, and a constrained minimization of cost, using linear programming. However, it is felt that these might be too elaborate for the measure data, and simpler comparison techniques will be more useful. Such a technique is shown in Fig. 23. These tables are intended to represent summaries of comparisons which the user would otherwise have to pick out for himself from measure totals for each alternative. They are applicable to both adjusted or unadjusted forces. The table on the left ranks the alternatives first, second, third, etc., for each measure. The measures at the top of the table would be listed by name, while the alternatives would be listed by both name and measure value. The table on the right lists for each alternative all its "firsts" among the measures. Its "seconds" and "thirds" could also be listed, but are not shown here. As before, the body of the table would contain both names and numbers.

Force Comparison Techniques

- **Combined measures & graphical displays**
- **Ranking of force alternatives for each measure**
- **Listing of dominant measures for each alternative**
- **Elimination of dominated alternatives**
- **Adjustment of forces to**
  - **OBTAIN AN EQUAL LEVEL IN A SINGLE MEASURE**
  - **IMPROVE PERFORMANCE WITHIN UPPER BOUNDS ON COST AND LOWER BOUNDS ON PERFORMANCE MEASURES**
  - **MINIMIZE COST WITHIN LOWER BOUNDS ON PERFORMANCE**

Fig. 22. Force Comparison Techniques

Some Techniques for Organizing Output Data

m_1	m_2	m_3	•••	A_1	A_2	A_3	A_4
A_2	A_4	A_1	•••	m_3	m_1	-	m_2
A_1	A_3	A_3	•••	m_4	m_{10}		m_5
A_4	A_2	A_2	•••	m_7			m_6
A_3	A_1	A_4	•••				m_8
							m_9

Fig. 23. Some Techniques for Organizing Output Data

SUMMARY

DISADVANTAGES

- **Multiple measures**
- **Performance is not effectiveness**
- **Lacks tactical detail**
- **Quantifiables only**
- **Limited capability to assess interactions**

ADVANTAGES

- **Rapid & simultaneous assessment of BOTH RESOURCE REQUIREMENTS AND COMBAT CAPABILITIES for many force alternatives**
- **Automatic adjustment of forces to aid comparisons**
- **Automatic ranking of forces to aid comparisons**

Fig. 24. Summary

Disadvantages and Advantages

Fig. 24 lists some of the pros and cons of the proposed model. The biggest disadvantage is its lack of tactical detail. But this can be left to other aids to force planning. It should be noted that the automatic ranking shown in Fig. 24 as an advantage is ranking per measure and not an overall ranking. There is also some hope that RECAP can be used to enhance the use of other aids, such as war games, by handling jointly with these other aids a large number of alternatives. In this case, the RECAP model would examine those alternatives not handled by the game, due to time limitations. But this must await the demonstrated feasibility of the RECAP model.

EXPLOITATION OF THE MIL-STD 782 RECON DATA SYSTEM

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From the dawn of recorded history to the mid-19th century, aerial reconnaissance was best typified by prehistoric man climbing a tall tree to report the location and size of hostile dinosaurs or the presence of an unwary mastodon herd. Although the content of the reported data varied with epoch, the acquisition techniques did not.

By the time of the United States Civil War, the range of weaponry had increased to the point that better and more immediate data was essential. Attempts to exploit tethered hot air balloons as reconnaissance platforms met with limited success and pointed the way to use of the aerial reconnaissance platform in World War I.

During World War I, hydrogen filled balloons were extensively used for artillery spotting and free flight balloon reconnaissance was attempted. The vulnerability of the observation balloon and the explosive quality of hydrogen gas tend to characterize these efforts as the first tactical usage of a hydrogen bomb.

The development of heavier-than-air craft to operational status during World War I allowed use of aircraft as reconnaissance platforms. Reporting was based upon visual observation and photography from hand held cameras. Despite obvious equipment limitations, airplanes and photography during World War I provided substantial quantities of valuable intelligence information.

By the end of World War II, Aerial Reconnaissance came into its own, not only as an arm of the military commander, but as a pure intelligence tool.

Since World War II, the capability of both military striking forces and aerial intelligence gathering systems has increased quite considerably. Advances in missilry, aircraft striking forces, air lifted ground troops and in ground transport have been thoroughly documented. Advances in aerial reconnaissance, although less publicized, include both orbiting and airborne platforms equipped with a wide variety of sensors. Data is acquired throughout the complete electromagnetic spectrum from communication frequencies, through microwave, infrared and visible light emissions. Both active and passive systems are used at all wave lengths providing substantially all-weather coverage over thousands of square miles with ground resolutions as fine as one foot. Although no single sensor provides all the capability desired for maximum data acquisition, selection of the most desirable combination results in collection of vast amounts of detailed information concerning extremely large geographic areas. As an example of the magnitude of the collection effort, unofficial figures show over 1.5 million feet of photographic aerial reconnaissance imagery was collected during January 1966 in Vietnam alone.

A major portion of aerial reconnaissance data is collected in the form of imagery on photographic film. In general, this imagery contains great masses of extraneous data interspersed with small quantities of vital information. The function of the image interpretation team is to extract the vital information and present it in usable form to the intelligence analyst or commander. Among the questions which must be answered concerning any item of interest are What, Where, When, How Many, How Large, What Change. These must be answered for the known and the suspected, also the unknown and the unsuspected. When dealing with counterinsurgency, the latter is often the case.

Although sensor systems have been vastly improved, the scale and resolution of the image is often marginal for detection, identification and measurement of vital images. Both natural and man-made objects may camouflage or obscure the installation. Lack of known terrain features often hinders determination of the geographic position of a detected object. The location of a known point in both the roll of film and in the frame of imagery, frequently, is difficult to identify.

In order to perform its function properly, the image interpretation team must correlate data from a number of sources to accurately locate and describe a potential threat. These sources include charts, maps, previous reports, previous imagery and may include data from non-imaging intelligence media such as ELINT, observers reports or ground intelligence. Accurate location of any object requires knowledge of the sensor parameters and of platform position, altitude and attitude during image acquisition, measurement of image coordinates and conversion to ground scale. Determination of object size requires similar knowledge and action plus derivation of height by stereoscopic measurement or shadow angle comparison.

If each interpretation task required detailed analysis of every object in every mission without a prior knowledge, the image interpretation team would be hopelessly lost.

Fortunately, the trained human mind is capable of rapidly correlating large numbers of apparently unrelated (and often nearly undefinable) decision criteria to reject areas of little interest and to provide amazingly rapid and accurate analyses of pertinent information. Unfortunately, the exponentially increasing quantities of incoming data and required information output are rapidly overtaking the ability of the image interpretation team to provide accurate timely analyses.

Among the efforts to alleviate the photo interpretation problem, is the application of automated and semi-automated techniques to assist the interpreter in location, orientation, mensuration, computation, retrieval of collateral data and report preparation.

One of the powerful individual techniques utilized in simplifying the task of the image interpretation team is recording pertinent flight data on each frame of imagery. MIL-STD-782 adopted first in June 1963, revised in August 1963 and again as MIL-STD-782 B in March 1965 defines the characteristics and content of the recorded flight data block. Proper exploitation of this data ensures certain correlation between flight data and imagery; substantially aids in orientation of the interpreter along the image flight path; allows rapid determination of the ground location corresponding to each image segment; provides the sensor and platform data necessary for conversion of image to ground scale; and allows rapid retrieval and presentation of previous or reference imagery and collateral data such as maps, charts, interpretation reports, etc.

Flight data is recorded in accordance with MIL-STD-782 B as excess 3 binary coded characters in a format occupying a maximum film area of 0.545" x 0.594". Figure #1 shows the configuration of a code block. Figure #2 shows one of the possible code block locations on reconnaissance frame photography. Figure #3 describes the data included in the reconnaissance data block and the information source. Similar information is recorded on mapping photography except that the B/N Mode character is replaced by a map format indicator, the two ELRAC (ELectronic Reconnaissance ACcessory equipment) output spaces are used for camera film identification and camera azimuth and the SLAR Mode character is used to identify mount mode.

Examination of Figure #3 shows that all information required for image location, coordinate conversion, date, time and source of imagery, sensor type and mode is contained in the code block. The addition of optional ELRAC data provides the interpreter with clues to the type and location of RF emitting installations. Complete data is recorded on each frame of imagery simultaneously with image acquisition. In consequence the interpreter can utilize any single frame or a complete roll without having to correlate the pilots log and mission plan with imagery to obtain required flight data.

A description of available techniques for exploiting the MIL-STD-782 code block requires some additional consideration of the code block characteristics and tolerances.

Data on the code block is accurate within the tolerances of the source data and has the resolution indicated in Figure #3.

The absolute accuracy of time data approaches the resolution of the code block (0.1 second). The time recording may be utilized for frame count (as it is always an ascending number), velocity determination, shadow height mensuration, etc.

Positional accuracy (latitude and longitude) depends on the aircraft inertial navigation system, the frequency and accuracy with which the system is updated, the per hour rate of deviation allowed by the total system, etc. Some INS systems update with LORAN or SHORAN achieve accuraces of ± a few hundred feet in a mission. Other systems relying solely on manual updating can provide accurances from this to 1-2 nautical miles (nm) but are subject to errors in update procedures. Unofficial information from S.E. Asia indicates that accuracies of 2-3 nm are common in operational missions but occasionally errors as great as 26 nm have been observed.

Altimeter accuracy approaches the resolution of the recorded data (10 feet for radar and 100 feet for barometric altimeters) but it is dependent upon the aircraft instrumentation, calibration procedures and flight altitude.

Attitude (pitch, roll, drift & heading) data should be as accurate as the recorded resolution (0.1°) and is sufficient for all but the most precise mapping missions.

ELRAC data is general as to location and type of emitter with more than sufficient accuracy for its purpose.

The remainder of the data does not involve accuracy considerations except as manual error may introduce faulty information.

The previous brief resume of data accuracy indicates that navigation data from remote aided systems is adequate for all but the most precise location which may be used to locate the immediate area. As will be discussed later, use of computer techniques in combination with code block data and visual determination of the recorded location of a few identifiable features can provide relatively precise location information from these navigation systems.

All other recorded data provides sufficient accuracy for normal reconnaissance missions. Extremely precise measurements such as may be required for mapping, careful target location or distinguishing between similar appearing artifacts differentiated primarily by small size differences, may require recourse to conventional scaling, mosaic or similar techniques involving comparison of known and unknown imagery. Even in the latter case, use of the data block information can ensure against gross errors by providing a reasonable check.

All flight data is recorded in the code block in the form of six bit characters. The first bit is an index bit and identifies the start of each character. The final bit is a parity bit used as a check against errors in recording and automatic reading. This bit is inserted only when required to make the total number of data bits plus parity an odd number. The center four bits contain the recorded information in the form of an excess-three binary code. Reading from the index bit toward the parity bit, each data bit is assigned a value 8, 4, 2, 1 respectively. The value of the recorded data bit is the sum of these values minus three. Thus a recorded character 110011 would have a value 8 + 0 + 0 + 1 - 3 = 6 since the index bit and the parity bit have no data significance. The numeric value - 3 is not used. Since a binary zero has no bits, the purpose of the shift is simply to insure that at least one bit is present in each character. The numeric values minus 2, minus 1, plus 10, 11 and 12 are used for sign or other special characters. The significance of each coded character is shown in Figure #4.

Present operational systems use a cathode ray tube to record the code block serially by bit through each character, serially by character down each column and serially by column. When forward motion compensation (FMC) is used in the sensor, film motion during the recording process leads to distortion of the code block. Reasonable tolerances for CRT recording in an aircraft environment introduce additional distortions. Variations in tube operating characteristics and alignment may cause contraction or expansion of the code block. Jitter in the retrace, sweep or modulation circuitry may cause displacement of bits relative to each other. Variations in modulation circuitry gain or film characteristics and processing may cause variations in the size of individual bits and in the density ratio between a bit and its adjacent background. Image exposure is often not optimum and variations in film processing and duplication must be utilized to optimize the image information content. These variations affect both bit size and code block density over a very wide range. Figure #5 illustrates the extremes of code block variation. Figure #6 illustrates the range of allowable density variations.

The first step in exploiting the MIL-STD 782 code block is to translate the recorded data into a format usable by the interpreter or by other equipment, i.e. a computer. With suitable magnification and illumination, visual interpretation provides the most reliable way of detecting bits since the range of the human eye and its adaptability to a wide variety of conditions exceeds that of nearly any automatic instrument. Conversion of the detected bits into human or machine usable data is a very time consuming process subject to substantial error. An immediate question arises. If humans can be trained to read alpha-numeric characters or teletype tape at several hundred words per minute and can receive Morse code aurally at several tens of words per minute, why can't they be easily trained to read a simple 16 character code system with more than adequate speed? The answer to this question lies in two parts. Anyone who has been trained to receive Morse code will recognize the differences in attainable speed and error rate when receiving "in the clear" and when receiving code groups. The lack of known relationships between the individual letters of a code group and between groups greatly lowers the intelligibility of the signal and increases error rates. A similar situation exists when translating all numeric data. Transposition and substitution of numbers in accounting are such common errors that a rigid set of checks is utilized as protection and most manual accountants routinely perform all operations twice. This problem is greatly increased when each character consists of 4 data bits plus two housekeeping bits. A second and perhaps equally important problem lies in the format of the MIL-STD-782 block. The geometric distortions inherent in the recording technique require that bit positions be read with respect to adjacent recorded bits to ensure non-ambiguous assignment of a detected bit to the correct file. The combination of size variations, skew and possible bit misalignment reduces the ability of the human interpreter to judge file assignment without careful inspection and introduces severe error rates into the pattern recognition process essential to rapid translation of code blocks.

The above remarks are not intended to imply that reading MIL-STD-782 blocks visually is an impossible task. Indeed blocks recorded outside the specifications of MIL-STD-782 may be interpretable in no other way and for a variety of reasons every photo interpreter should be capable of reading the code block by eye. They do indicate that manual reading is a time consuming process, subject to severe error rates, unsatisfactory for effective and/or consistent use with semi-automatic or automated interpretation techniques.

Efforts have been made to allow the interpreter to concentrate on bit detection and location by providing keys into which he can punch the l's and 0's detected visually from the code block. Use of this technique minimizes the interpreter training required to translate the code blocks but does not solve the problem of file determination. Additionally such equipment is relatively slow compared to pattern recognition, accentuates the problem of l-0 transpositions and requires relatively expensive displays or formatting equipment to allow visual or machine utilization of the output. The speaker has no authoritative data concerning tests performed with this type of equipment.

Several known types of semi-automatic code readers have been and are being considered. These readers are relatively low cost units designed to read and display stationary MIL-STD-782 code blocks. In general, these units utilize a low speed scanning and detection mechanism to detect the recorded bits and arrange them for display or utilization. Geometric tolerances are compensated by manually distorting the scanning path or the optical projection of the code block. Since code block recording systems do not usually show gross geometric changes from frame to frame, a single setting is normally sufficient to read several blocks or possibly a complete mission. The semi-automatic readers will not read worse-worse case blocks but depending upon interpretation mission requirements may read a sufficiently high percentage to warrant their use. Output from semi-automatic readers have been primarily in the form of visual displays for interpreter use. Digital outputs could be provided but the time consumed in stopping the film, positioning the block in the reader, performing any required adjustments and allowing the slow scan does not appear compatible with automatic control or computation systems and certainly would prohibit any automatic point or frame coverage searching.

Fully automatic code readers and displays which read MIL-STD-782 code blocks at rates of 4 blocks per second or film speeds of 20" per second are in operational use. These readers will operate with positive or negative film emulsion up or emulsion down and will present their output through a digital buffer to automatic computation and control systems or as direct reading or buffered digital displays. They are operational as modules of Image Interpretation Systems in the U.S. Navy and mobile image interpretation environments. Configurations to fit standard light tables or special purpose viewers are available. A variety of efforts to improve operational characteristics are in progress.

Selection of an optimum operating technique and equipment configuration for exploiting MIL-STD-782 coded flight data is very much dependent upon predicted mission requirements. For certain types of missions such as strike damage evaluation of know targets with excellent documentation of original target size and surrounding ground scale, the primary value of the data block, other than for on-line computer use, may be in verification of the date and time of image acquisition and quick retrieval of previous imagery for comparison purposes. Similarly evaluation of repetitive border surveillance missions over well marked and well known territory may utilize the data block primarily for sortie, time and date verification with detection, identification, location and measurement performed by identifying and scaling from known objects within the imagery. It should be noted, however, that even in missions of this type, large volume or very short reaction time requirements may warrant extensive use of data block information for quick automatic or automated location of desired imagery and rapid call-up of comparison data.

In other types of missions such as spot or area surveillance over areas with few distinctive terrain features, such as jungle canopy, extensive use of navigation data from the code block is a practicable solution to correlate the imagery with the ground coordinates.

Several possible uses of the data from MIL-STD-782 code blocks can be contemplated. The degree of automation required for effective performance is suggested where appropriate. There are, however, some assumptions concerning work load and allowable interpretation time implied. Each function can be and is being performed manually. The intent of this paper is to illustrate alternate techniques to assist the image interpretation team in its task.

Use of data from the MIL-STD-782B code block can provide substantial assistance to the interpretation team in several major areas. These include:

Photo interpretation orientation
Rapid location of imagery covering specific geographic areas or locations

Determination of approximate and exact location of detected installations
Synchronization of new and reference imagery with charts and maps
Collateral information retrieval
Pilot trace correction
Plots of image cover
Plots of known installations
Ground scale determination
Object height determination
Data base organization

One of the basic problems of image interpretation is orientation of imagery with respect to the terrain. Typically this operation is performed by locating recognizable terrain features in the imagery and using the pilots log and interpreters memory to assist in locating the same features on charts or maps of the area. Once a reference point and heading are established, the interpreter can "fly" the pilot trace through successive frames using additional terrain features to maintain correlation between imagery and geographic position. This procedure is effective where terrain features are plentiful and is particularly useful when the interpreter is familiar with the terrain. If the area contains few recognizable terrain features, or mapping is poor, the procedure becomes very time consuming and may at best result in only approximate orientation.

Use of navigation data from the MIL-STD-782 code block can substantially assist in interpreter orientation. Since latitude and longitude are provided to 0.1 minute on each frame (approximately 0.1 mile at the equator), the interpreter may directly refer nominal aircraft position to the appropriate chart or map position. Depending upon the estimated navigation accuracy and terrain characteristics, the search for corresponding features may be limited to a relatively few frames to establish a reference. Correlation between imagery and chart position along the mission is provided by reference to the navigation data and occasional correction by comparison of terrain features. Manual or semi-automatic data block reading is satisfactory for establishing the reference point but becomes cumbersome if continual reference to the data block is required. Automatic reading with a visual presentation allows quick reference to data block and chart coordinates particularly if a conversion overlay from latitude-longitude data to chart coordinates is used in connection with the chart. If a computer and a suitable input-output (IO) device is associated with the automatic reader, a cursor on the chart display may be automatically tracked with aircraft position or even with a corresponding cursor on the imagery. Tracking accuracy is dependent upon the recorded navigation data and the correction information and program supplied to the computer. In theory, accuracy may be equal to the best obtainable from mission photography. Practical considerations will probably dictate less precise correction except for specific installations.

Many interpretation missions require periodic reports on specific installations at known locations. Substantial reduction in interpreter effort is possible if the imagery covering the specific installation can be rapidly presented to the interpreter. Often imagery for several of these missions will be procured in a single sortie and presented on a single roll of film. Use of the code block navigation data allows rapid image positioning to the desired frame or nearby frames. If manual or semi-automatic reading is utilized, the position of the mission imagery on the roll is estimated from the pilots log, the film slewed to approximate position and the desired frame located by reference to the navigation data and imagery. If automatic code reading is available with visual display, the interpreter can slew the film near the desired location by reference to the more significant digits of the sequential latitude and longitude displays and locate the desired frame by slowing the film transport to allow reference to the least significant digit. Depending upon the accuracy of the navigation system, the desired installation will be located within a few frames of the nominal position. Used with an on-line computer, the frame nominally covering the desired area can be directly positioned since each frame coverage can be computed while the film is being slewed.

Approximate position of any installation detected on the imagery can be provided by reference to the navigation data, the nominal film scale (focal length/altitude in the same units) and the aircraft heading. More accurate position information may be obtained by correcting the navigation data by reference to the nearest known terrain feature. Still greater accuracy is obtained by correcting navigation data for position, velocity and heading from two or more known terrain features and including the effects of scale distortion resulting from aircraft altitude. The above comments apply particularly to vertical frame photography. If oblique or panoramic photography is used for scale measurements, corrections must be inserted for the effects of sensor angle and for forward motion compensation distortion. Absolute determination of ground distances should include the effects of changes in ground elevation. As each correction is added, ground scale computations become more complex and time consuming.

The simplest computation for reasonably high accuracy is provided by scaling two or more known terrain features on the same frame and proportioning the unknown to the measured scale factors lineally or with corrections for obliquity if the imagery is not vertical. If, as is often the case, multiple known terrain features are not available in a single frame, more complex manual computations become quite time consuming and are seldom attempted in reconnaissance interpretation. Provision of an electronic programmable desk calculator and reference to code block data and nearby terrain features provides the capability for relatively accurate position determination with reasonable effort. Use of an automatic code block reader on-line with a general purpose computer and provisioned for manually or semi-automatically supplying the image coordinates of known features allows very accurate determination of ground position. Inclusion of terrain slope data from reference charts or maps will improve positional accuracy determination, but should seldom be required unless slopes are unusually great. Certain sensors may introduce sufficient distortion to warrant inclusion as a correction. Correction of such distortion requires detailed knowledge of sensor characteristics as a function of viewing angle.

Code block navigational data can also be used to provide descriptors for retrieval of reference or collateral data filed by geographic area, time, scale and sensor.

Most of the above functions rely heavily on the use of navigation data to provide information. Inertial navigation systems allow positional errors during a mission ranging from a few hundred feet to a few miles. Use of an automatic code reader interconnected to a general purpose computer with facilities for manually or semi-automatically entering the recorded and actual coordinates of known terrain features allows for a navigation correction table routine that can adjust the navigational data on every frame. Each terrain feature entered improves the accuracy of the navigation correction.

Computerized interpolation and extrapolation from the terrain features will provide substantially improved navigation data accuracy since inertial navigation systems typically provide cumulatively increasing error. Computer programming can recognize INS reset points and include the effects of these resets in their computations. Most inertial navigation systems are somewhat maneuver sensitive. If the navigation system characteristics are known, these effects may be programmed in as weighting functions in the extrapolation program.

From the corrected navigation data the computer-automatic code reader combination automatically provide data for manually or automatically plotting the pilots trace for each mission. If desired, altitude, altitude and sensor scale may be used to plot coverage. Scale time and other annotations may be inserted on the coverage plot. Area plots of known or suspected installations may be prepared in a similar fashion. Use of an automatic code reader - general purpose computer with manual or semi-automatic input of image coordinates and manual input of installation identification codes provides facilities for developing the signals necessary to operate an automatic or manual plotter. Such situation displays might be stored graphically as described above or stored in computer memory for updating and display as required. To avoid confusion unverified installations may be so annotated and displayed with a distinguishing color or symbology.

Determination of scale factors to allow measurement of the size of ground objects small in comparison to the area covered by a single image is less complex than determination of geographic location. On vertical imagery the height of the aircraft above the object and the lens focal length provide a nominal scale factor of sufficient accuracy. Except in areas of extreme terrain slope the radar altimeter reading and sensor identity, from the code block, provide the data to determine scale factor. Correction data to compensate for viewing angle must be applied to oblique or panoramic imagery. If the sensor attitude is substantially off horizontal, corrections must be introduced for the change in attitude. Manual or semi-automatic code reading techniques and the use of suitable nomograms or charts will provide reasonable capability for scale determination. Use of a programmable desk calculator with or without automatic code reading will decrease the effort required in these operations. Use of an automatic code reader on-line to a general purpose computer with manual or semi-automatic entry of film coordinates will provide still faster operation with improved accuracy.

It is often desirable to determine the height of objects with respect to the ground plane. Three techniques are in common use. The first--use of stereo pairs--essentially utilizes triangulation of two images taken of the same object from different points of view. The second measures the shadow length cast when the sun angle is known. The third measures image size on oblique photography. In each of the three cases, speed and accuracy will increase as the level of equipment sophistication is raised and as in the instance of shadow length would allow height determination in many cases where it would not be attempted otherwise.

Intelligence agencies serving large organizations usually accumulate an extensive image data base. Automatic code readers and general purpose computers with manual input canbe effectively used to assist in indexing this imagery. The techniques are similar to those described for plotting image coverage and situation displays except that the computer would be programmed to organize the index and descriptors in a manner most useful for data retrieval.

Both image and other intelligence data indexes may be merged in this fashion to provide convenient access to any portion of the data base in response to queries containing many combinations of descriptors. Usual procedure in preparation of a storage and retrieval index for a large data base would read pertinent code block data directly onto magnetic tape with interspersed interpreters entries. Processing, merging and reorganization of the data into the storage and retrieval system is provided by the computer from the magnetic tape input.

In conclusion, the problem of the interpretation team - visual analysis of tremendous masses of graphic information in ever decreasing time periods - is becoming more and more critical. Automatic pattern recognition techniques require substantial development before they provide real assistance. Improved work flow, better presentation and automation of time consuming peripheral tasks offer the promise of providing considerable relief. Inclusion of flight data on each frame of imagery is key to much of the improvement. MIL-STD-782 defines the flight data content and format for United States military aerial reconnaissance systems. Proper exploitation of this data allows substantial reduction in the effort and time required for the performance of many interpretation tasks. Facilities and techniques are available for exploitation of MIL-STD-782 data ranging from essentially manual to visually aided, semi-automatic, automatic to fully automated systems.

As increasing use of code block data is contemplated, use of an automatic code reader becomes increasingly desirable. Visual presentation of code block data provides substantial improvement in interpreter orientation and the ability to locate imagery of specified areas. Combining the automatic code reader with a general purpose computer provides substantially increased capability in searching, determination of coverage, object location, size and height as well as correlation of imagery with reference and collateral information. The addition of suitable I/O equipment and automatic plotter allows automatic tracking of multi-sensor imagery, area coverage and situation plotting. The automatic code reader-computer combination also provides a powerful tool for data organization, storage and retrieval in both large and small installations.

Selection of the proper combination of equipment and operating procedures is very much dependent upon predicted interpretation missions, allowable reaction time, quantity of information desired per unit of imagery, cost and many similar items. The optimum utilization of the code block data depends on your requirements.

CODE MATRIX BLOCK DIMENSIONS

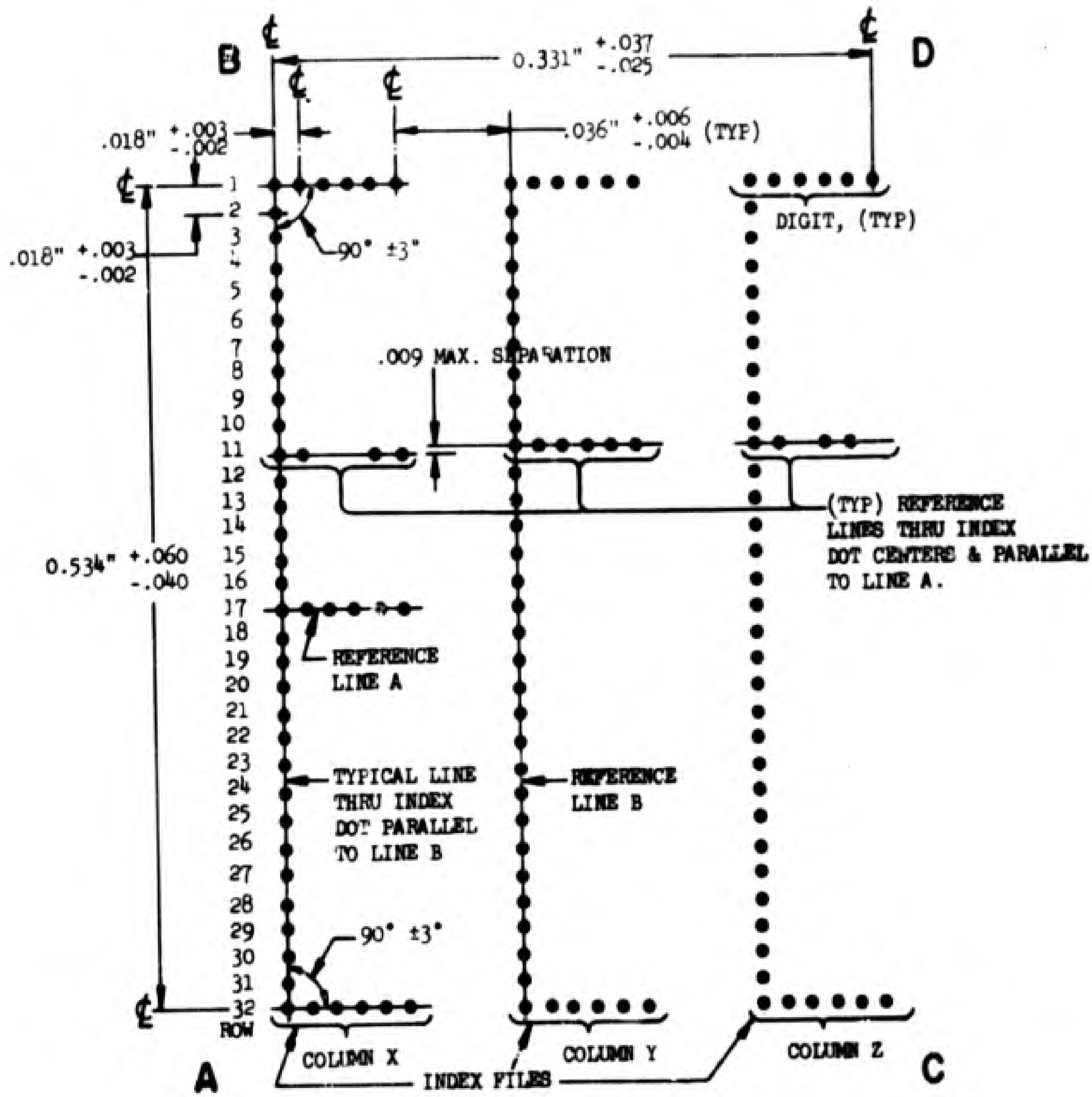


FIGURE 1

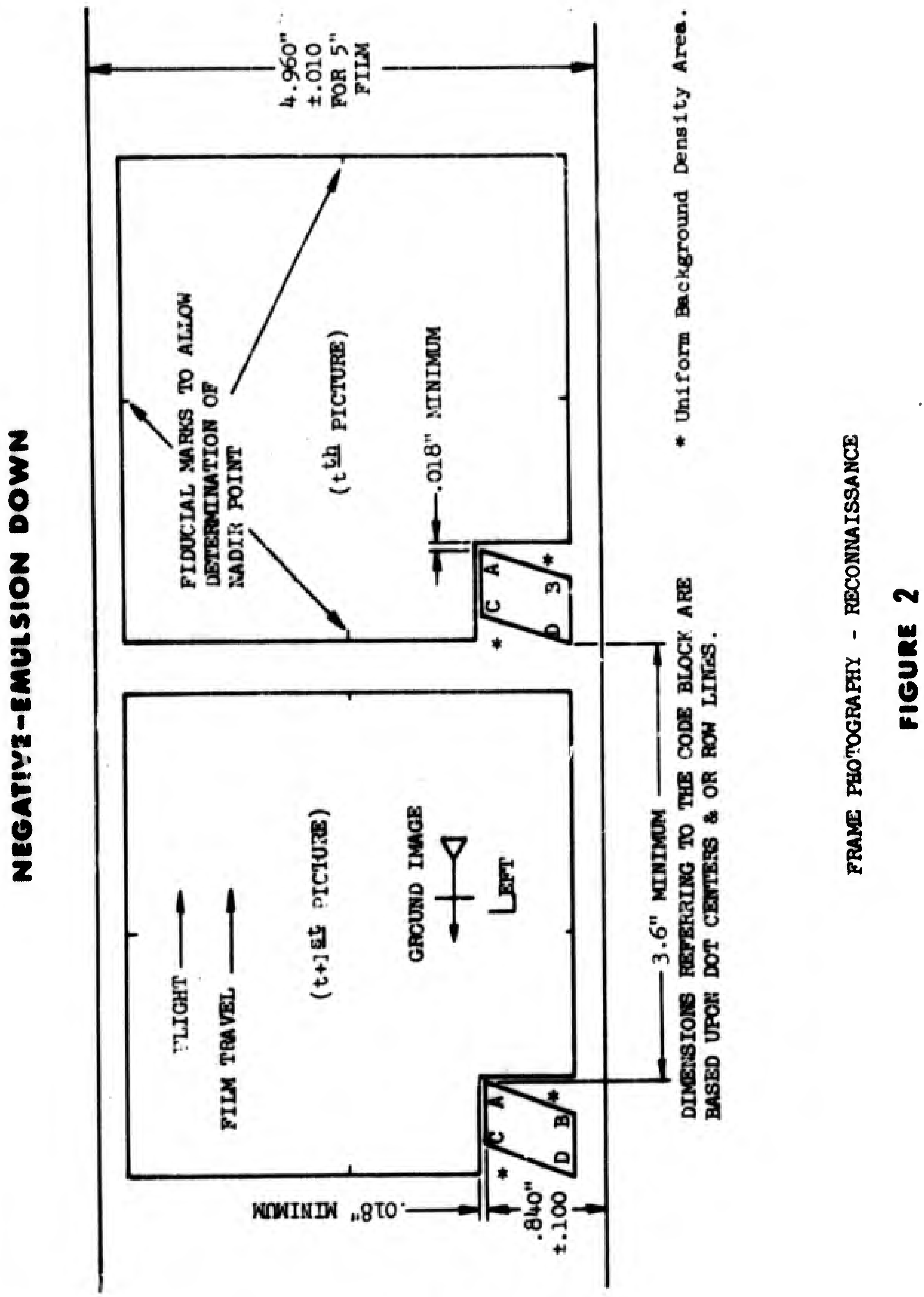
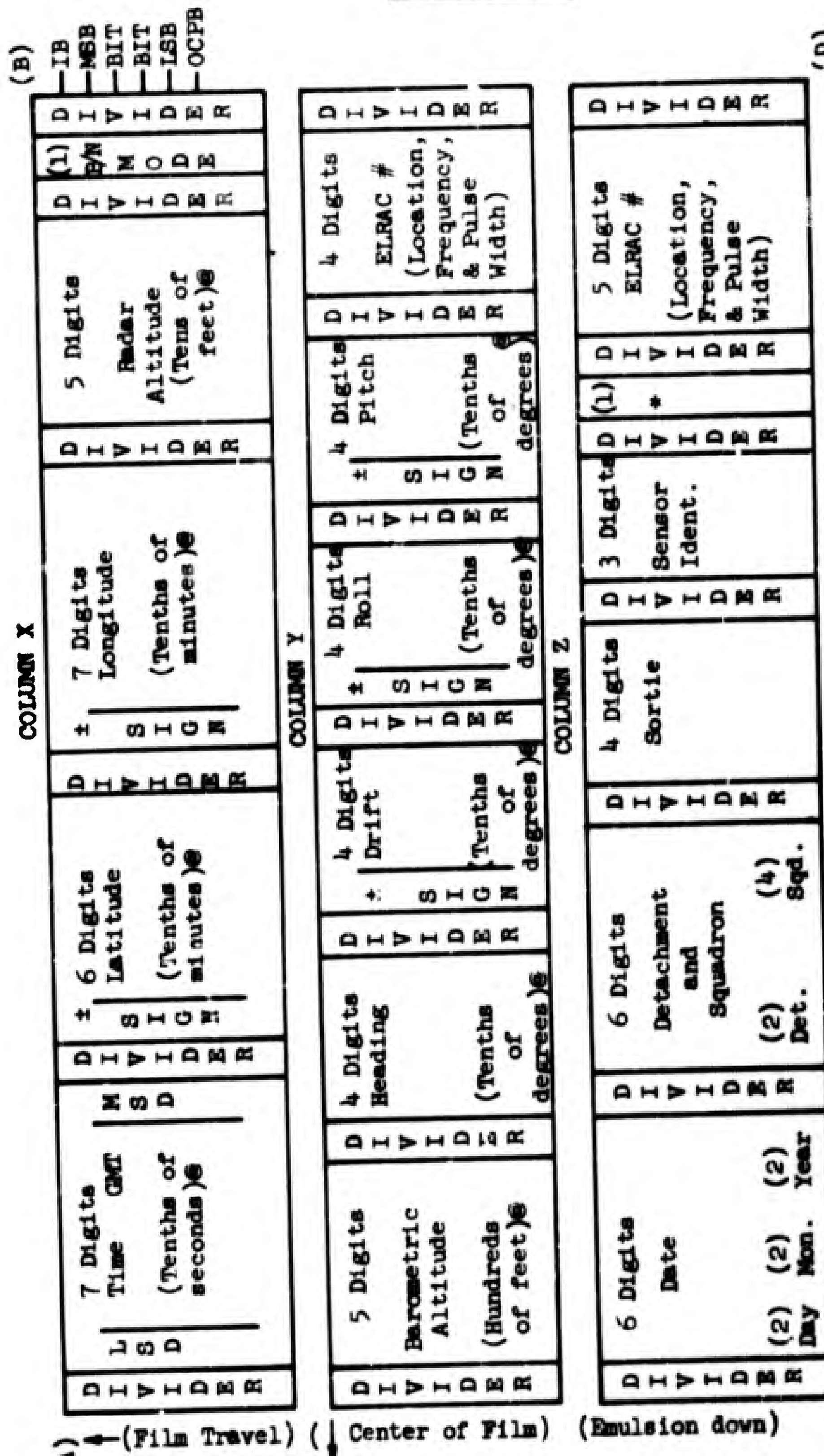

NEGATIVE-EMULSION DOWN
4.960"
±.010
FOR 5"
FILM
FIDUCIAL MARKS TO ALLOW
DETERMINATION OF
NADIR POINT
(t th PICTURE)
.018" MINIMUM
* Uniform Background Density Area.
FRAME PHOTOGRAPHY - RECONNAISSANCE
FIGURE 2
FLIGHT
FILM TRAVEL
(t+1st PICTURE)
GROUND IMAGE
LEFT
3.6" MINIMUM
DIMENSIONS REFERRING TO THE CODE BLOCK ARE
BASED UPON DOT CENTERS & OR ROW LINES.
.018" MINIMUM
.840"
±.100

FIGURE 2

CODE MATRIX BLOCK CONTENTS

RECONNAISSANCE



LEGEND: OCPB - Odd Character Parity Bit
IB - Index Bit
LSD - Least Significant Digit
MSD - Most Significant Digit
DIVIDER - Excess 3 Code w/OCPB & IB as (111111)
LSB - Least Significant Bit
MSB - Most Significant Bit
SPACE - Excess 3 Code w/OCPB & IB as (100001)
* SLR Mode Switch Position or Pan Prism Ident. (Left or Right) or Space
# ELRAC data requirement in columns Y2 thru Y5 and Z2 thru Z6 is optional.
@ Practical degree of accuracy.

FIGURE 3

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DATA MATRIX CODING

The data matrix is coded in excess three binary coded decimal. This system uses decimal numbering but it is recorded in a coded binary form as listed below. It is read as a normal binary system, that is right to left, making a summation of the significant bits, then subtracting three to obtain the decimal values tabulated below:

DECIMAL VALUE	INDEX BIT	D4 8	D3 4	D2 2	D1 1	PARITY BIT (Bit value)	NUMERIC VALUE OR MEANING
-3	o					o	Not Used
-2	o				o		Minus Sign
-1	o			o			Error
0	o			o	o	o	Zero
1	o		o				One
2	o		o		o	o	Two
3	o		o	o		o	Three
4	o		o	o	o		Four
5	o	o					Five
6	o	o			o	o	Six
7	o	o		o		o	Seven
8	o	o		o	o		Eight
9	o	o	o			o	Nine
10	o	o	o		o		Plus Sign
11	o	o	o	o			Special
12	o	o	o	o	o	o	Divider

NOTES:

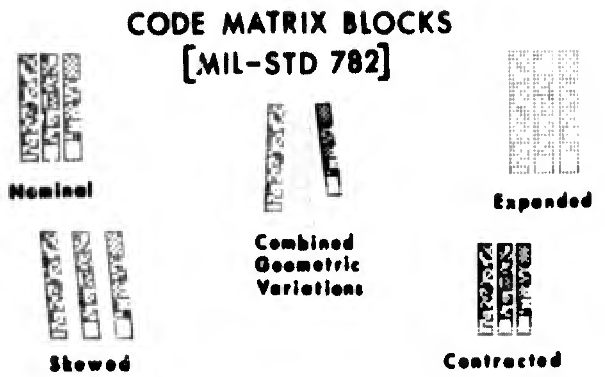
1. The index mark is always present.
2. The parity bit is present to cause the total count of dots across one column to be an even number. This provides the "odd parity check" to insure that the bit recording is correct.
3. The divider is used as a visual indicator to separate major groups of characters within the code matrix block.
4. Significant bits progress from D4 (most significant) through D1 (least significant).
5. "Error" indicates the information generated for recording is outside the range of the particular sensing device in use.
6. "Special" indicates that the information normally presented in this location will be found in some external device.
7. A plus or minus code may occur in the code matrix block. This is an acceptable coded digit. The plus and minus code convention is as follows:

Latitude: +North -South   Longitude: +East -West

Drift: +A/C Nose Left of Ground Track   -A/C Nose Right of Ground Track

Roll: +Right Wing Down -Right Wing Up   Pitch: +Nose Up -Nose Down

FIGURE 4



ACTUAL SIZE

EXTREMES OF CODE BLOCK VARIATION

FIGURE 5

DENSITY AND DIMENSIONAL REQUIREMENTS FOR AN ISOLATED DOT

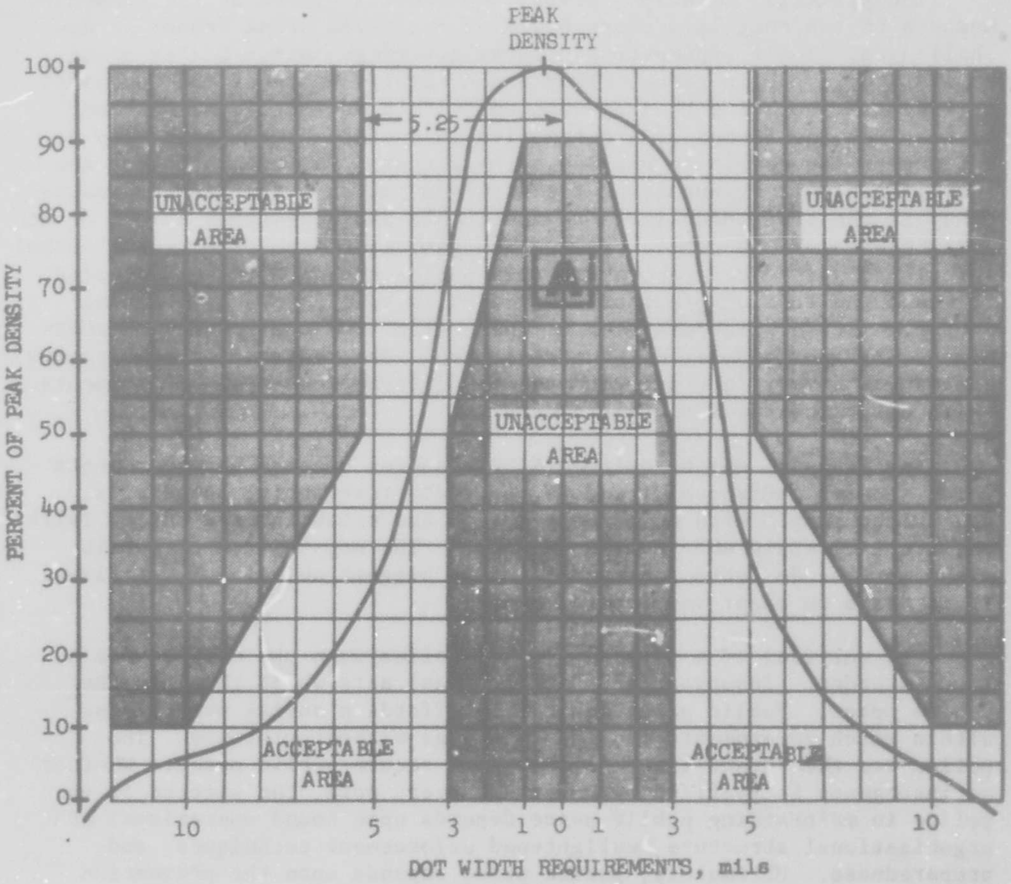


FIGURE 6

RESISTANCE RESEARCH AND POLICE TECHNIQUES

RECIPROCATE PUBLIC PEACE ($Rr - Pt \simeq p^2$)

Colonel D. R. Dingeman and Major Ovid E. Roberts, III
Military Police Agency
US Army Combat Developments Command

The pitfalls, swindles, traps, and deceits played by the Communist masters on the real life chess board of the world arena cannot go unchallenged. Their opponents are those sovereign nation-states whose aspiration is public peace. They are generally aware of the Communist strategy of replacing their government with a de facto one, but they either lack the forces or are beguiled into complacency, thus they do not accept the gambit to challenge the threat. Failure to accept the real life gambit by uprooting the insurgent at an early time in insurgency is the trap which leads to inevitable and disastrous defeat or at least breach of the public peace. The gambit, if accepted, means social turbulence which accompanies vigorous police action. If not accepted, it means the loss of precious time which is rarely favorable to the sovereign state. The emerging nations often lack the forces and techniques with which to accept the challenge. The reasons for complacency are many and vary in proportion to the different cultural environments which determine types of governments.

Public peace may be defined as the socius created by governments which secures individual freedoms, protects territorial boundaries, alines the people with government goals, and establishes a united faith between the people and their government. The negotiation of public peace for the de facto government is the biggest swindle of our times! It is based on cheat and deceit.

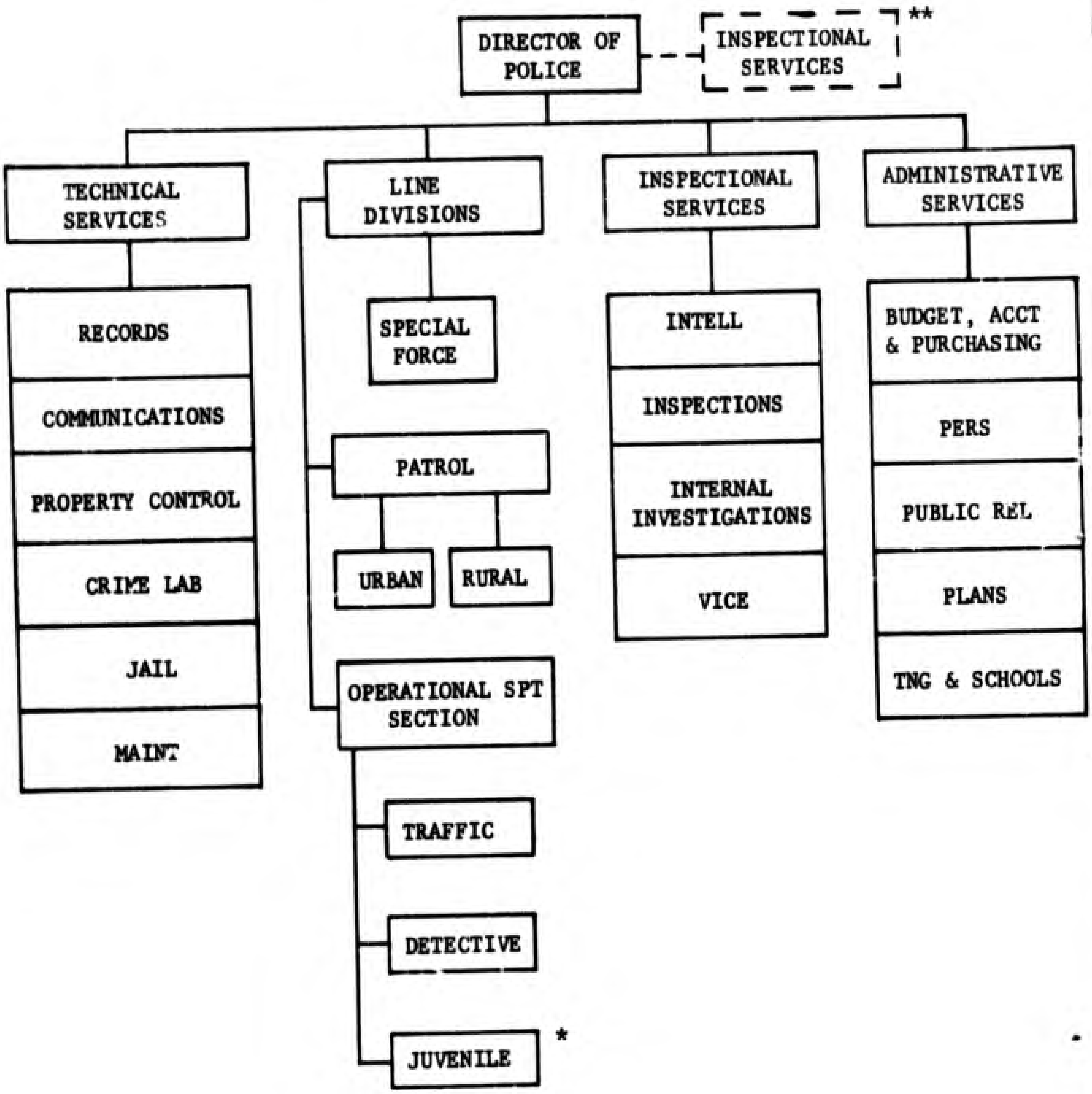
The survival of a sovereign state relies upon the maintenance of law and order. Insurgent acts are criminal acts which threaten the public peace. Public peace inherently affords a social orderliness within which governments can induce change without violence. The police are the "front line" forces which secure public peace. Whether an insurgency is typified by covert or overt acts, the success of the police in maintaining public peace depends upon sound operational and organizational structure, enlightened enforcement techniques, and preparedness. Ultimately, public peace depends upon the prevention of insurgency through a proficient, people-oriented, police force.

The "rising tide of expectations" expressed by emerging nations includes not only material well-being, but a social order through which material wealth can be realized. This social order, or public peace, is the aspiration of mankind through which our government seeks association with other nations through commonality of understanding. It is the bulwark of American freedoms created under a government of law whose aim is justice for all. The commonality of understanding is the basis for their assurance that once our assistance is requested, it will follow.

Our military forces have been called to assist police of other nations. Assistance given to the Philippines in developing a constabulary and our assistance to gendarmarie in Iran and the National Police in Korea all provided actual knowledge and some experience, but little doctrine. Part of our military assistance problem to other police forces of the world has stemmed from the divergence in US police organizational and operational structure with their police structures. Most nations of the world have a centralized system of organization and operations, while our own is highly decentralized. There is no foolproof template for police forces which the United States can superimpose on a host nation which would be applicable anywhere in the world. This problem is further compounded since military and/or paramilitary forces of other nations often have a police role.

Our Commander in Chief has said that our Army must be ready to assist any sovereign state anywhere and at any stage of insurgency. This requirement underlines the question, how best to organize for the task? To attempt to answer part of this question, this Agency developed a police "model." It could represent, organizationally and operationally, a structure which might solve the organizational part of the problem. Using the systems analysis approach, a comparison was made of existing police forces of the world to obtain data on strengths, organizations, responsibilities, and functions. This was accomplished by a search of the literature. A questionnaire was sent to 158 cities in the United States to compare percentages of personnel occupied in the basic functional areas of administration, auxiliary services, operational support, and patrol. One hundred and six responses were received. Six of these were invalidated because of unresolved mechanical errors. Based on the validated returned questionnaires, the organizational and functional areas of each department were analyzed to determine the ratios of effort devoted to each area. An analysis of these ratios was made and a simplified police force "model" was constructed which can be used to determine police requirements and develop an organization. It has been encouraging to note that a similar model was derived by the Research Analysis Corporation. This Agency's model is shown below.

MODEL POLICE ORGANIZATION NATIONAL LEVEL



*As required.
**May be attached to director's office when subsections are combined because of limited personnel.

Further research projects which will assist the US Army in devising doctrine and techniques that can be successfully employed in securing public peace seem to present themselves. These are:

a. Developing police organizations adaptable to specific cultural environments.

b. Developing doctrine and principles for police and/or military or paramilitary forces acting in a police role.

c. Developing police techniques which counter subversion, sabotage, and espionage within specific cultural environments.

d. How to create a favorable police image which will enhance public peace in various types of cultural environments.

The doctrine ultimately developed for our assistance to other nations will be principle-oriented, but it must also be flexible in application through techniques applicable to various cultural environments. The questions of -- Where will we be called on to assist? - How will we assist? -- create the need for answers in the form of doctrine. Too often, the call for assistance has come when insurgency was deep rooted and reflected the result of inability of police to quell or contain disorder. What, then, can be done to develop the needed doctrine to assist the police of other nations in this struggle? The answer rests in part in operations research and systems analysis, some of which can benefit our own police efforts.

The key to successful police efforts in securing public peace is crime prevention, since insurgent acts are usually criminal acts, if only under treason and sedition statutes. When crime is prevented by an efficient, even though unsophisticated, police force, insurgency requiring the commitment of massive national resources and external support to extinguish cannot, or will not, occur. The determination that an insurgency is taking place is usually made after-the-fact.

The fear of giving the police greater powers to counter insurgent efforts, buttressed by inadequate supporting laws and regulations, often limits police capabilities. The police image of acting within the law is enhanced when they have the power to secure the public peace, and insurgent propaganda is nonproductive when directed at the government for using strong countermeasures. The weakness of laws within which the police are forced to operate is advantageous to the insurgent. Such weaknesses create opportunities to foment insurrection, disorder, and chaos. Recognizing that stringent laws and increased police powers for enforcement are obvious after an insurgency has occurred, and crime prevention can prevent insurgent acts, how does a sovereign state determine that crime trends indicate that strong action is required to prevent the insurgency from becoming a threat to its existence? The answer to this question eludes us, but is under active study under the aegis of the Department of Defense through ARPA. Nevertheless, the prevention of crime can prevent the insurgent from reaching his goal.

Basically, a police crime prevention program must include police proficiency in:

a. Riot control.

b. Physical or plant security.

c. Criminal investigations.

d. Police intelligence.

e. Basic police duties, i.e., patrolling, checkpoint operations, apprehensions, searches and seizures, and communications.

It is this unsophisticated, efficient base that provides the scaffolding upon which effective police advisory effort can build. Too often, emerging nations are too late in recognizing this type of force as essential to their existence. Unfortunately, even in strong nations, public apathy toward crime prevention and brutality committed by the untrained or uneducated police officer influence the support given to the police. Yet, in maintaining law and order, as a part of public peace, the police forces of the world stand as the fulcrum of a lever which can determine a nation's existence. Funds expended to improve its capabilities may appear initially exorbitant, but they are minimal when compared to the military expense required to combat insurgency in the <u>developed</u> stages.

We are also learning that to successfully counter the insurgent requires an appreciation of <u>his</u> means of controlling people. This requires an understanding of the entire milieux of the target area; i.e., political, economic, and social. Whatever assistance is provided must be in harmony with that environment. Mores, customs, and taboos may have greater impact than legal (or lack of legal) rules imposed upon a police force. The propaganda theme developed by the insurgents depends on the failure of the sovereign power to maintain its own favorable image of order and respect in the eyes of its people. The aim of insurgent forces to discredit the government in being is broadly applied, but the police execution of law and order tasks, as an integral part of the public peace, stands in its way. Massive military campaigns eventually must be reduced to the concerted police action of apprehending or destroying insurgents, one by one. It is the attack on the infrastructure of the insurgency movement that will bring its downfall. In this, the police play an important part. It has been evident in Korea, Philippines, Malaya, and Iran that elimination of the infrastructure is essential to the defeat of the insurgency - control of the center of the board! An understanding of the environment in which our police advice will be given will answer the question, how will we assist?

Since insurgencies are often successful where a reliable police force is lacking, it is essential that more emphasis be given to the development of sound police systems as the stabilizing force to prevent insurgent fires from starting, or to extinguish the sparks when they appear. To assist newly developed or emerging nations whose political structures govern (if not determine) the operational employment of their police and control the economic resources which affect their capability to create, restore, and maintain law and order, a thorough knowledge of police forces of the world likely to require our support is imperative. It is imperative to us from a political and economic point of view, and it is imperative to the recipient if our assistance is to be meaningful to him. We are hopeful that a compendium of this nature can be compiled.

If our assistance in securing public peace of other nation-states is to be <u>lasting</u>, it will depend largely upon what we have done to help them <u>maintain</u> law and order. The expense of large military forces is a drain on all societies everywhere.

Further research should be directed toward developing techniques which will make the police job in internal defense operations more effective. Some of the areas where research should be directed are:

a. Interrogation methods and possibilities.

b. Counterterrorist methods and when best to commit them.

c. Censorship mechanisms and plans, particularly for sudden needs to control mass media.

d. Rationing and financial controls.

e. X-ray type search devices to rapidly process masses of people and luggage.

f. Nonlethal weapons for use in crowded situations.

g. Effective roadblocks and barricades.

h. Police morale.

The recognition of police contributions to internal defense operations is not new. In 1962, U. Alexis Johnson, in an article in the Foreign Service Journal entitled, "Internal Defense and the Foreign Service," stated that, "if a government is to survive it must be able to protect the lives and property of its people, its territorial integrity, and the sovereignty of the state. Economic and political development requires that the citizenry be free to realize their political and social aspirations and enhance their economic status in environment free from violence and unrest. An effective police force, trained in public service concepts and employing modern techniques, should be able to contain public disorders without excessive violence and also cope with conspiracy and subversion."

Recently, the Communist Party leader in Russia, Leonid Brezhnev, in a speech addressed to the East German Communist Party in East Berlin, proposed a unity of action between Soviet and Chinese Communist to halt the United States in Vietnam. They would ploy forces politically and militarily -- rooks to the center files!

Operations research devoted to completely answer the question -- How does a government secure public peace? -- deals with a whole panoply of problems, none of which are without the sphere of police influence. The collective efforts of research agencies can lead us in overcoming those who would achieve their goals by the overthrow of peaceful governments through unlawful means.

BIBLIOGRAPHY

ABT Associates Inc. The Urb-Coin Game. Cambridge, Massachusetts: October 1966.

Barss, Dr. Lawrence W. Urban Disequilibrium Study. Cambridge, Massachusetts: Associates for International Research Inc., 1966.

Breit, J. M., et al. A Summary Report of Research Requirements for Sensing and Averting Critical Insurgent Actions in an Urban Environment (U). McLean, Virginia: Research Analysis Corporation, June 1966.

Clutterbuck, Richard L. (Brigadier). The Long, Long War. New York: Frederick A. Praeger, Publishers, 1966.

Deputy Chief of Staff for Military Operations. PROVN (U). Washington, D. C.: March 1966.

Deputy Chief of Staff for Military Operations. WINS II (U). Washington, D. C.: 1 March 1965.

Foster, Robert J., et al. An Analysis of Human Relations Training and its Implications for Overseas. Alexandria, Virginia: The George Washington University, August 1966.

Gartoff, Raymond L. Soviet Military Strategy. New York: Frederick A. Praeger, Publishers, 1966.

Glick, Edward Bernard. ORBIS. A Quarterly Journal of World Affairs, "Conflict, Civic Action and Counterinsurgency," Vol X, No 3, Fall, 1966.

Jones, Adrian H., and Andrew R. Molnar. Internal Defense Against Insurgency: Six Cases. Washington, D. C.: Center for Research in Social Systems, The American University, December 1966.

Kaplan, Robert L., and Daniel Parker. Supplemental Computations on Insurgent Incident Rates and Incident Generation Capabilities (U). Alexandria, Virginia: Defense Document Center, December 1965.

Lybrand, William A. The U. S. Army's Limited War Mission and Social Science Research. Washington, D. C.: Symposium Proceedings, Special Operations Research Office, June 1962.

Molnar, Andrew R., et al. Human Factors: Considerations of Undergrounds in Insurgencies. Washington, D. C.: Center for Research in Social Systems, The American University, December 1966.

Rosenthal, Carl F., et al. Economic, Social, and Political Factors in Counterinsurgency Intelligence Planning. Washington, D. C.: Center for Research in Social Systems, The American University, December 1966.

Sorenson, J. L., et al. An Inventory of Urban Insurgent and Counter-insurgent Tactics (U). Tech Memorandum 415. Santa Barbara, California: Defense Research Corporation, August 1966.

Sorenson, J. L. Urban Insurgency and Military Requirements (U). Tech Memorandum 307. Santa Barbara, California: Defense Research Corporation, November 1965.

Sorenson, J. L., et al. Urban Insurgency Studies (U). ARPA Order No 687. Santa Barbara, California: Defense Research Corporation, August 1966.

Stathacopoulos, A. D., and Z. Pazamy. Background for Counterinsurgency Studies in Latin America - II (U). Santa Barbara, California: Defense Research Corporation, September 1964.

Trinquier, Roger. Modern Warfare. A French View of Counterinsurgency. New York: Frederick A. Praeger, Publishers, 1964.

US Army Combat Developments Command. Planning and Programming Forces for Stability Operations (U). Fort Belvoir, Virginia: August 1965.

US Congress, Senate, Internal Security Subcommittee. A Communist Plot Against Free World Police: An Expose of Crowd-Handling Methods. Washington, D. C.: US Government Printing Office, 13 June 1961.

MEDICAL WORKLOADS FROM CHEMICAL AND BIOLOGICAL WEAPONS 1967 - 1972

Work done by the Research Analysis Corporation, McLean, Va.
Cognizant Agency: USA Combat Developments Command Medical
Service Agency, Fort Sam Houston.

Paper is based on the resulting study RAC-R-29, Vol I:

"Medical Workloads from Chemical and Biological Weapons 1967-1972"

Dr. Donald M. Boyd
Mr. Howard S. Greer
Mrs. Betty W. Holz
Mr. Richard C. Robinson, Chairman
(presented paper)

RAC is currently engaged in a Medical Workloads Study sponsored by the Medical Service Agency (MSA) of the United States Army Combat Developments Command (USACDC). This is a part of the Medical Service Agency's overall research effort to determine the impact of future combat patient loads on the field medical system. We have just completed the second phase of our study and are taking this opportunity to present the methodology, which we believe could have application to other studies. Specifically, I will briefly describe the structure and capabilities of the simulation developed as the primary research tool for investigating medical workloads from chemical and biological weapons. Planning for efficient organization and staffing of medical units to support combat troops in a theater of operations requires estimates of anticipated casualties. Estimates should include the numbers of killed and wounded in action, type of injury, severity, frequency of occurrence, and the impact of casualties on organization and treatment-time requirements of the MSA field installations.

The primary objectives of this RAC study are to estimate the expected number and type of U.S. combat casualties that would require treatment by medical organizations in a theater of operations and to develop a computer simulation that will permit calculations of casualties by type from the effects of chemical, biological, improved fragmentation and nuclear weapons within stated tactical situations when one or more weapons systems are employed. Phase II of the objective, concerned with developing a computer simulation model and estimating medical workloads from CB weapons in the 1967-1972 time frame, has just been completed. Work was recently begun to augment the simulation to estimate medical workloads from the effects of improved fragmentation weapons. The various submodels of the computer simulation also can be applied for purposes other than medical workloads estimates, and a detailed user manual has been prepared as Vol II so that other organizations can use this fairly sophisticated model with minimum effort.

To interpret the output of the model in terms of the implication to the Medical Service Agency, and to avoid use of ambiguous terms such as "incapacitation" and "ineffectives", the medical workloads are estimated in terms of the number and types of casualties requiring professional medical treatment, and the time-phasing of the incidence and termination for the need of medical care. That is, each person in the target area under attack by CB agents is assessed and classified into a treatment category according to the dose he receives; then the periods of required treatment are determined for those requiring more than outpatient care. Thus following an attack, each man is initially placed in one of the following four categories according to his simulated response from the dose he received:

Category A: Those who are capable of continuing their military duties without any professional medical treatment. (however, assistance by the unit medical aid man, buddy-aid, or self-aid may be required).

Category B: Those who require medical attention, either intermittent outpatient care or observation and treatment for a short period of time. (this treatment is followed by return to their immediate units).

Category C: Those who require definitive treatment and continuous or intensive care. (tenure in this category also includes the time the patient might be held pending diagnosis and decision for his need for intensive or continuous care).

Category D: Those who die before any medical treatment can be provided, i.e. the KIA's.

Category E: Those who die despite medical treatment.

In addition to these, a Category E was created for delayed disposition of patients who are initially classified as Category C, but having received a dose in the lethal range, eventually die. It should be emphasized that all of these categories are classes of treatment requirements and are not intended to indicate that a certain type or location of field medical facility will necessarily provide the care attributed to that category. Other studies being conducted by the MSA are addressing the problem of the location of casualty treatment facilities and the flow of patients within the field medical system.

These categories laid the foundation for a definitive formulation of medical workload. Thus for the purposes of this study, the medical workload from chemical and biological casualties is defined to be:

(1) the number of men in Category B and the percentage of initial target personnel this represents;

(2) the number of men in Category C and the percentage of initial target personnel this represents; and

(3) the time-phasing of the need for medical treatment for those in Category C.

During the feasibility stage of the study it was decided that adaptation of an existing computer simulation, rather than development of an entirely new one, was necessary due to the overall time limitation. In view of the CB casualty data required by the study, the study group chose a simulation called PHAROS, developed for the Operations Research Group (ORG) at Edgewood, Maryland, by Operations Research Incorporated for evaluation and comparison of weapons systems. It had the degree of fine structure necessary for accurate analysis and was suitable to adaptation for our purpose. This model had been under continuous development for four years and its complexity actually enhanced the adaptive process of incorporating new routines and modifying existing ones. During the past two years the PHAROS simulation has undergone extensive modification at RAC, more than doubling its original size. Due to these changes and also to the different intended purpose and type of output, it was decided to rename this augmented simulation PHARAC, in order to avoid confusion with the PHAROS model.

PHARAC is a Monte Carlo simulation programmed in FORTRAN IV for compilation and execution on the IBM 7040/44 and 7090/94 computers. It can simulate a variety of anti-personnel biological and chemical agents. The chemical agents simulated are the nerve agents, of either high or low volatility, and the vesicant mustard (HD). PHARAC is a fairly comprehensive casualty model for CB weapons employment and has considerable flexibility in target generation and selection, agent delivery means and associated errors, and choice of agent. Mathematically, it is a 4-dimensional space-time model which considers the interaction of the agent concentration history (dependent on the munition and meteorological conditions), the man's breathing-pattern history (a function of activity rate and breathhold control), and his position relative to each agent source (munition burst). Thus, the dose ingested by each man is found by integrating the product of the agent concentration function and the volume intake function with respect to time. Then the dose in functionally related to the probability of a medical treatment requirement by use of probit analysis.

Basically the simulation details the medical workload and deaths resultant from a single attack against specified targets using either biological or chemical weapons. It does not represent a period of sustained combat. It is a stochastic model in that probability distributions are used to decide between alternatives; and thus repeated runs of the same situation yield a distribution of results. There are four major sections of the simulation. These are:

(1) Targeting - which defines the target area and forms a set of target elements representing soldiers;

(2) Delivery - which simulates the delivery of CB agent to the target area;

(3) Effects - which calculates the agent dose received by each target element; and

(4) Workload - which classifies each target element into one of the five medical treatment categories (A, B, C, D, or E), according to the dose received.

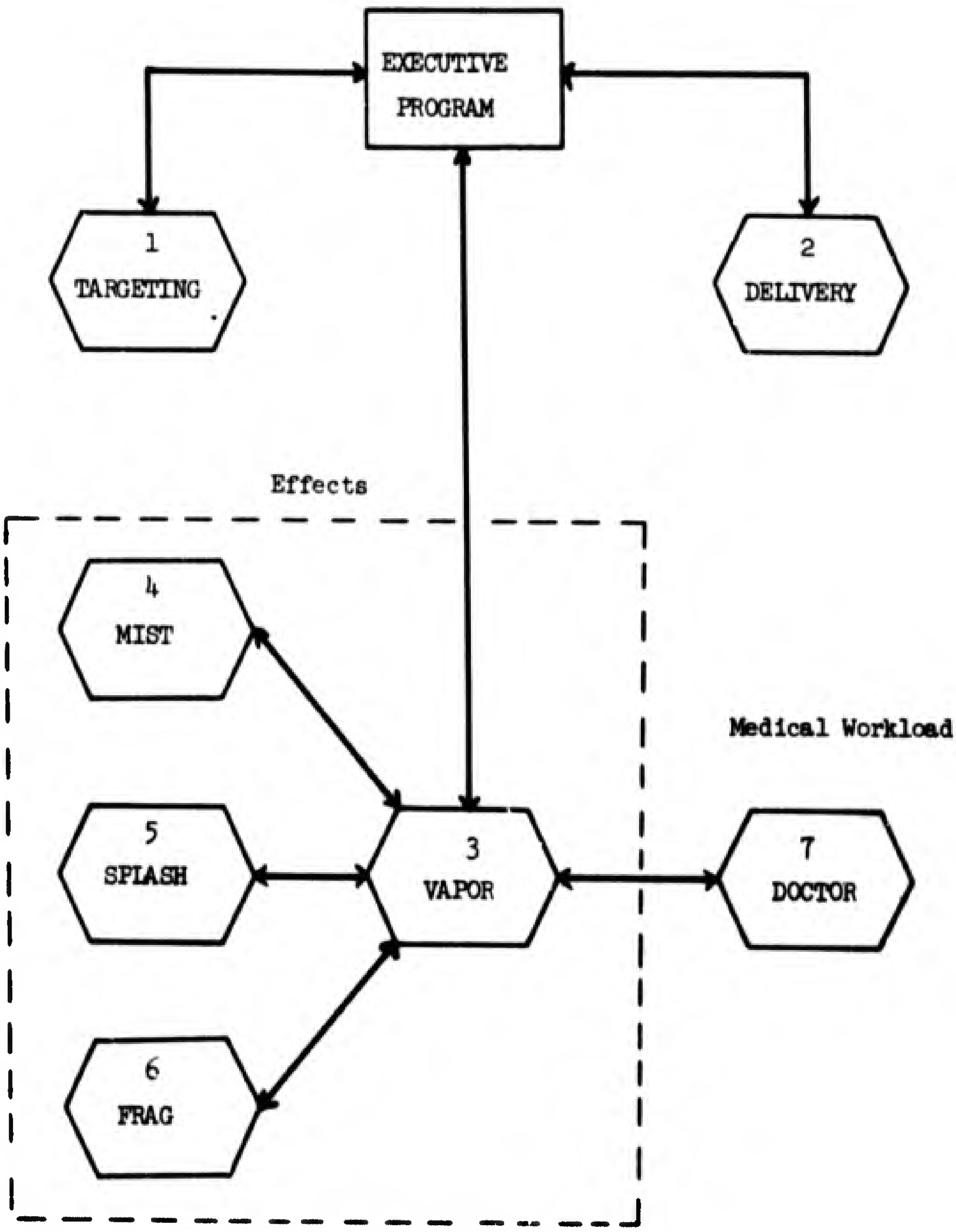
This last section also determines the time-phasing of treatment required for those in Category C. The diagram shows the sequential flow of control through the 7 major subroutines. The double headed arrows indicate that control returns to the calling program. These will be discussed one at a time.

The Executive Program is quite large but merely has the function of controlling the simulation logic and handling numerous housekeeping chores such as reading input data, printing much of the output, and calculating numerous variables used by the various subroutines.

Targeting

The function of the Targeting section of the model is to provide a set of target elements, identified by their x,y-coordinates in the target area, which will be challenged by CB agents. A target element is a conceptual entity representing an individual soldier or a group of men. If the elements represent groups, all members of a group have identical characteristics since the simulation does not distinguish between constituents within a target element. Thus a target element might be a squad or a platoon, and all individuals within this group are assumed to receive the same dose of agent and respond in the same way. For convenience in the rest of the briefing, the term "man" will imply either a single soldier or a target element representing a group of soldiers. Target elements may be either read in as data or generated by the program. To provide a means of generating the target element coordinates, the concept of a target area is used. A delimited target area is a rectangular or circular area which contains target elements. The program can position elements, either uniformly or randomly, in up to 10 distinct target areas, and these areas may be of different sizes and located independently of each other. This capability can be useful, for example, in evaluating the downwind effects on areas with varying target element densities.

In addition to the delimited target area just described, the model will also simulate the aircraft delivery of a line of BW bomblets or aircraft spray dissemination against a target area which cannot be conveniently delimited. Such an area is termed an extended target area.



General Flow Diagram of PHARAC

By using the crosswind distance over which the bomblets will be dropped and the maximum downwind distance at which bomblets can produce casualties, the model in effect converts this problem into a delimited target area. The total number of men within a target area can either be specified or be computed on the basis of the size of the area and a specified troop density. The coordinates of the individual men are then located with either uniform spacing or obtained by sampling from a uniform random distribution.

Delivery

The function of the Delivery section of the model is to construct a set of 4 tables concerning the munitions employed against the target elements generated by the Targeting section. The four tables are:

(1) the x,y-coordinates of each munition burst;

(2) the time of burst of each munition relative to the first;

(3) the height of burst of each munition; and

(4) the amount of agent disseminated by each munition.

The delivery model can produce these tables under a variety of input conditions. It can simulate the effects of target detection, aiming, and munition delivery errors.

The subroutine simulates munition delivery by both aircraft and artillery. For aircraft delivery, the model can handle line of bomblets and spray dissemination, accomodating up to 10 aircraft. The general approach for simulating spray delivery is to treat it as a special case of a line of bomblets, where the height of burst is equal to the aircraft altitude. Area bomblets, say from a missile, can also be simulated with up to 10 missiles, but all restricted to the same release height.

For artillery delivery, the model can simulate 10 batteries each consisting of up to 10 tubes or rocket launchers, where all batteries are assumed to have the same number of pieces as well as the same number of available rounds. It is further assumed that all pieces in a battery are fired simultaneously; however, each may fire as many rounds as desired and the total time to fire all rounds may be specified. If launchers are used, not all rockets need be fired in one ripple.

The model can accommodate three standard firing patterns for tube artillery: (a) a linear sheaf, (b) a parallel sheaf (with lateral displacement if desired), and (c) a converged sheaf. These standard patterns determine the intended aim points of the shells, and munition errors determine the actual impact points.

Effects

The Effects section of the model calculates and accumulates the dose or dosage of CB agent received by each target element from every munition. In addition to data describing agent effects, the munition, meteorological conditions, and other parameters, this section utilizes data generated by the Targeting and Delivery sections. That is, it uses the X,Y-distances between each target element and munition, and the height of burst, agent fill, and time of detonation of each munition. The effects of a munition are divided by this section into the four general classes shown earlier:

(1) Fragmentation - effects due to the exploding casing;

(2) Splash - dose due to the nearly instantaneous splashing of the agent close to the impact point;

(3) Mist - the dose due to droplets of agent that undergo gravitational settling from the agent cloud as it travels downwind and is deposited or impinged on the man;

(4) Vapor - the dose due to vapor or aerosol of agent particles which are small enough to be inhaled and follow the airflow to the lungs. This aerosol-vapor cloud may present both an inhalation and percutaneous hazard.

Of course, all munitions need not necessarily exhibit all four effects. It should also be mentioned that the fragmentation subroutine in the present model is a rudimentary model from PHAROS and, until further improved, estimates only whether the man is a frag casualty. It does not assess this effect on the medical workload. The fragmentation weapons phase of the study, on which we are now working, bears specifically on this aspect of the simulation.

Time does not permit further discussion of each of these subroutines, but since a valuable feature of the model is a capability to include the effects of protective devices and defensive procedures, we will briefly discuss the use of the Effects section to represent these important factors affecting medical workload.

It is assumed that a soldier is initially breathing at some steady rate with a tidal volume selected by sampling from a probability distribution of tidal volumes that correspond to various selected activity levels. Somewhere on the battlefield the enemy attacks with CB weapons. A "nonmasking" soldier is one who continues to breathe normally throughout the simulation, as if unaware of the attack or without a mask. However, a "masking" soldier, after a time lapse, through either an alarm system or his own senses, is suddenly aware that he is in danger.

This time lapse, called the warning delay time, is an input variable which may be used to simulate various alarm systems or communication chains. His reaction time, following receipt of a warning, delays his initiation of defensive procedures and is also an input variable. Next he gasps and holds his breath while attempting to don his mask. The volume of air inhaled during a gasp and his breathholding time are input parameters and may correspond to his previous activity level. The model permits him to continue gasping and breathholding until fully masked. The total time required for masking may be sampled from a probability distribution and is usually related to his previous activity level. Once the man is masked, the effects of mask leakage may also be measured by a procedure that samples from an appropriate probability distribution, also usually related to his activity level.

Now other protective measures can be represented as reliable data become available. For example, the influence on the medical workload of immunization against BW diseases can be simulated by introducing dose-response curves for agent doses that can overwhelm the immunity attained. The influence of temperature and humidity on mustard-casualty workloads can be also shown. Also by shifting the medians and/or probit slopes of the dose-response curves, which separate the four treatment categories, one can examine the advantages (but probably not disadvantages) of new drugs that might be developed to neutralize the nerve agents. The effects of future antibiotics, used either prophylactically or therapeutically, can also be simulated by varying the sampling distributions of incubation times and/or treatment times required for the various BW agents.

To determine the effects of passive defense on the medical workload, there are additional input parameters. Protective clothing, for example, is represented by a clothing penetration factor. Protection afforded by open foxholes is simulated by introducing fixed parameter values obtained from field test data. In addition, the effects on medical workload from protection afforded by covered foxholes, buildings, and vehicles can also be simulated by using applicable ventilation rates. It is believed that this covers substantially all of the pertinent defensive measures that can be quantified.

<u>Medical Workload</u>

The DOCTOR subroutine uses information from the Effects model, together with additional input data, to calculate the medical workload as previously defined. For each agent considered, dose-response curves separating the treatment categories are required which represent the median dose and the probit slope for each category. In general, for any one agent, these dose-response curves result in overlapping regions for a given dose. Then each man is assigned to one of the categories by Monte Carlo sampling based on the amount of agent received. For each man who is assigned to Category C, a prediction is made as to when he enters and leaves the medical system. A CW casualty is assumed to enter the medical system in the first time period; whereas for a BW casualty, the day of entrance is determined from the probability distribution of the incubation period. When a patient leaves the medical system depends on two factors: (a) the probability that the patient will die while in Category C (and subsequently be reassigned to Category E) and (b) the probability distribution of the length of treatment time until recovery or death.

Outputs

When the simulation has made the assignment of all target elements to the various treatment categories, one replication has been completed. During the replication, information from the Targeting, Delivery, Effects, and Workload sections are printed out. In addition the DOCTOR subroutine prints summary data at the end of each replication in the following format:

1) For each target element, the dose received under three separate assumptions:

   (a) masking with perfect mask fit;

   (b) masking with mask leakage;

   (c) nonmasking;

2) The number and percentage of target elements in each category:

3) The number and percentage of target elements in Category C during each time period following the attack.

After executing a specified number of replications the simulation summarizes the information from all replications and calculates confidence intervals on the percentage of target personnel placed in Categories A through D. This process completes the simulation of a scenario for a given set of parameters.

This simulation has been employed rather extensively in an effort to examine the range of medical workload requirements resulting from enemy use of CB weapons. The results are classified and are reported in RAC publication R-29, which discusses the model and the application of this model to a parametric analysis of 10 basic scenarios. It also presents input data and sample outputs and synthesizes the results to permit conclusions regarding medical workloads from CB weapons attacks.

A PAPER

"The Application of Classic Operations Research Techniques for Examining the Tactical Optimization of the UH-1B/M22 Weapon System"

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ABSTRACT

Application of classic operations research techniques to the solution of an operations research problem involving tactical optimization of the UH-1B/M22 Weapon System is the subject of this paper. The approach to the solution of the problem was a five-step process: (1) a clearly defined statement of the problem, namely, an analysis of the threat, (2) construction of an analytical model and consideration of the interdependencies of variables, (3) derivation of hypotheses from analysis of the model, (4) tests and verification of solutions to the model by field experimentation (the primary mission of the U.S. Army Combat Developments Command Experimentation Command, USACDCEC), and (5) implementation of the solution via the USACDCEC chain of command.

The paper summarizes the methodology and techniques employed by USACDCEC in examining the tactical optimization of the UH-1B/M22 Weapon System along with the findings and results of field experimentation.

"THE APPLICATION OF CLASSIC OPERATIONS RESEARCH TECHNIQUES FOR EXAMINING THE TACTICAL OPTIMIZATION OF THE UH-1B/M22 WEAPON SYSTEM"

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I. INTRODUCTION

Recent developments in U.S. Army Aviation Tactics and Materiel has focused attention on the need for developing reliable measures of tactical efficiency, cost comparison, and projected 1970-1975 time-frame organizational philosophies for airborne weapon systems. Air mobile concepts recognize that inherent in any airborne weapon system, the tactical optimization of that weapon system is a many-faceted, complex problem which can only be resolved by the application of scientific method and operations research techniques.

For a number of years, the U.S. Army Combat Developments Command Experimentation Command, USACDCEC, has devoted considerable attention to the conduct of target acquisition and live-fire experimentation with the UH-1B/M22 Helicopter Weapon System (previously the M22 Weapon System has been referred to as the SS-11 Weapon system—using the French-manufactured SS-11 missile nomenclature as a descriptor for the weapon system). The UH-1B/M22 Weapon System has been adopted for field use as an anti-tank weapon. And in this role, it affords much opportunity to analyze, in a pure sense, the interrelationship of air-to-ground weapons. Therefore, in treating and examining the tactical optimization of the UH-1B/M22 Weapon System, the empirical relationships between the variables of intertarget visibility, probabilities of detection, acquisition, hit and/or kill, arising from two-sided ground-to-air engagements can be of considerable value in postulating the outcome of two-sided engagements with sophisticated weaponry—specifically, the weapons envisioned for the AAFS and Cobra high-speed helicopter family.

II. A CLEARLY-DEFINED STATEMENT OF THE PROBLEM

Within the scope of the U.S. Army Aircraft Survivability experiment series at USACDCEC the examination of airborne weapon concepts has focused on two related problems:

1. The ability of an airborne weapon system to detect and acquire suitable ground targets. (And conversely, the vulnerability of the airborne weapon system to the ground weapon threat.)

2. The operational hit/kill probability of an airborne weapon system as a function of the ground target threat and tactics.

The above mentioned problem descriptions result in shortened definitions of the problem (useful in identifying the phase of the problem solution) and are referred to as:

1. The Target Acquisition Probability Problem

2. The Operational Hit/Kill Probability Problem

Having defined the problem(s) (the first step in the operations research process), it is the purpose of this paper to present the step-by-step solution by applying the techniques of classic operations research.

III. THE TARGET ACQUISITION PROBLEM—CONSTRUCTION OF THE ANALYTICAL MODEL

It is necessary to define the parameters which are involved in airborne acquisition of a ground target, (for this treatment, consider a tank as the target, and an armed helicopter as the airborne platform). In any attempt to evaluate the total acquisition probability of an experimental trial, by integrating over all phases of the trial, it is desirable to analyze the functional dependencies of each of the parameters in the following manner (refer to Figure 1).

a. Parameters involved in airborne (helicopter) acquisition of a ground target (tank):

1) Atmospheric visibility conditions ≅ 15 miles (constant).

2) Ambient light intensity ≅ 1.5×10^{-3} foot Lamberts

3) SD = Visual spot detection acuity angle of a pilot (or observer) over a 5 degree field of view.

4) r_0 = Radial measure of uncertainty in reported position of target

5) k = Contrast of target with background

6) R = Range from helicopter to spotted target

7) t = Time that target is in view of helicopter

8) S = Search plan (zone, area, route)

9) F = Flight profile (contour, nap-of-the-earth, pop-up, dismount)

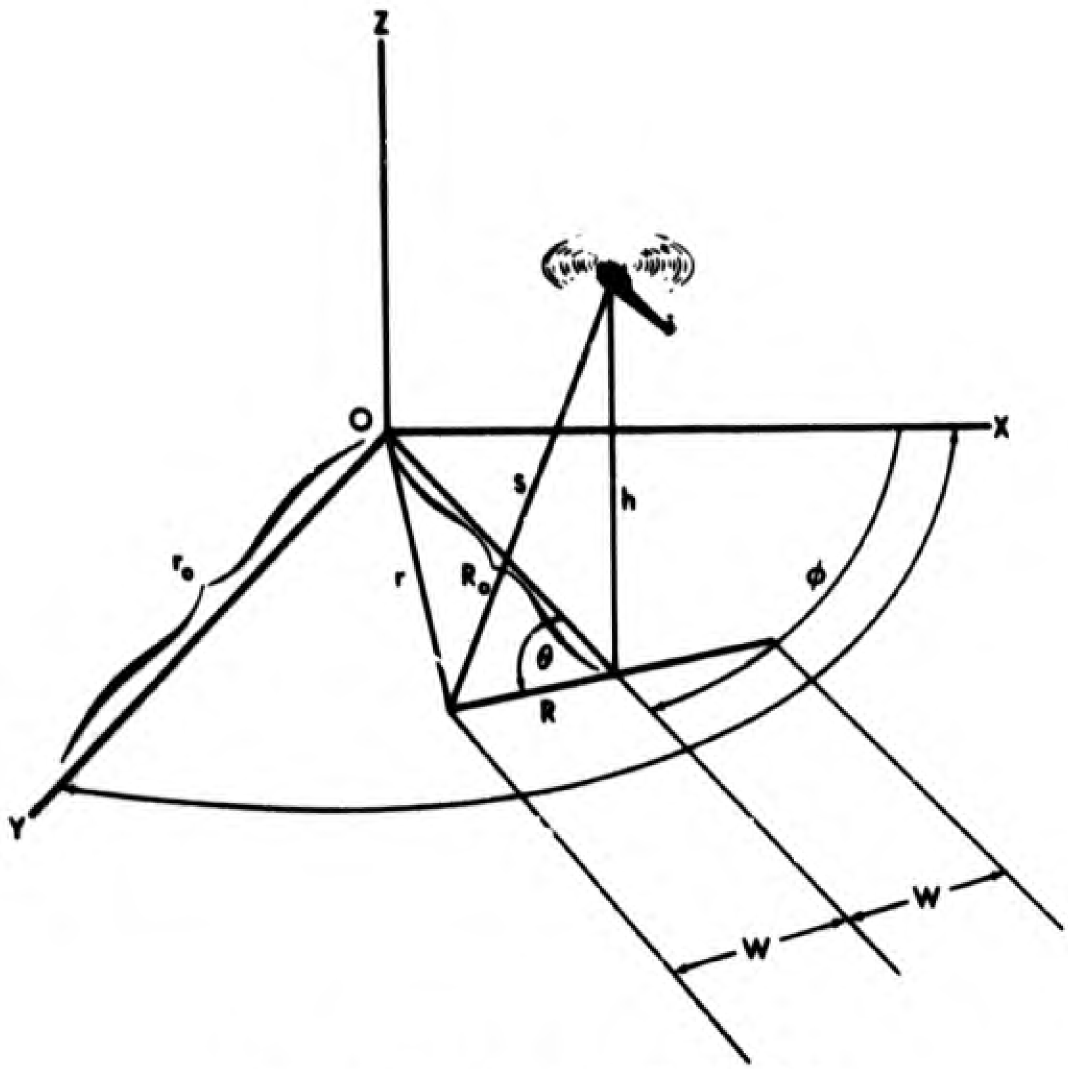

Figure 1 TARGET ACQUISITION MODEL

10) A = Assault plan

11) V = Procedure to vector the helicopter to the target

12) C = Target composition, disposition, and readiness condition

13) P = Target posture (static moving)

14) SP = Pilot/observer search procedures (constant)

b. Dependencies between parameters:

1) SD = SD(L, M, k) = 0.5 mil for target in bright daylight for target with 0.3-0.7 background contrast.

2) $R = R(SD, r_o, S, M, F, A, V, C, P, SP)$

3) $t = t(SD, r_o, S, M, F, A, V, C, P, SP)$

4) $S = S(SD, r_o, M, C, P)$

5) $F = F(SD, r_o, M, V, C, P)$

6) $A = A(r_o, M, V, C, P)$

From analysis of the dependencies of the above listed parameters, it is possible to develop the parameters which can be varied independently.

c. Parameters capable of independent variation:

1) r_o

2) k

3) M

4) V

5) C

6) P

7) L and SP are constant

Figure 1 shows a helicopter at a distance R_o from the reported position of the tank target at the origin, O, toward which it is flying at altitude, h. The pilot scans the sector in front of him on each side of the center line of his aircraft, thereby searching a band of width 2w. The probability of acquisition of a tank at Q depends on:

1) $P_Q(r, r_o)$ $= (1/\pi r_o^2) \exp(-r^2/r_o^2)$

= probability per unit area that tank is at Q (where r_o is measure of uncertainty in reported position).

2) $P_M(R_o, \omega, h, R, \theta)$ = statistical terrain mask probability that there will be a line of sight from helicopter to the tank at Q.

3) $P_D(S, S_o)$ = probability of detecting and recognizing the tank if a line of sight is available (where S_o is the slant range at which the target is detected 50% of the time).

Then the probability of acquisition of a tank at Q per unit area is:

$$4)\quad P_A = P_Q(r, r_o)\, P_M(R_o, \omega, h, R, \theta)\, P_D(S, S_o)$$

The variability of the P_M terrain masking probability function of five arguments can be extreme. A computerized terrain model derived from a contour map and surveys of vegetation would provide an acceptable approximation to the distribution of results obtained in field observations. But great caution would have to be exercised in attempting to apply the statistical predictions of a computerized terrain model to some area judged to be equivalent in an actual theatre of war. If the enemy makes use of the most advantageous cover the average statistics will predict acquisition over-pessimistically. The enemy will always use the particulars of a situation so as to make the true acquisition probability bear little relation to gross average terrain statistics.

In arriving at data-supported acquisition probabilities for a given flight path and target, field experimentation techniques are focused on examining the target acquisition probability for a given set of conditions as a function of terrain in which the ground target is located. For this purpose, there are generally only 7 terrain categories of interest:

1) Flat, open

2) Flat, medium vegetation

3) Rolling, open

4) Rolling, medium vegetation

5) Flat, dense vegetation

6) Rolling, dense vegetation

7) Jungle canopy, mountainous.

Within each terrain category, an examination of target posture (speed, aspect, armament signature) as a function of acquisition probability is possible. A logical matrix design which permits examination of the primary parameters of target acquisition probability as a function of terrain is outlined below:

Trial No.	Terrain Type	A/C Altitude		A/C Speed		Target Aspect		Pilot/Observer Team
		50	200	50	200	Moving	Static	
1	Flat, open	X		X		X		A
2	Flat, open	X		X			X	B
3	Flat, open	X			X	X		C
4	Flat, open	X			X		X	D
5	Flat, open		X	X		X		D
6	Flat, open		X	X			X	C
7	Flat, open		X		X	X		B
8	Flat, open		X		X		X	A

Thus, each primary parameter is introduced as a function of terrain. Obviously, other parameters can be examined by inserting additional columns. For example: 500' altitude, 0 speed (hover), 0. 5, 10 mph increments of target speed, etc.

It becomes evident that this minimum number of 56 trials (8 trials x 7 terrain types) is sufficient to develop gross target acquisition data using this matrix design. In order to attain a predetermined level of statistical confidence, additional replications would be required.

Another feature of the matrix design is that it minimizes the requirements for pilot/observer player personnel. In the matrix presented here, a team of 4 pilots and 4 observers are considered adequate for developing target acquisition probabilities since no member of the team is subjected to an identically repetitive trial. This design purposely reduces the influence of "learning." From the reduced field acquisition data, survival probabilities for both the air and ground targets can be generated by means of an analytical model shown in Figures 2 and 3. Accumulations of air-to-ground target acquisition field data from the USACDCEC "data bank" are used to fill data gaps and reinforce the data base for specific sets of flight and target conditions.

IV. THE OPERATIONAL HIT/KILL PROBABILITY PROBLEM - CONSTRUCTION OF THE ANALYTICAL MODEL

Subsequent to developing a data base for generating target acquisition probabilities, it is necessary to develop compatible operational live fire hit/kill probabilities for the interacting targets. For the UH-1B/M22 Weapon System experimentation, a total of 387 missile firings, combined with extensive firings of the 105 tank main armament and the 50-caliber machinegun were deemed

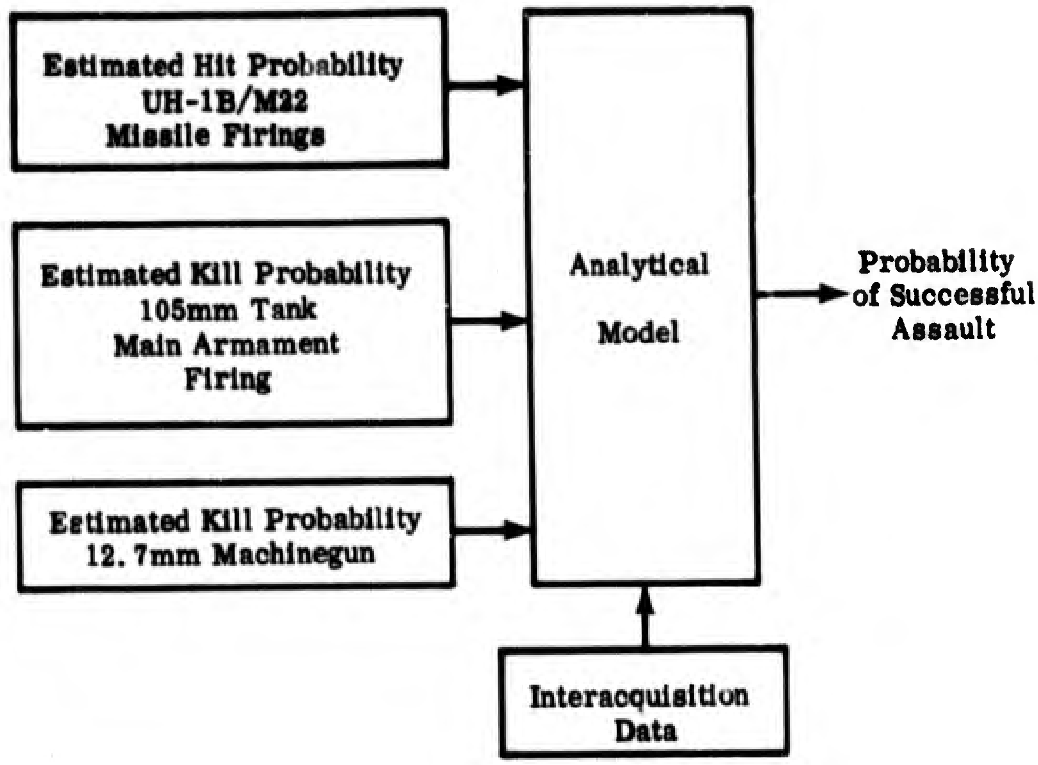

Figure 2 FLOW OF DATA FOR DEVELOPING OPERATIONAL HIT PROBABILITIES

statistically sufficient for establishing operational hit probabilities with a 90 percent confidence level. The flow of data into the analytical model (Figure 2) provided operational hit probabilities under conditions which permitted injection into the analytical model of Figure 3. By adjusting the live fire results for the terrains examined in the acquisition experimentation, a valid solution to the outcome of a two-sided air-to-ground engagement as a function of terrain was achieved.

V. ACHIEVEMENT OF SOLUTIONS BY THE OPERATIONS RESEARCH PROCESS

Thus, the second, third and fourth steps of the operations research process (construction of a model and consideration of the inter-dependencies of variables, derivation of hypotheses from analysis of the model, and tests of solutions to the model by field experimentation) were accomplished.

The final step of the operations research process - implementation of the solution - was effected by providing aircraft survival probabilities as a function of assault tactics and terrain to the Department of the Army (via the Combat Developments Command chain of command).

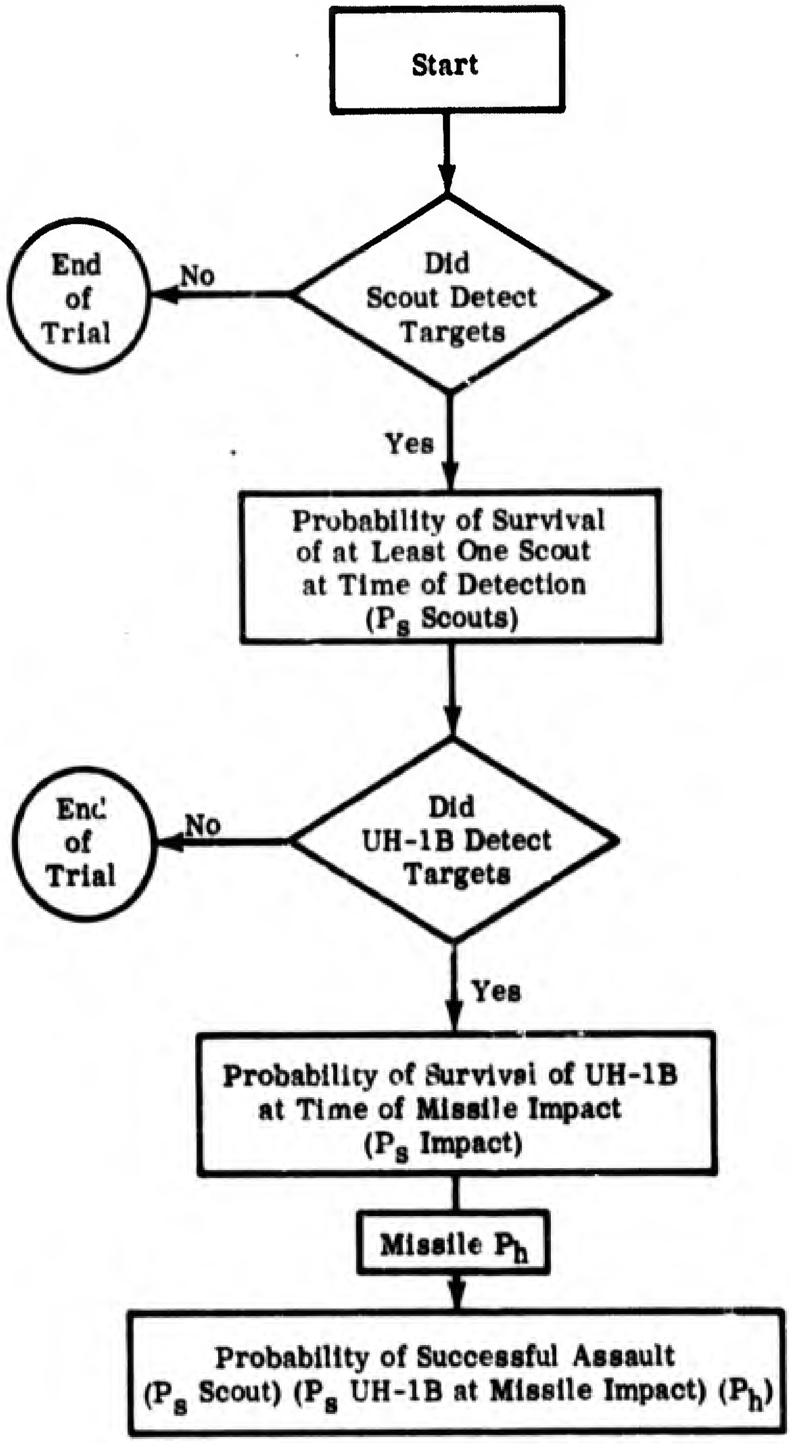

Figure 3 FLOW OF DATA FOR DEVELOPING PROBABILITY OF A SUCCESSFUL ASSAULT

ON THE GENERATION OF ARMY AVIATION REQUIREMENTS IN A COUNTERINSURGENCY ENVIRONMENT

By

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ABSTRACT

This paper discusses a computer simulation and war game developed and manipulated by Planning Research Corporation under contract to the U.S. Army study group, ARCSA II. Both the war game and the computer simulation have as their primary purpose the generation of data for the determination of aircraft requirements in a counterinsurgency environment.

The model, designed for the UNIVAC 1107 computer, may be described as an expected-value, time-sequential, event-type model. It is used to calculate the number of airborne systems that must be realized in a particular organizational/operational concept to satisfy the tasks associated with the functional areas of firepower, maneuver, intelligence, command and control, and logistics. In the calculations, the model considers such factors as availability, survivability, performance, and responsiveness. The war game is of the theater-level, seminar type. It is two-sided and open, with variable level of aggregation and time resolution.

In the paper, the required inputs, internal logic, and outputs of both the model and the war game are covered. However, emphasis is placed on describing the interrelationships between the model and the war game and the outputs derived from their manipulation.

I. INTRODUCTION

This paper is addressed primarily to the exposition of a methodology to determine Army Aviation requirements in a counter-insurgency environment. The methodology was developed and subsequently pursued by PRC under contract to the Department of the Army. It essentially comprises the exercise of both a mathematical/logical model designed for manipulation on the UNIVAC 1107 computer and a seminar-type war game. In this paper, these elements are discussed only in the degree of detail required for a basic understanding on the part of the reader. For more detailed descriptions, reference in made to PRC R-940, DA Study: Aviation Requirements for the Combat Structure of the Army II (U), (ARCSA II), ANNEX F, 31 March 1967 (Secret).

II. COMPUTER SIMULATION

A. General

The basic mathematical/logical model that underlies the computer simulation was initially developed in a previous PRC study effort. The purpose of the model was to generate data on the relative effectiveness of various candidate organizational/operational concepts associated with the employment of tactical airborne systems in the firepower role. In the context of the former study effort, four measures of effectiveness were defined: availability, survivability, performance, and timeliness.

The main concern was to measure the capability of the various airborne systems called forth by a particular organizational/operational concept,[1] given a requirement to inflict damage and/or casualties on a target embedded in the tactical environment of interest. The capabilities that were measured included availability for the task, survivability in a combat environment, satisfactory performance of the mission (i.e., inflicting a desired level of

[1] The concept defines the level of command, employment policy, and tactics and techniques that govern the behavior of the tactical systems.

damage and/or casualties), and responsiveness. Because of the mutual interdependence and complex interactions that exist among these factors, it became evident that it would be virtually impossible to develop closed-form mathematical expressions to characterize their relationships. It was therefore necessary to resort to simulation techniques, which subsequently resulted in the generation of a model known as the Air Weapon Response Model (AWRM).

The Mobility System Response Model (MSRM), which is discussed in the following subsections, represents a second iteration in the AWRM's evolution. The MSRM has achieved the capability to measure the relative effectiveness of concepts associated with the employment of airborne systems in the functional areas of logistics, intelligence, maneuver, and command and control, in addition to firepower.

B. Model Characteristics

The MSRM is an expected-value, time-sequential, event-type model. The events that are generated in the model are ordered in the time continuum, and the average outcome for each event is computed as opposed to associating a range of outcomes with each event.

The model is designed for manipulation on the UNIVAC 1107 computer and is programmed for the most part in FORTRAN IV. In addition, the MSRM is of modular construction so that modifications or changes can be made easily.

C. Model Logic

For an a priori defined set of tasks arising from a tactical situation, the tasks are distributed in the time continuum and the model calculates the numbers of airborne systems that must be realized for a particular organizational/operational concept to ensure successful task accomplishment. In the calculations, the factors of availability, survivability, performance, and timeliness are considered dynamically. Briefly, the logic employed in the simulation is as follows.

Let S equal the set of tasks to be accomplished, where may be denoted as $S = \{S_i/i, 1, \cdots, m\}$. For each S_i , the model calculates the following variables:

t_i = the time at which the aircraft must be assigned in order to accomplish S_i within a specified time

n_i = the number of aircraft required to satisfy the task S_i

N_i = the number of aircraft available to be assigned at t_i for the S_i task

The model then proceeds to order the set of t_i according to a $\leq$ relation, which results in a nondecreasing sequence. Considering the earliest assignment time first and proceeding to successively larger values, the model calculates the number of aircraft that must be added to the pool for the accomplishment of the various tasks. This value, Δn_i, may be expressed as follows:

$$\Delta n_i = \begin{cases} n_i - N_i & \text{for } n_i > N_i \\ 0 & n_i \leq N_i \end{cases}$$

The total pool size required, N, is expressed as:

$$N = \sum_{i=1}^{m} \Delta n_i$$

There are three distinct options with which the model can calculate the assignment times, t_i. In the first option, t_i is defined as the earliest time at which the aircraft can be assigned and still satisfy the time criteria associated with the various tasks. The second option is the latest time at which the aircraft can be assigned. The third option determines that t_i in the closed interval $[t_E, t_L]$, where t_E and t_L are the earliest and latest possible assignment times, respectively, at which full advantage is taken of aircraft returning to the pool during the interval.

The n_i are determined by the accomplishment of the following steps:

1. By means of a table lookup, determine the number of airborne systems, A, required to accomplish a particular task. (This value does not reflect any survivability or abort rate considerations.)

2. Modify A to reflect the probability of survival, P_S, in the destination area, where the area may be defined as a landing zone for troops or supplies or as the area within which a target is located. The modified value, B, is given as $B = A/P_S$.

3. Modify B to account for survivability of the aircraft enroute to the destination area. The resultant value, C , is defined as $C = B/\bar{P}_S$, where $\bar{P}_S$ is the probability of survival of the aircraft enroute to the destination. $\bar{P}_S$ is calculated as a function of such variables as enemy weapon density over the area flown and the speed and altitude of the aircraft.

4. Finally, modify C to reflect the probability of abort, P_A , which yields D ; $D = C/(1-P_A)$.

It is precisely the value D which is defined to be n_i . It should be noted that the number of aircraft that return to base and will be available for subsequent tasks after appropriate time delays is computed in a manner similar to step 3 above.

The N_i are calculated in a straightforward manner. Every task that arises during the course of the simulation has an associated response criterion (the time within which the task must be accomplished). In determining N_i for a particular S_i , the model considers only those aircraft that are potentially able to be responsive; i.e., according to the particular t_i calculated, the number of aircraft that will be available in the pool to be assigned at time t_i .

Finally, in this discussion of the model logic it is worthwhile to point out some of the major differences between the AWRM and the MSRM (the first and second iterations of the model development). The primary difference exists in the application of the simulation to mobility and logistics-oriented problems. To amplify, a movement of troops and/or supplies could involve a path composed of three node points: the base at which the transport aircraft are located, the point at which troops and/or supplies must be picked up, and the landing zone to which the goods must be delivered. (In addition, shuttling could occur between the latter two node points.) The MSRM has the capability to simulate these movements.

Also, relative to the shuttling between the loading and unloading points, options were given for echelonment to occur with or without preserving tactical integrity. Finally, time criteria could be defined in the MSRM by setting the appropriate combination of times for a particular task--earliest or latest time of pickup at the loading point and earliest or latest time of arrival at the landing zone.

D. Input Requirements

Two basic categories of qualitative data are required for model manipulation. The first category comprises data associated with the operational characteristics of the tactical airborne system under consideration as the characteristics are embedded in an organizational/operational concept. The second category consists of data that define the various tasks to be performed and their concomitant criteria with respect to timeliness and performance. Since the war game constitutes the primary vehicle for the generation of data in the latter category, those data will be discussed in the following section. The most significant data that are specified in the first category are discussed below.

Coordination and Control Time: The time lapse between the initial request for a specific task to be accomplished and the assignment of the task to a set of aircraft at the base.

Alert Time: The time delay between the receipt of the request at the base and the completion of takeoff.

Turnaround Time: The amount of time required for reprovisioning of aircraft upon return to base.

Abort Recovery Time: Given an aircraft abort, the time consumed for repair.

Performance Data: Speed/altitude combinations for task accomplishment; numbers of aircraft required for various defined tasks as a function of payload/range capability, weapon lethality and accuracy, and detection capability; vulnerability data, expressed in lethal ground range for various combinations of friendly aircraft and enemy air defense weapons.

Threat Data: The density of the various enemy air defense weapons defined over prescribed areas.

E. Model Output

The primary output of the model is the number of airborne systems that must be realized for a given organizational/operational concept to ensure the accomplishment of a finite set of time-sequenced tasks arising from the environment. This value was described above as N.

In addition, for each task performed during the course of the simulation, the following outputs are specified:

- o Number of aircraft assigned, n_i
- o Number of aborts
- o Number of aircraft that return
- o Time the aircraft are assigned to the task, t_i
- o Time the aircraft return
- o Time the aborted aircraft recover
- o Amount of time the time of assignment was delayed
- o Maximum amount of time the assignment could have been delayed and the task still accomplished in a responsible manner
- o Number of aircraft available to be assigned, N_i
- o Number of aircraft that have to be added, Δn_i
- o Number of sorties accomplished
- o Time of delivery of troops, supplies, or ordnance
- o Number of hours flown

Finally, various summary statistics are generated:

- o The ratio of tasks actually performed to the total number of tasks required to be accomplished
- o Ratio of sorties performed to number of sorties required
- o Total numbers of flying hours consumed
- o Number of flight hours consumed per sortie

F. Model Capabilities

As the preceding discussion has demonstrated, the model is flexible in that it can be applied to a myriad of problems dealing with the determination of aviation requirements. This fact is further corroborated by the employment of various configurations of the model in several previous PRC study efforts. For detailed descriptions, the reader is referred to PRC R-789, Operational Analysis of the Advanced Aerial Fire Support System, ANNEX E (U), 24 January 1966 (Secret Noforn), and PRC R-907, Evaluation of Fleet Tactical Support Squadron and COD Aircraft (U), 30 August 1966 (Confidential).

III. WAR GAME

A. General

There are three major factors that underly the approach to the development of the war game used in the ARCSA II study effort. First, the game's primary purpose is the generation of a data base from which the majority of the inputs required for the simulation activity are defined. The data derived are sufficient for drawing meaningful conclusions, with minimum analysis required. Hence the game is not concerned with making detailed assessments in terms of casualties inflicted on both Red and Blue sides, as are most conventional gaming pursuits; rather, it involves only the determination of such data required for subsequent analyses. The second factor evolves from the tactical environment that is the subject of analysis. Considering the nature of the counterinsurgency environment in terms of both historical evidence and what is actually taking place, the game developed must be flexible to reflect both the actions and reactions of the combatants. To ensure this flexibility, the game that was developed employs seminar techniques which maximize the set of action alternatives for both Red and Blue sides. Finally, in view of the time constraints associated with the study effort, the probability of successful consummation of the war game effort becomes critical. Again, a seminar-type game maximizes this probability.

B. Game Description

The game developed and subsequently manipulated by PRC for the ARCSA II study effort may be described as a theater-level, seminar-type game with the following concomitant properties: two-sided, manual, free, and open.

Both the level of aggregation associated with simulated combat units and the time resolution for assessments are of a variable nature. These variables are fixed according to the tactical situation at hand and the requirements for fineness of data defined by the computer simulation. Typically, the maneuver elements and artillery units were aggregated at battalion and battery levels, respectively; the time resolution was 1 day. In the detailed input preparation phase of the game (discussed below), various tactical events had to be set in time during the course of play, especially relative to the scheduling of moves, in order to achieve compatibility with the computer simulation input requirements.

C. Game Structure and Logic

The logic of the game is composed of the following five steps: game preparation, initial seminar session, detailed input preparation, analyses, and final seminar session. The major participants in these steps are the Blue and Red teams and the Control personnel.

1. Game Preparation

In the first step, using a scenario as a point of departure, initial conditions are set that primarily involve the generation of the following data:

Blue Force Structure

- Physical location of Blue units
- Command relationships
- Levels of supply at various node points in the LOC system
- Logistic support complex
- Operational states of the various units--search and destroy, base security, LOC security, reserve, and support of ARVN and/or Third-country forces

Locale Description

- Weather
- Terrain
- LOC network--roads and airfields (location, capacity, and state of usefulness)

Enemy Situation

- Location
- Concept of operations
- Pattern of past events
- Threat potential

2. Initial Seminar Session

In the next phase of the game, five major activities are undertaken. First, the spectrum of tactical actions to be considered is defined relative to an a priori defined set of game objectives to ensure the collection of data that will satisfy the input requirements of the computer simulation. Second, considering the range of actions prescribed, initial tactical events are set forth by Control personnel. Third, detailed tactical plans are generated on the part of the Blue team. Fourth, after suitable discussion of the possible Blue/Red interactions, a summary of the significant tactical events is developed which embeds the events in the space-time continuum. Finally, the results derived from the session are reviewed and evaluated with a view to analytical sufficiency.

3. Detailed Input Preparation

This phase is addressed primarily to the preparation of precise inputs for the computer analyses in suitable formats for keypunching.

4. Analyses

In this phase, the computer simulation is manipulated to the maximum extent possible. The results derived from these analyses serve as the major input to the final seminar session.

5. Final Seminar Session

The results obtained from the previous activity are reviewed by all participants in the game, and, if necessary, an iteration is made through the appropriate segments of the previous three phases of the game.

D. Game Output

The outputs of the game, which provide the major input to the computer simulation, are addressed in terms of realistic requirements for aviation elements and the quantification of these requirements in space and time. PRC's participation in the ARCSA II study effort was oriented to the determination of Army Aviation requirements in the maneuver and logistics functional areas. Therefore, the tactical moves of combat and/or support elements are defined in terms of the following variables:

- Units or amount of supplies to be moved
- Distances to be traversed
- Move logic (single or multiple lifts)
- Time of earliest pickup at the loading point
- Time of latest pickup at the loading point
- Time of earliest arrival at the unloading zone
- Time of latest arrival at the unloading zone

These variables represent most of the data that derive from the game exercise for eventual manipulation in the computer simulation. In addition, the following types of data were generated for various side analyses and use as a game record.

- Intensity of combat engagements between Red and Blue as a function of size and duration
- Operational status of Blue units over time
- Location of Red and Blue units over time

IV. DESIGN AND EXPERIMENT

In the environment of the ARCSA II study group, PRC's participation was mainly directed to the determination of preferred organizational/operational concepts relative to the functional combat areas of maneuver and logistics.

Utilizing the seminar gaming technique described above, two games were played. Each game was composed of two excursions; one excursion represented an ambient level of activity as a function of Blue/Red interaction, and the other represented an intense level of activity. The two games differed in the tactical area of interest, with one game addressed to the I FFORV area of responsibility and the other to the II FFORV. An average of approximately 20 days was played for each excursion. Tactical requirements were generated for each excursion and embedded in the space-time continuum. These requirements provided the main input for the simulation activity.

Next, a design was developed to determine, for each excursion, the type and number of computer runs to be accomplished in the simulation activity. The design provided for the comparison of three separate and distinct organizational/operational concepts for the employment of Army Aviation elements in the accomplishment of the tasks derived from each of the game excursions. The main differences among these concepts depended largely on the reliance placed on the utilization of either the UH-1D or the CH-47C aircraft for the transport of maneuver elements, artillery, and supplies. In addition, various parametric runs were performed to measure the sensitivity of the results to changes in some of the basic data relating to system performance and task criteria.

For each concept and excursion match, the simulation yielded the numbers of UH-1D and CH-47C aircraft required in the mix to satisfy various tactical requirements, considering the factors of availability, performance, and timeliness. Survivability and abort factors were not considered; the probabilities of survival and no abort were set equal to one in order to preserve integer aircraft definition.

Based on analyses of the simulation output, the habitual requirements for Army Aviation units to be realized for each concept were determined. Relationships were then established wherein for each game the percent of time the tasks were accomplished was plotted against incremental changes relative to the habitual requirements.

V. SUMMARY

PRC's participation in the ARCSA II study effort consisted of the application of both a seminar-type war game and a computer simulation. The war game exercise evolved from the analysis of a counterinsurgency environment and is therefore limited to such an environment. However, the simulation model is not similarly constrained and can be applied to a wide range of problems relative to the determination of aviation requirements, encompassing all of the military services and in more sophisticated tactical environments.

The role of the war game was only to provide a data base relative to the input requirements of the simulation activity, especially in the description of tactical requirements for Army Aviation elements. By means of the simulation, the model then manipulated these inputs in a logical and systematic way, representing the dynamic interactions associated with the various organizational/operational concepts postulated, with a view to the effectiveness measures of availability, performance, and timeliness. The result was the generation of the number of tactical airborne systems required to be realized for each concept to ensure the successful accomplishment of the tactical requirements.

VI. ACKNOWLEDGEMENT

Recognition is given to the following PRC personnel: Messrs. Charles E. Gremer and Maurice Pollack, major contributors to the simulation activity, and Mr. Richard A. Wise, project manager of the PRC study effort in the ARCSA II program. The author would also like to thank Mrs. Marilyn Baxter for her editorial assistance.

SYMWAR & Its Application to Forecasting Aircraft Replacement Requirements

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ABSTRACT

SYMWAR (Systems for Forecasting Materiel Wartime Attrition & Replacement Requirements) is an AMC sponsored effort designed to develop methodologies for forecasting wartime replacement requirements: for all major items - ranging from aircraft and tanks to rifles and radios; under all conditions of warfare and theaters of operation; for current and future time frames. Historical, operational, and war game data are utilized in the methodologies to derive loss rates by item and forecast replacement requirements in mission oriented terms. Special techniques have been developed to forecast aircraft replacement requirements. The paper describes the data bases and the forecasting systems.

SYMWAR & Its Application to Forecasting Aircraft Replacement Requirements

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INTRODUCTION

This paper summarizes SYMWAR which means "Systems for Forecasting Materiel Wartime Attrition & Replacement Requirements." The study area is devoted to development of methodologies and the requisite data bases for forecasting loss and replacement requirements for all major items ranging from aircraft and tanks to rifles and radios - under all conditions of warfare, time frames, and theaters. Losses and replacement requirements incurred from the CONUS shore up to and including the direct combat zone are accounted for.

SYMWAR has been a continuing project sponsored by the Army Materiel Command and has expanded in both sponsorship and scope. It currently includes both the development of wartime replacement requirements methodologies and technical support for developing and analyzing a data base for loss and expenditure of items and ammunition in Vietnam.

Part 1 of this paper describes the general SYMWAR methodology and Part 2 discusses its special application to forecasting Army aircraft replacement requirements.

PART 1 GENERAL SYMWAR METHODOLOGY

The method currently employed by the Army to forecast PEMA wartime replacement requirements in support of annual procurement objectives involves application of replacement factors developed from World War II and Korean experience. These factors have been criticized as being based on obsolete data with no assurance that they are still valid under changing technology and tactics. In view of this difficulty and the large monetary implications of wartime PEMA replacement requirements, RAC was requested to undertake the development of a new methodology utilizing simulation techniques to the maximum extent practical.

The effort has been described as one of the most difficult tasks ever undertaken by ORO-RAC. This statement is founded on: the lack of precedent for a research approach to a problem of this magnitude; the immensity of the scope of the undertaking in items, theaters, and types of warfare; the need to adapt and develop war games to an entirely new application of quantitative rather qualitative requirements; and the simultaneous requirement to develop a new data base together with a sophisticated computer system - adaptable, to the maximum extent practical, to Army capabilities and its plans and programs.

Methodology Characteristics. The methodology is designed to be sensitive to and compatible with changing Army scenarios and force structures; carefully designed and documented in a manner in which its logic, assumptions, and data bases can be scrutinized and its dependence on opinion reduced to a minimum; and be responsive to new technology and tactics through the effective use of war games and simulations.

APPLICATION OF THE METHODOLOGY TO CONVENTIONAL WAR IN FUTURE TIME FRAMES

Our first methodological development was directed at forecasting requirements for conventional war in Western Europe in the 1970 time frame.

In order to provide a new capability as rapidly as possible - within rigid constraints of time, cost and manpower - the methodology is designed to capitalize on operational experience in addition to the wide range of war games, simulations and research studies currently available or under development by the military services. Our approach in developing the methodology was to break the wartime losses into separately defined loss categories, select 22 representative items, analyze the causes of losses, and devise a system to forecast losses under each category by item. The categories selected - which are also represented as the system's loss models - were combat losses of equipment in use, non combat losses of equipment in use, losses in depot storage, losses in intratheater movement and losses in intertheater movement.

Figure 1 illustrates the items selected for initial analysis and development of the methodology.

The New Methodology. Figure 2 schematically illstrates the new methodology. The methodology consists of a computerized system and its associated loss-rate tables - together with well-defined procedures for developing the loss-rate tables and adapting the computerized system to a wide range of warfare and theater conditions. The computerized system applies a wartime scenario or theater plan through the five loss models against loss-rate tables for each item and produces a time-phased forecast of replacement requirements by item. The wartime scenario or theater plan and loss-rate tables are defined in terms of appropriate missions and deployed units applicable to the theater and type of warfare.

Development of the loss-rate tables contained in the data bank has been a key methodological effort. These loss-rate tables reflect the percentage loss for each item by mission, type unit, and category of loss. Figure 3 illustrates the data sources currently utilized to establish the loss-rate tables for conventional war in Western Europe in the 1970 time frame. The combat loss and non combat loss models compute losses of equipment in operation, while the depot, intra and intertheater models account for losses in storage and shipping within and to the theater of operations. Thus the analysis and development of loss-rate tables for the combat and non combat models differ in approach from those of the other models. In the case of the combat and non combat loss models the loss rate tables are developed through analysis of the operational use, and the threat to which the item will be subjected. For the other models the loss rate tables reflect susceptibility to loss in storage and in movement under a given enemy threat.

Figure 4 illustrates the type of documentation and justification developed for each of our selected items in establishing the combat and non combat loss rate tables. This "loss analysis package", for each selected item, consists of: a photograph and description of the item; an analysis of how we lose, compute and validate the wearout and combat loss; the numerical basis for computation and the data sources, the development of a correction factor which permits us to relate the distribution and vulnerability of personnel and equipment on the battlefield; and recommendations for improvement of the data. Documentation of this type provides the primary basis for meeting the methodology objective - to provide a logical and defensible basis for forecasting wartime replacement requirements. Furthermore, this aspect of the research effort: provides the guidelines for development of similar loss-rate tables for other PEMA items; a systematic basis for extending the capability under new conditions of warfare; and a practical guide for establishing the data required to develop meaningful loss-rate tables.

The next Figure, Figure 5, shows the complete system for forecasting requirements under conventional war for future time frames - from basic data inputs to generation of requirements reports.

APPLICATION OF THE METHODOLOGY TO COUNTERINSURGENCY IN THE CURRENT TIME FRAME

Data Base and Forecasting System Development - We have two on-going efforts in the area of counterinsurgency: One under sponsorship of AMC which involves developing the SYMWAR forecasting system for loss and replacement requirements

PEMA SAMPLE ITEM LIST

1. Airplane, Combat Surv. OV-1 Mohawk
2. Helicopter, Utility/Tac/trans UH-1 B/D Iroquois
3. Tank Combat 105mm Gun F.T. M60 A1
   Recovery vehicle med
   Launcher M60 Series Scissors Bridge AVL
4. Carrier Personnel Armored F.T.
   Carrier Command Post
   Carrier Mortar 4.2" F.T. S.P.
5. Mortar 4.2" on ground mount
6. Rifle 7.62mm M14
7. Howitzer 155 S.P. F.T.
8. Gun Field Arty 175mm S.P. F.T.
9. Truck ¼ Ton 4 X 4 ABT
10. Truck ¾ ton 4 X 4 ABT
11. Truck 2½ ton 6 X 6 ABT
12. Truck, Tractor 5 ton
13. Tractor full tracked D.D. Med DBP
14. Radio Set AN/GRC 19
15. Radio Set AN/PRC 25
16. Radar Set Portable AN/PPS-4
17. Generator Set Gas 1.5 KW 60 Cy 120V-AC
18. Launcher Rocket 762mm Tk Mt
19 Launching Station GM Sergeant
20. Radar Set, CW Acquisition Hawk
21. Antenna-Receiving-Trans Group Acq-Nike Herc.
22. Radar Set, AN/MPQ-4A (MORTAR LOCATOR)

SYMWAR

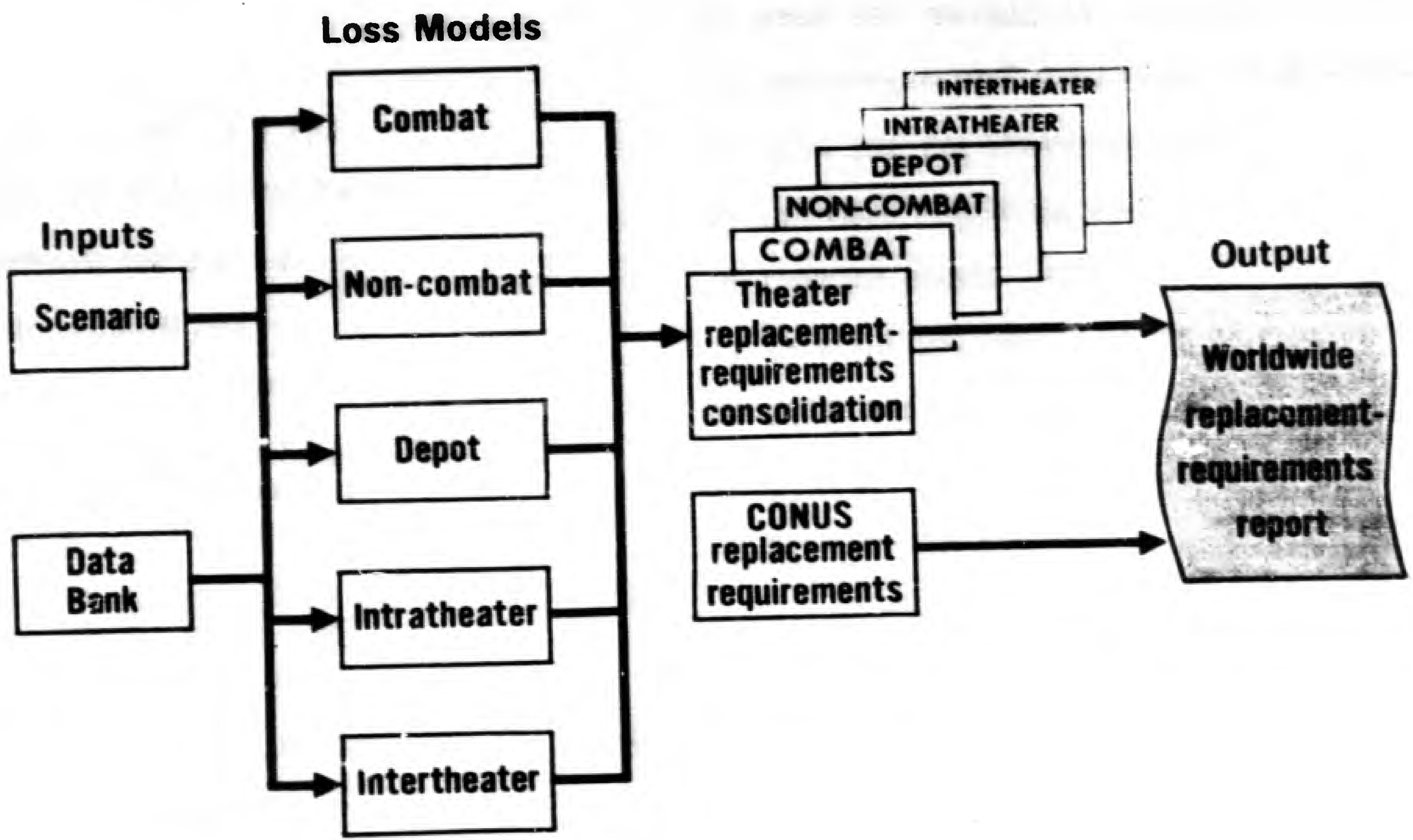
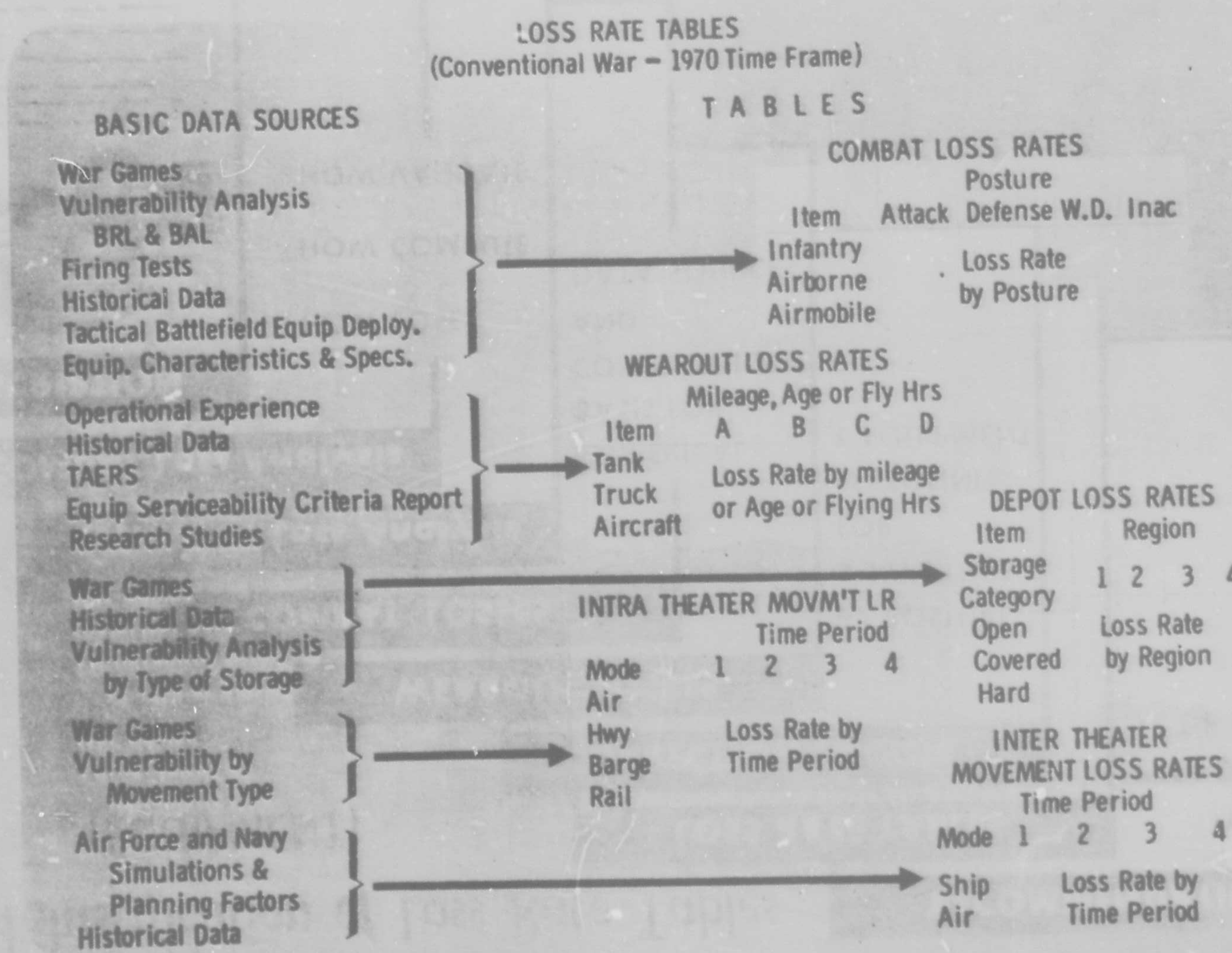
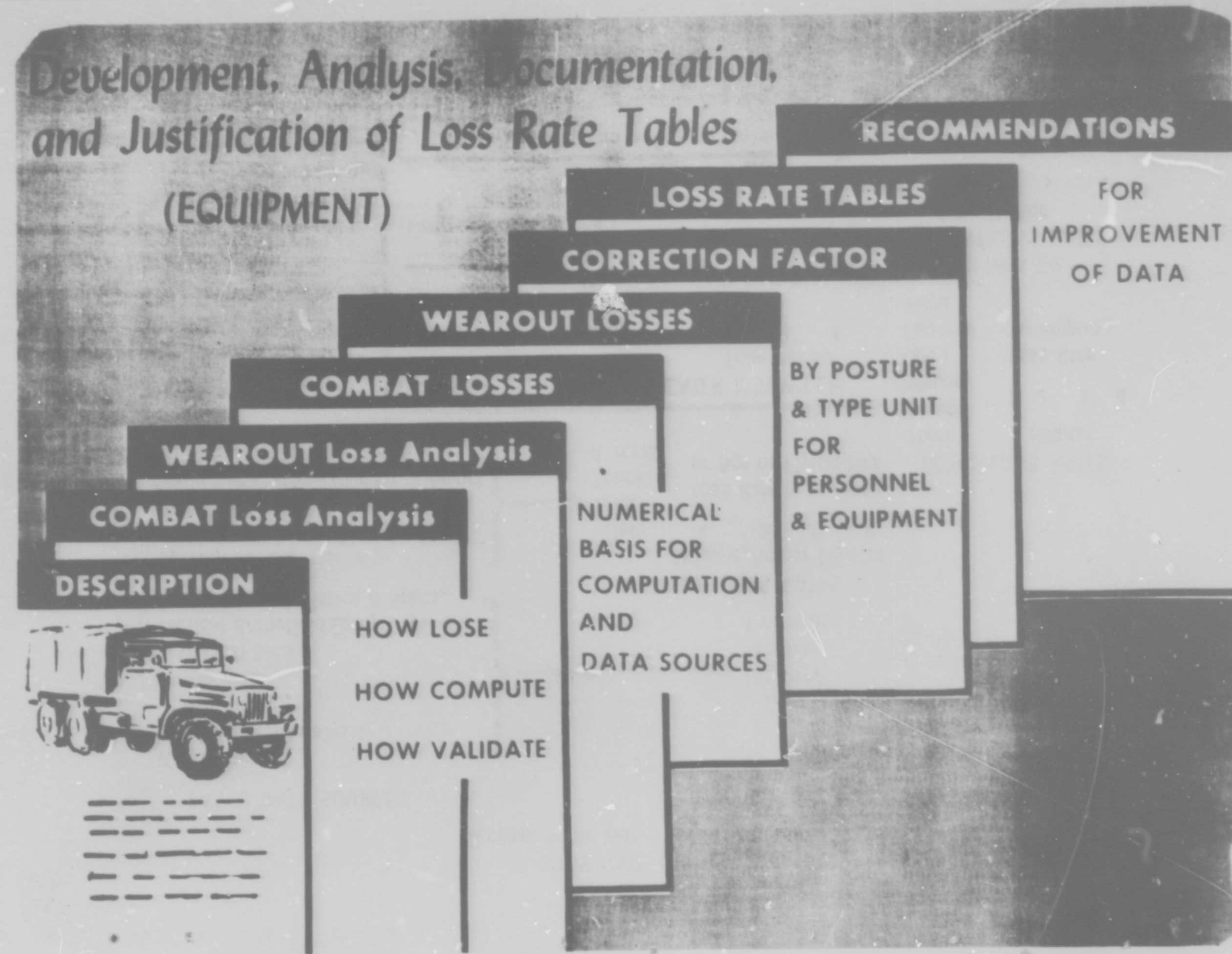


Figure 2



LOSS RATE TABLES
(Conventional War – 1970 Time Frame)
BASIC DATA SOURCES
TABLES
War Games
Vulnerability Analysis
BRL & BAL
Firing Tests
Historical Data
Tactical Battlefield Equip Deploy.
Equip. Characteristics & Specs.
COMBAT LOSS RATES
Posture
Item Attack Defense W.D. Inac
Infantry
Airborne
Airmobile
Loss Rate by Posture
Operational Experience
Historical Data
TAERS
Equip Serviceability Criteria Report
Research Studies
WEAROUT LOSS RATES
Mileage, Age or Fly Hrs
Item A B C D
Tank
Truck
Aircraft
Loss Rate by mileage or Age or Flying Hrs
War Games
Historical Data
Vulnerability Analysis by Type of Storage
DEPOT LOSS RATES
Item
Region
Storage Category 1 2 3 4
Open
Covered
Hard
Loss Rate by Region
War Games
Vulnerability by Movement Type
INTRA THEATER MOVM'T LR
Time Period
Mode 1 2 3 4
Air
Hwy
Barge
Rail
Loss Rate by Time Period
Air Force and Navy Simulations & Planning Factors
Historical Data
INTER THEATER MOVEMENT LOSS RATES
Time Period
Mode 1 2 3 4
Ship
Air
Loss Rate by Time Period

Figure 3


Development, Analysis, Documentation,
and Justification of Loss Rate Tables
(EQUIPMENT)
RECOMMENDATIONS
FOR
IMPROVEMENT
OF DATA
LOSS RATE TABLES
CORRECTION FACTOR
BY POSTURE
& TYPE UNIT
FOR
PERSONNEL
& EQUIPMENT
WEAROUT LOSSES
COMBAT LOSSES
NUMERICAL
BASIS FOR
COMPUTATION
AND
DATA SOURCES
WEAROUT Loss Analysis
COMBAT Loss Analysis
DESCRIPTION
HOW LOSE
HOW COMPUTE
HOW VALIDATE

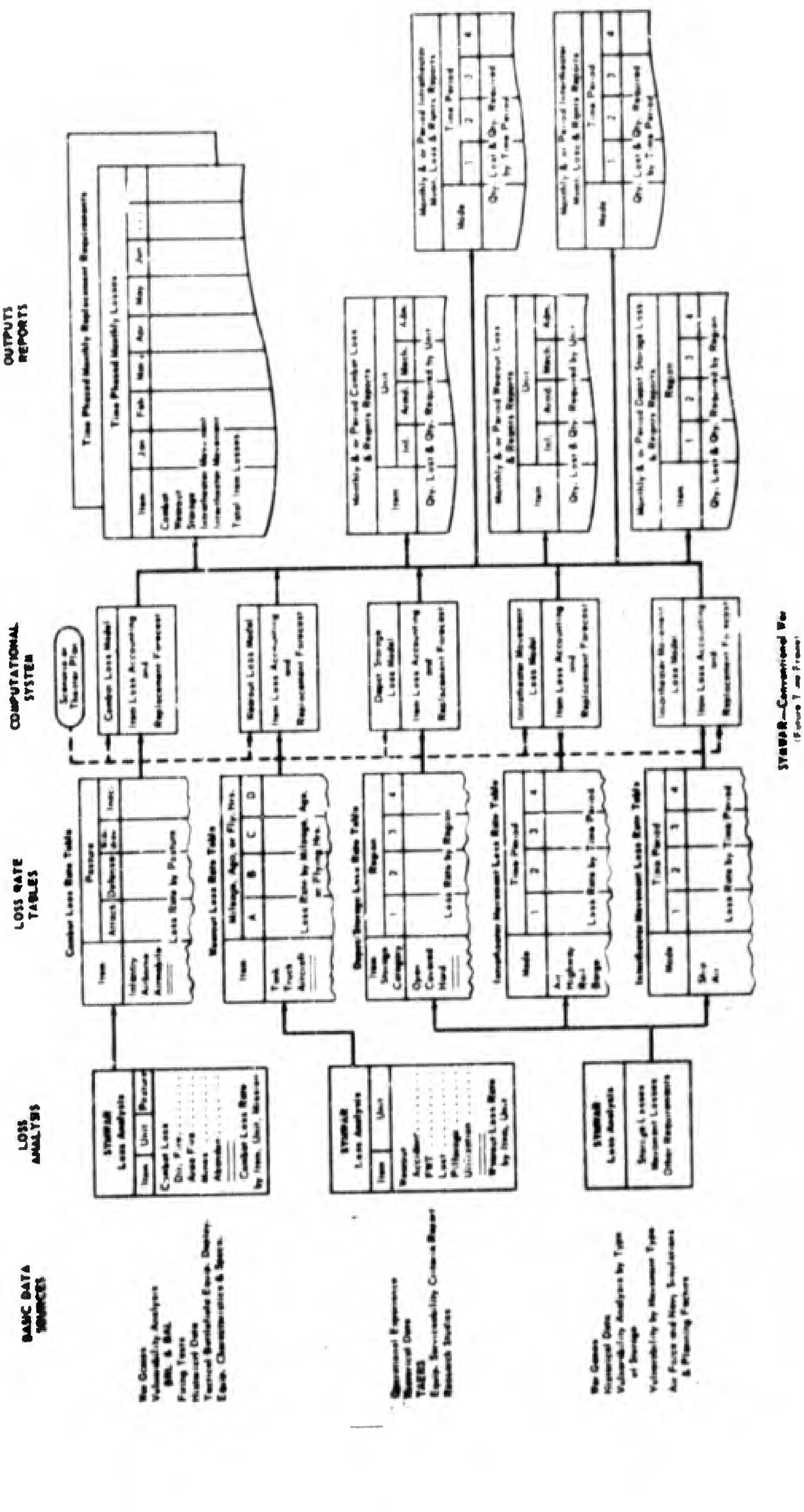

BASIC DATA SOURCES
LOSS ANALYSIS
LOSS RATE TABLES
COMPUTATIONAL SYSTEM
OUTPUTS REPORTS

Figure 5

for PEMA items and a project for CDC which involves the technical support for development of a data base for item and ammunition loss and expenditure in Vietnam. The CDC effort is termed COLED-V - Combat Loss & Expenditure Data - Vietnam.

The objective of the COLED-V study is to establish a data and information base on item loss and ammunition loss and expenditure - in a form useful for forecasting purposes. COLED-V represents the most extensive efforts undertaken by the Army to collect data in a wartime environment - of use in this conflict and future operations.

A major utilization will be the input to the SYMWAR forecasting system for counterinsurgency. The requirements for the data base was established by the Vice Chief of Staff. Responsibility for developing the data collection plan and its implementation was assigned to CDC. The SYMWAR study team assisted in the development of the COLED-V data collection plan and was selected to provide the technical support to CDC for the plan's implementation.

As shown in Figure 6 the COLED-V data collection plan includes a data collection center in Vietnam staffed by Army personnel and the COLED-V CONUS office headed by a CDC project officer with the technical support of the RAC COLED-V study group. Data from; item loss and ammunition loss and expenditure reports, intelligence summaries, situation reports, operations reports, etc. is being acquired and analyzed in a "War Room" set up at RAC. Results of the data analysis will be: fed directly back to the theater to assist in its operations; provided to the Army in a series of special reports; and used as a direct input to the Army in a series of special reports; and used as a direct input to the development of the SYMWAR forecasting system for counterinsurgency operations.

Figure 7 illustrates the complete counterinsurgency forecasting system from data sources to forecast of requirements.

REQUIREMENTS FOR IMPROVEMENT AND CONTINUING USE OF SYMWAR

Obviously the problem of forecasting losses and replacement requirements is as fundamental and continuing as war itself. Accordingly it is essential to improve, adapt and expand the SYMWAR capability as concepts of warfare change, and new requirements to use the capability arise. One part of our program of continuing improvement, involves the use and improvement of war games ranging from: the utilization of results from pre-played games; participation in major war games; recommendations for improvement in assessments, data and procedures of play; and the development of side by side analysis techniques to be utilized concurrently with war game play.

Figure 8 illustrates major interactions required to insure a continuing confidence in the validity of the methodology. Efforts in all the areas depicted have and are being undertaken and channels are being established to insure a continual feed back and improvement of the SYMWAR capability.

GENERAL APPLICATION OF SYMWAR

Although the system is designed to provide a forecast of wartime materiel replacement requirements for procurement purposes, it has a variety of other planning and operational applications as shown in Figure 9.

a. The system can be applied directly to evaluation of contingency plans.

b. The impact of differing deployment schedules, force levels, threats, and concepts of operation on materiel losses can be explored and planning tables established under a wide range of scenarios.

c. Extensions of the current system development - which includes a capability for forecasting combat personnel casualties - could produce time-phased statements of both personnel and materiel replacement requirements.

In addition, system results can assist in policy decisions relative to stockpiles and production base and can assist in evaluating the risks involved

Application of COLED-V SYMWAR to Theater and CONUS Requirements

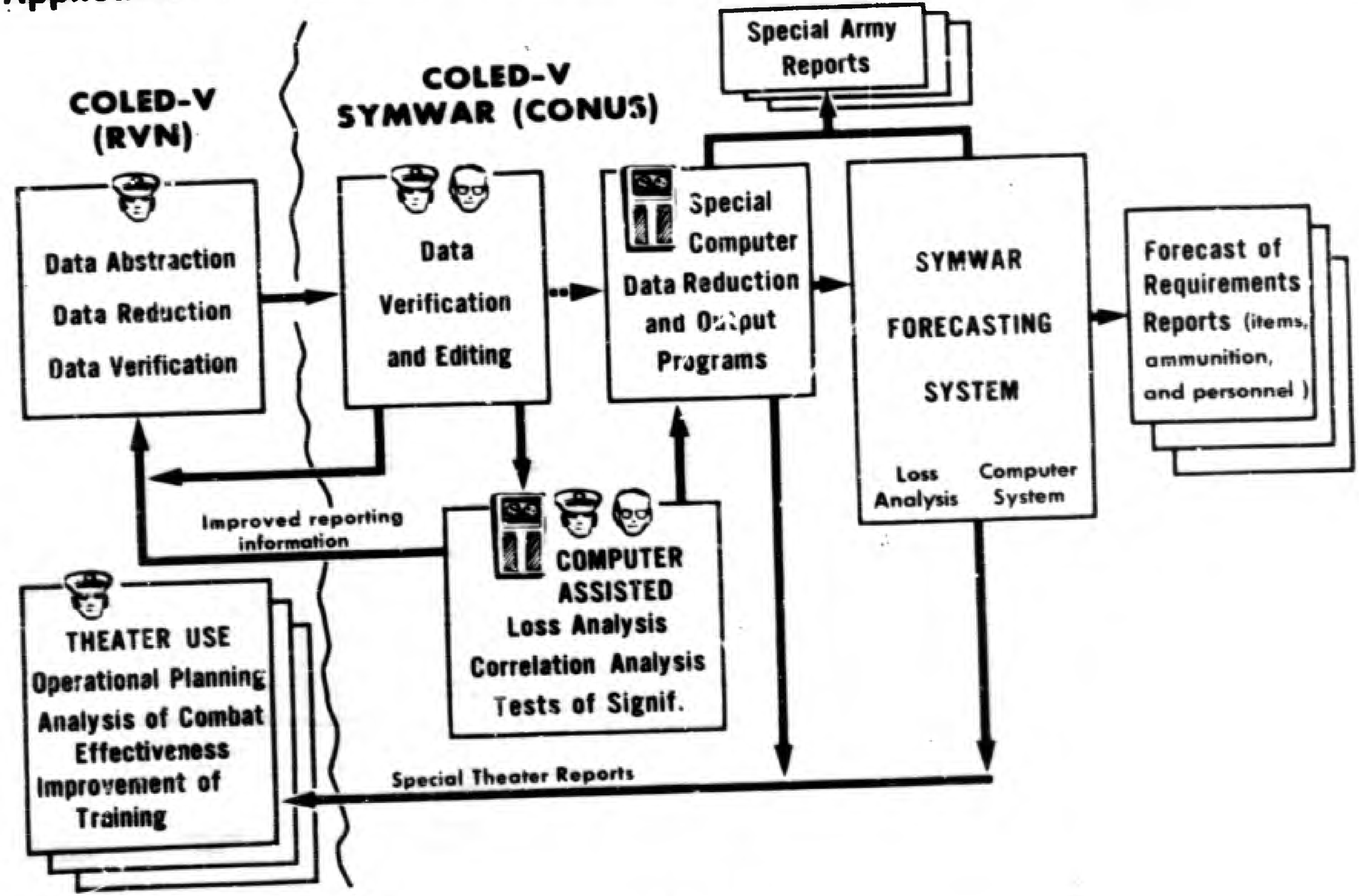
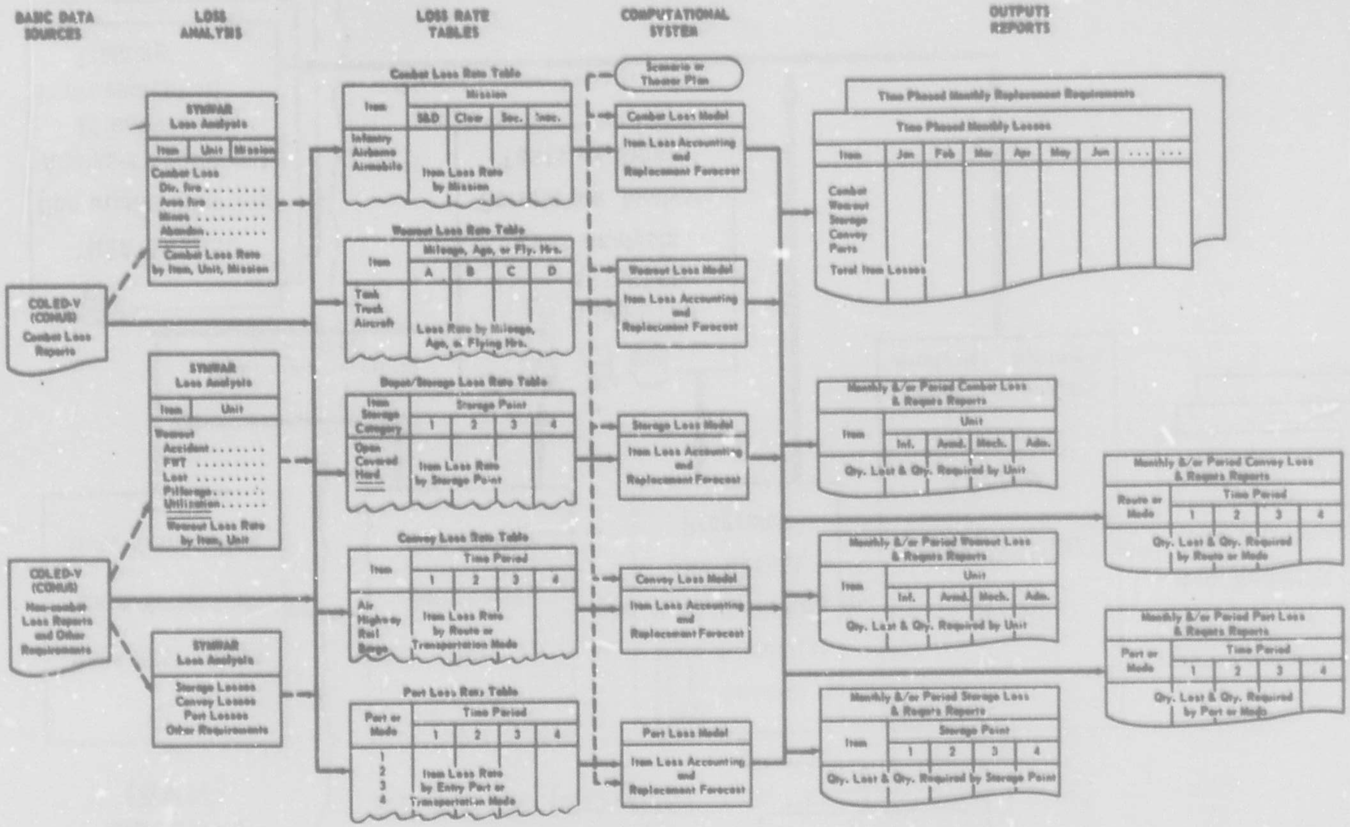


Figure 6



SYNWAR—Counterinsurgency
(Current Time Frame)

Figure 7

System Validation & Improvements

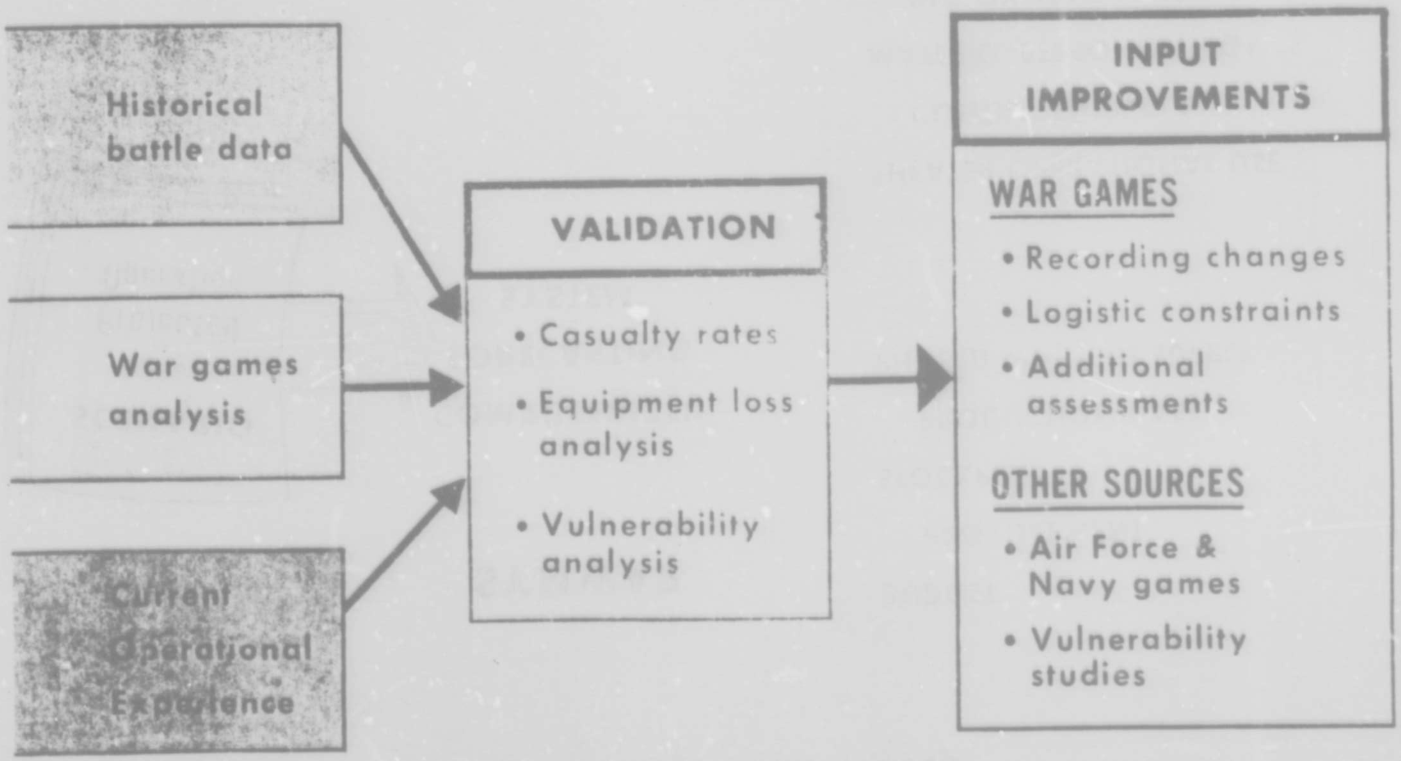


Figure 8

SYMWAR APPLICATIONS

SYMWAR

COMPUTERIZED FORECASTING SYSTEM

BUDGET
PROCUREMENT
STOCKPILES
PRODUCTION BASE
PHASED WARTIME SUPPLY

THEATER OPERATIONAL USE
CONTINGENCY PLANS
MATERIEL-PERSONNEL RQMTS
DEPLOYMENT SCHEDULES

in such decisions. Planning tables can be developed for various threat levels, theaters, and types of operations. These tables can provide a basis for supply requirements in the early stages of a war - before operational experience is available. At the same time the system's loss-rate tables can provide a guide for data collection during a conflict, and results can be fed back into the system to improve its operational predictive capabilities - one such immediate application is the current operation in Southeast Asia.

PART 2 - FORECASTING REPLACEMENT REQUIREMENTS FOR AIRCRAFT

This section of the paper is devoted to a discussion of our work in analysis and prediction of aircraft attrition. Aircraft have received a special emphasis in the SYMWAR development both due to their high cost and the specialized problems in forecasting their requirements. Unlike many items of Army equipment whose operational loss can be related rather directly to the ground missions being performed - the operational loss of aircraft is a function of both the air missions performed and ground missions supported. In addition, a requirement exists to express aircraft losses in a variety of other ways including: relationship to sorties and flying hours.

DEVELOPMENT OF LOSS RATE TABLES

Development of loss rate tables as in the case of other items of equipment is a major part of the SYMWAR effort. Again a loss analysis procedure is utilized to establish the loss rate tables. Figure 10 illustrates the loss analysis for aircraft due to combat and non combat causes. Loss causes include: direct enemy fire, indirect fire from bombing and strafing on the ground and mechanical failure over enemy territory. Losses due to accidents and wearout are also considered.

<u>COMBAT LOSSES</u>

Direct Fire from enemy air and ground fire

Indirect Fire from enemy artillery, missiles, bombing or strafing against aircraft on ground

Mechanical Failure and abandoned in enemy territory

Accidents in enemy territory followed by abandonment

<u>NON COMBAT LOSSES</u>

Accident in friendly territory

Normal Wearout

Figure 10-Computational Factors for Aircraft Losses

For applications in future time frames - reflecting new technology and tactics - direct fire loss data is drawn from such war games as RAC's Theaterspiel and Tacspiel.

For data which is unavailable from war games or not sufficient or useful for the application - SYMWAR relies both on operational data and aircraft vulnerability data. Flying hours and missions are obtained from war games, Vietnam data or the scenario. This data is analyzed to provide various type aircraft mission profiles. Using loss data and mission data, aircraft loss rates can be computed for various missions. Loss and vulnerability data for these computations have been obtained from Vietnam, the RAC war games, the USSTRICOM Data Base, and the Cornell PACE and RAND aircraft studies among others.

Figure 11 illustrates the computational procedure for determining non combat losses such as accidents and mechanical failures. Data supplied from AVCOM and USABAAR for world-wide and theater non combat losses is compared with the wartime non combat losses to derive a wartime accelerator. This accelerator is multiplied by the peacetime non combat loss rate for a theater under study to develop a wartime non combat loss rate for the particular theater.

$$(\text{Wartime Accelerator})^{*} \text{X} (\text{Peacetime Theater Rate}) = \text{Wartime Rate}$$

$$^{*}\text{Wartime Accelerator} = \frac{\text{Wartime Rate}}{\text{Peacetime Rate}}$$

Figure 11- Procedure for Non Combat Losses

Figure 12 illustrates SYMWAR's loss analysis for combat and non combat losses. The data developed from war games, simulations, operational experience etc. is reduced to this format. This analysis is then used to develop the loss rate table utilized by the SYMWAR forecasting system.

AIRCRAFT COMBAT LOSS

Causes of Loss	Computational Elements
Direct Fire (Air or Ground Fire)	(# A/C Lost, # Hrs. Flown)
Indirect Fire (Bombing, Strafing, Attacks)	(# A/C Lost, # Hrs. on Ground)
Mechanical Failure (Abandoned in Enemy Territory)	(Mech. Fail. Rate, Hrs. Over Enemy Territory)
Accidents (Abandoned in Enemy Territory)	(Accident Rate, # Hrs. or Sorties)
	Total Combat Loss

AIRCRAFT NON COMBAT LOSS

Cause of Loss	Computational Elements
Accidents	(Accident Rate, # Sorties or Hrs.)
Wearout	
	Total Non Combat Loss

Figure 12 Aircraft Loss Rate Components

IMPROVEMENT OF FORECASTS

We have utilized results from, and engaged in war games ranging from specialized games to evaluate a particular question of aircraft capability to generalized war games designed to evaluate a new organization of the ground combat forces. In all cases the applicability of the game to the problem of aircraft losses must be carefully investigated. Rarely have the games utilized, for example, been designed primarily to develop aircraft losses nor have they fully played the interaction of losses and tactics. Accordingly the results must be carefully utilized, and improvements in the games and analysis developed.

We are currently focusing on three specific areas for improvement of our aircraft forecasting capability:

1. Improvement of war games.
2. Development of side by side analysis.
3. Development of means of reflecting by analytical means the effects of military effectiveness and tolerable limits of loss into the results of war games and eventually into the procedures of play.

ABCA Operational Concept Formulation
Analytical Development of Impact of Science & Technology

(Post-1980)

Charles J. Davis
Office, Operations Research
Office, Under Secretary of the Army

Background. On 6 December 1966, the Quardripartite Working Group on Army Operational Research, at the request of the Washington Standardization Officers, outlined terms of reference and specific guidelines to be used by a Quadripartite Working Party on Impact of Science and Technology (QWP/IST). The goal of this four-country group was to produce a supported forecast of future operational capabilities as derived from an analysis of expected trends in contributory scientific and technological effort.

Objectives. The broad goal which our group was given was further partitioned into two specific objectives:

- Estimate expected improvement in equipment system performance due to expected technological advances.

- Describe potential effects of these expected technological advances on military combat operations.

Problem Structure. Faced with the rather extensive and complex task that was implied by the goal and the two objectives, the Chairman of this Working Party sat down and developed an orderly approach to the problem which we shall call Problem Structure. At Chart 1 (Slide 1 on) you will see what we can to call an ordered array for use by the QWP/IST. I have had to compress the actual chart in order that I could display it using this equipment, bu the essential elements are present and the rationale leading up to this order was as follows:

It did appear that all combat actions from a technical and scientific point of view consisted of four fundamental cybernetic-like functions. These we chose to call the sensing function, the decision function, the action function, and the sustaining functions. These are the items that you see along the top of the chart. The subitems under each of these functions are those classes of military operational activity, generally cast in known military terms, which we felt formed the significant parts of each of the fundamental functions. For example, under sensing, one includes reconnaissance, surveillance, and target acquisition. The elements of the decision function are information processing, analysis, display, transfer, and assessment. Under action, one includes maneuver and delivery of fire or other effect. Finally, under sustaining, one finds combat support, logistics, protection and survival, and personnel training, replacement and human factors. So much for the columns of the array.

We next had to come to some agreement as to how we were going to classify expected operations. Rather than do a "blue sky" job, we felt that while operations in the 1980-1990 time frame might not still be called by such names as armored, infantry, air defense, etc., that in all probability these types of operations might well still be taking place. Therefore, we took all military battlefield operations and grouped them into the five operations found on the left side of the array. Namely, armored, infantry, air defense, air mobile, and support weapons system. Under each of these, we then introduced the most typical tasks that take place within the operation such as tank vs. tank, tank vs. antitank, etc., in the armored case; individual weapons vs. personnel; crew-served weapons vs. personnel and hard targets, etc.

The object then was to gather data and analyze it in such a fashion that we could create for each element in this array some evidence as to what we expected science and technology to contribute to each of the operations that we had specified: out in the 1980-1990 time frame. (Slide 1 off.)

Analytical Methods. Given the array that I have just shown you, I want to describe next the analytical approach that each country, more or less, used. It ran as follows and we can refer to Chart II (Slide 2 on). We decided that since the effectiveness of an operational unit in combat was some kind of a complex function of the men and systems which make up that unit, that in order to get out a really valid forecast of what impact science and technology was going to have on future military operations, we would have to first identify the detailed scientific and technical parameters which go into or contribute to performance of individual items of equipment and/or the larger systems which these items of equipment consist of. Hence, our rationale and more or less sequential analytical approach was as shown on the chart.

First, identify the major effectiveness parameters, in the scientific and technological sense, that pertained to each of the functions and subfunctions that you saw on the array. As a matter of convenience, as well as order, we also attempted to differentiate between the kinds of technical and scientific parameters and equipment that apply to each of the five types of operations which we listed down at the left side of our array.

Second, having identified effectiveness parameters, and incidentally having identified some of the past trends in improvement in these parameters, and made a forecast through polling experts or studying recent forecasts of record, we then went on to identify the major performance parameters, and here there is a difference which most of your surely recognize. A scientific and technological parameter might be something as detailed as the sensitivity of a given sensor. A typical performance parameter for a sensory system in operation would be its scan rate for example.

Going further and using trend-line techniques, we third, identified the significant technological advances associated with the parameters described above.

We then, fourth, looked into an estimate of improvement in performance due to these identified technological advances then went on.

Fifth, to comments on the effects of physical limitations or environmental limitations on these technological advances, and

Sixth, comments on resource constraints.

Seventh, we decided to insert, where appropriate, those speculative new developments which appear to offer promise.

As far as method is concerned, and in order to create an auditable document, we decided to carefully annotate as to where we obtained each of the bits of information, graphs, charts, displays, or what have you: through careful annotation to the source material.

Finally, we accumulated all of this evidence in the ordered format of the array so that one can, in the future, sort on it quite readily.

In a nutshell, our method was to create an easily traceable trail of evidence leading up to the conclusion which we eventually wrote up in the summary part of our document (Slide 2 off).

All of the above problem structure and analytical method guidance was passed on by the U.S. Chairman to the three other countries to participate in the effort. Using this guidance, all four countries did varying degrees of work on the project, but each attempted to cover the entire spectrum of the problem. All of this work was done in-country during the period 6 December 1966 to 12 February 1967. Then in mid-February, a Quadripartite Working Party Meeting was held in Washington. During this meeting, the country representatives looked at each other's work and applied the following criteria during this preliminary review process. (Slide 3 on.) Going down the list on the slide as we looked at the input from each country, we asked, is it time series oriented? Were the best available sources used? Was this a best effort in the time availabile? Is it logically organized? Was a strong attempt made to transform from technical and scientific terminology into operational terms and, finally, was the material auditable? Having looked at the individual efforts of each of the participating countries, the Working Party was then faced with a synthesis task. We had to pick and choose in the interweaving kind of process which we then applied. And the criteria that we used in this part of the methodology was as follows: Is the material we are including well organized? Is this proper date? Is the presentation useful? Useful to an operations man? Is the analysis creditable? Is our effort complete? Do we have internal consistency? Have we treated of the interrelationships between systems?

and finally, since this was a Quadripartite Working Party effort, is the material going into the draft documents agreeable?

Results to Date. I had hoped to present to you at this meeting some of the substantive results of this effort. Unfortunately, the material is still being reviewed within the countries who participated and I am not at this moment free to address substance. However, in the interests of better analyses in the future, I will describe what we have produced. There now ecists in each of the quadripartite countries a document entitled "Chapter 3 - Impact of Science and Technology on Operations." This chapter is a summary view of the expected effects on operations in the post-1980 time frame of scientific and technological developments that can reasonably be expected to take place and be adopted by that time. Supporting this chapter is an annex which comprises a partially reviewed amalgam of the three sets of national scientific and technical evidence in support of the forecasts found in the chapter. It is in the annex where one finds the analysis leading up to the specific forecasts that have been made. Finally, supporting the annex is an appendix of some several hundred pages which consist of the tecnnical and scientific evidence used in the analysis, In effect, it is a collection of charts and graphs and a certain minimum amount of commentary as to what our scientists and technologic parametric point of view by the post-1980 decade.

Critique. The material that has been produced by operations research analysts up to this point in time has isolated the more obvious impacts that could be deduced from the assembled material but does not deal in detail with some special aspects of operations appropriate to specific forms of warfare. For example, we, the anlysts who worked on the project, recognize that we have not fully examined the future of close air support, BW and CW, command and control, and service support. Further, the document in its present form is somewhat out of balance in that infantry, air defense and air mobile type operations have been examined to a lesser degree than have armored and support weapons systems operations. Never-the less, the current feeling is that the chapter and its supporting annex and appendix can easily be extended and refined in consultation with combat development experts for whom we have done this job.

Forecast of Future Activity. I am sure that many of your will be interested in the possible future events in which this operations research analysis might find it is imbeded. In the first place, some of you may end up participating in the exercise in the not too distant future. The documents which this four-country group of Army operations research analysts produced has already been briefed to the Quadripartite Working Group on Combat Developments, and it was well received. It is already planned that the Washington Standardization Officers will receive a briefing on the material sometime in June prior to the item appearing on the Agenda of TEAL XI to be held in Canada, also in June. In the meantime, the Quadripartite Working Group on Army Operations Research from whom our working party of operations research analysts received their guidance, will shortly release the draft material which we have prepared to the Armies for their formal review. It is during this exercise that I am sure many of you will become further acquainted with what to us turned out to be one of the most fascinating and occasionally frustrating operations analyses that we have ever been associated with.

Thank you.

An Ordered Array for Use by the QWP/IST

FUNCTION (App.) / (Annex) OPERATION	SENSE			DECIDE					ACT		SUSTAIN			
				INFORMATION										
	R	S	TA	P	A	D	T	As	M	DF	CS	L	P&S	P[illegible]F
ARMORED														
T vs T	X	X	X	X	X	X	X	X	X	X	X	X	X	X
T vs AT	X	X	X	X	X	X	X	X	X	X	X	X	X	X
T vs B	X	X	X	X	X	X	X	X	X	X	X	X	X	X
INFANTRY														
IW vs P, H	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CW vs P, H	X	X	X	X	X	X	X	X	X	X	X	X	X	X
AIR DEFENSE														
vs. A		X	X	X	X	X	X	X	X	X	X	X	X	X
vs. M		X	X	X	X	X	X	X	X	X	X	X	X	X
AIR MOBILE														
L	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FS	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SPT WPNS														
C vs P, M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M vs M, PT	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X = Coverage Desired

CHART 1

Analytical Method - QWP/IST

1. Identify major equipment/system scientific and technical parameters, for each function and sub-function; by operation, task. Examine time dependent trends.

2. Identify and examine equipment/system operational performance trends.

3. Isolate parametric trends with significant slope.

4. Isolate performance trends with significant slope.

5. Comment on physical and/or environmental restraints.

6. Comment on resource restraints.

7. Include some speculative new developments.

8. Cite sources.

9. Arrange all material per order of the array.

CHART 2

Criteria for QWP/IST Meeting

As to Country Input

1. Time series Oriented?
2. Best sources?
3. Best effort in time available?
4. Logically organized?
5. S & T data ⟹ opnl terms?
6. Auditable?

As to Synthesis Task

1. Well organized?
2. Proper data?
3. Useful presentation?
4. Credible analysis?
5. Complete?
6. Internally consistent?
7. Opns, Functions, Systems: interrelated?
8. Agreeable to ABCA Armies?

CHART 3

Mr. Djoerd Hoekstra
Inventory Research Office
AMC Systems Support Center
U. S. Army Materiel Command

The Inventory Research Office is a staff element of the U. S. Army Materiel Command with its office located at the Frankford Arsenal in Philadelphia, Pa. The Inventory Research Office provides AMC with an in-house OR capability with primary emphasis upon introducing the concepts of inventory theory into Army logistics management practice. Most of its efforts relate to the wholesale management of spare parts and components at the higher echelons in the supply system where control over procurement, distribution, and allocation of stocks is centralized in the various National Inventory Control Points (equivalent to the Air Materiel Areas of the Air Force and the Navy's Bureaus).

Historically speaking, the work at the Inventory Research Office is an outgrowth of the research in inventory models done by Professor Morse, Herb Galliher and their associates at MIT in the 50's. The basic optimal lot size model developed by them led to further contract studies by the MIT OR Center, into the nature of the demand process and into the measurement of relevant cost factors. Based on this work, the Army implemented the lot size model for what were formerly the Ordnance Corps NICP's in the early 60's. A group of analysts at the Frankford Arsenal having been involved in this implementation eventually became the Inventory Research Office and as a result of this earlier involvement, the IRO has always conducted a substantial portion of its work in the area of decision-making at the "micro" level, decisions that can be characterized by the questions of how much, and when, as they relate to an individual item at a given point in time. For instance, how much should we buy, how much should we schedule for repair, should we issue to this customer or not, and if so, how much. Should we keep this materiel or dispose of it or sell it to a foreign country, etc. The following research projects come under this heading of studies on decision making at the detail level:

a. Lot size models were developed that apply to situations where deliveries as a result of a procurement action do not come in all at once in a predetermined quantity, but where there are phased delivery schedules, option clauses and other types of open ended procurement contracts.

b. A lot of work has been done on inventory model for repairable items that is, items which are not all discarded upon failure but of which some or all come back to the NICP for rebuild.

c. A rationing methodology was developed that tells one when to stop issuing stock to low priority customers in order to insure later availability of stock to higher priority users.

d. Under this heading also some work was done on a policy rule for deciding if and when an outstanding procurement contract should be cancelled if the need for the materiel on order seems to have decreased.

In addition to this work on decision making at the transaction level of detail, we are now devoting an increasing share of our efforts to the development of methods to deal with aggregate measures of performance as they apply to wholesale logistics organizations such as NICP's. Our ultimate objective here is to develop a macro model of each Army NICP which will enable us to relate resource inputs such as people, money, and computer capability to the performance turned in by the logistics organization as measured in a variety of ways.

In the last few years also, the scope of our work has broadened as the IRO has gotten involved in studies on not merely spare parts but the major items, (helicopters, vehicles, missiles.) themselves and as we have had the chance to work on logistics problems at lower levels in the system, involving the Army in field. For instance, in 1964 we did a system study on the management of components such as engines, transmissions, and gear boxes for helicopters. We found that, compared with commercial airlines and even compared with the Air Force, the Army's total cost/performance experience was quite poor. But then such a comparison may not have been entirely meaningful. However, as the result of this study, recommendations were made in several broad areas of operations including means of improved data collection, control over engines in the field, improved methods of reliability forecasting, and control over pipeline times. Embedded in all this was a multi-echelon inventory model, essentially a queuing model which enables one, knowing the reliability and failure characteristics, the maintenance capability, and the pipeline times in the various theaters of operations, to calculate the level of supply performance and thus to calculate the optimal stockage policies for the system and make various other trade off analyses. This model has been used experimentally but is still not in day to day operational use mainly because of slow development of data collection systems which gather the necessary information on which the model would operate. However, interesting enough, basically the same model was used in a variety of other applications subsequent to this first study.

One application was made in a study our office did last year for DA Board of Inquiry into the Army Logistics system (Brown Board) on spare parts stockage policies in the field. The question is, if we have a number of support echelons, with forward support at the bottom and going upward in the system main support and then at the top general support which in turn is supplied from a theater depot, at which level should a particular part be stocked and in what quantity. Physical constraints of mobility and of course economics, make it impossible to stock all the many hundreds of thousands of items the Army uses at all support levels, and the Brown Board essentially questioned the various institutionalized rule of thumb and policies which are presently in use. The multi-echelon queuing model was used to examine the effect of various alternative stockage and reordering policies on materiel readiness and cost. The results which are presently being expanded showed that the present policies of for instance always stocking a part if it is stocked at a lower level in the system, can be significantly improved upon.

Several other studies were done using essentially this simple queuing model which enables one to compute the supply performance in a multi-echelon system. First there was a study on maintenance float requirements for combat vehicles performed by another team of the Brown Board using the exact same model as was developed for aircraft engines. The Army Chief of Staff just recently approved the recommendations of that Board to put the model to continuing use in further studies of supply and maintenance activities and to tactical support level. This same model was also used by the Firm of Davidson, Talbird and McLynn in a study for the Chief of Staff for Force Development to determine aircraft float requirements, which is still being reviewed.

A great deal of our efforts in the past year have gone into design of the standard management information system to be used by the various NICP's, of which there are seven in the Army. Today, every NICP has its own computer system with its own file structure, its own operating philosophy, and its own decision logic. The installation of next generation hardware in the coming years will at the same time introduce a standard integrated management system encompassing all the materiel management functions. This is a very large undertaking, the outcome of which will determine to a large extent the ability of the Army to manage its vast logistics business. Besides our work in analyzing and synthesizing the multitude of decision making models to be incorporated in this system, we are also planning to do some work in the key problem area of file structures, or data base management systems, and alternative hardware configurations.

In closing, let me just mention a few other areas of research.

1. Demand forecasting mainly directed at estimating the mean and variance of future demand, and the development of tracking signals and outlier detection methods.

2. Military Essentiality of spare parts: in cooperation with the George Washington University's Logistics Research Project, a project has been underway at the IRO to develop Military Essentiality ratings of spare parts for various Army equipments. This work is an adaptation of the work that was done by George Washington University on the Polaris and later on some aircraft systems. A lot of work remains to be done in this area before we can truly say that consistent and unbiased estimates of mission essentiality of spare parts can be developed in a routine fashion.

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CRITIQUE

Dr. Seth Bonder
University of Michigan

Colonel Billingsley: Fifty-five papers later, three tremendous lunches later, two big dinners later, and we have arrived at the final "go-round" of the Sixth Annual Operations Research Symposium. This is the first symposium of this nature that I have attended, at least the first one in this area. I have gleaned a few impressions which I will pass on to you for what they may be worth.

I got the impression the first afternoon that there was some disappointment on the part of some of the participants inasmuch as the time that was permitted for them was, in their opinion, much too short. When there are as many papers as there were at this Symposium squeezed into a short period of time, there is always the tendency for one to look at the individual papers and get lost "among the trees" instead of seeing the overall subject matter that is covered or that is the keynote of the Symposium. I did have the feeling that there was some disappointment, and I could understand why. I would like to suggest that future symposia of this kind have a high degree of selectivity of papers, and that they also have at least one or two sessions in which the presenter would be permitted to go into greater depth. While I recognize the fact that these papers were done by Operations Research analysts and mathematicians, I would have liked to have a little more information on how they got the input in many of the papers that were presented. How valid was the data that was used for their particular problem? I think that one or two papers, selected very carefully, could cover the whole spectrum of Operations Research. I believe that those of us who are attending symposia of this kind for the first time would, in this way, get a much better and broader knowledge of what is actually going on in this field.

I also felt that some of the papers in the "What Are You Doing?" sessions needed more time, and that others had too much time.

The idea of concurrent sessions was excellent. I have been to a number of meetings of this kind in other areas of endeavor, where the participant or the observer had no choice as to what he was going to attend. I personally liked the opportunity to make a selection. Having chairmen and organizers for each session was an excellent idea; it gave continuity to that particular session. By and large, I would say that the good features of this Symposium far outweighed the other aspects which I have mentioned.

This afternoon we are privileged to have a real expert in this field to handle the Critique of the Symposium. I am sure that all of you know who he is and what he is, and so I am not going to take any length of time to introduce him. I will merely say that it is a pleasure to have Dr. Seth Bonder from the University of Michigan to conduct the Critique.

Dr. Bonder: When I was asked to critique this session, I was somewhat reluctant, since I knew that I would be following in the footsteps of my elder statesman-colleague : Bob Thrall, who has critiqued three of these symposia; George Nicholson, Chairman of the Mathematics Department at UNC; and Frank Grubbs from the BRL who did this last year. Another factor that reinforced my reluctance to serve as a critic is the meaning of a "symposium". I didn't realize how enjoyable these were. The Greeks defined a symposium as a "convivial meeting usually following a dinner, for drinking, conversation, and intellectual entertainment." I'm glad I have attended so many. However, I can just see the students at Michigan with their banners raised on high: "Michigan professor critical of drinking, conversation, and intellectual entertainment."

Seriously, it is a pleasure to be back here again. I missed last year's Symposium at Fort Monmouth, although I did read Frank's critique. Critiquing a symposium, I must confess, leaves little time for this thing called drinking, conversation, and intellectual entertainment. In fact, in reviewing some of my notes, I think I have taken steps to insure that I don't get offered the job again. I agreed when I accepted the responsibility of critiquing the Symposium to critique not only the Symposium but also, in general, Army Operations Research and to review, of course, what went on. I think I outdid myself. I may be somewhat overly critical, but let's judge that at the end.

Let me give you some background on how I intend to perform this critique. As you know, the program does not list any objectives this year. This was done purposely, I think. We know that among last year's major objectives (there were 6 or 7 of these) were, first, to get the key personnel together (and obviously, we're all the key personnel in Army Operations Research) and, second, to hold a forum for papers (we've had a very large forum for papers). It seems to me that those objectives, however, are sub-objectives. There is a global systems objective, and that's the improvement of Army Operations Research. Those other objectives are subsumed under the whole idea of Army Operations Research and its improvement.

I think when we say "improve Army OR" we are implying several things. Is it an activity worth improving? I think so. I think Army OR is a very important activity, although there are obviously some who disagree with this. Is there room for improvement? I think so. We are a profession, and all professions have some room for improvement. I think we do. Does the capability exist for improvement? Again, I think so. All three of these are the considerations we must give to Army Operations Research. With this, as the so-called global objective of the Symposium, let me make my final introductory comment. I am usually critical of good activities. I am most critical of my better students--those who have stronger capabilities.

The first slide is the outline of what I plan to do. I would like to discuss briefly the attendance and the organization structure of the Symposium itself, then spend quite a bit of time on the papers (number, subject, the time frame that the studies devoted themselves to, the methodologies used, quality, and my own general observations), and finally yield to the session chairmen who will give their views. I have asked them to address their comments to two questions in particular: what did they learn from their sessions in the subject area and what problems exist in the subject area.

The first item is attendance. In 1963, at the second of the Army OR Symposia, I think I saw one Lieutenant Colonel. The rest were of higher rank. I assume that the civilians present were of equivalent rank. There may have been lower ranks present, but not very many. This year, there were 83 military names on the roster, 60 of which were Lieutenant Colonels or below. Twenty were full Colonels, and we had three of General rank. This indicates to me that the population has changed and maybe that the structure of the Symposium should also change slightly. We no longer have to convince people that this is a good activity. We are of the operating level (if the Lieutenant Colonels will pardon my putting them in the group of operating level), those of us who perform the Operations Research activity, the analysts per se.

Next consider the organization of the symposium. As usual, credit goes to Marion Bryson for the administrative activities that are always well performed. The dinners are always good, the buses are always on time; in fact, this is one of the finest symposia in this respect.

People always overemphasize the importance of the theme of the Symposium. We had a theme, but purposely it wasn't really a Symposium theme. It was really the theme of one panel. I think themes tend to be artifacts anyway, and they just restrict good papers. The fact that there wasn't really an overall Symposium theme is, I think, in no way derogatory; in fact, I believe it is a plus.

There were some very interesting changes in the administration and the organization of the sessions this year. We had nine technical paper sessions, and I will discuss these in depth in a moment. We had sessions on what I call "position" papers. Some of these were not intended to be position papers, but they turned out that way. One of the groups was specifically indicated as a "position" group, Session II, the Management of Operations Research Groups. We had some papers on OR education, on what the Military Academy is doing, on the Military OR book that is being prepared and on concept formulation (Emery Atkins' session). Since the latter seemed likely to be a non-technical session on personal philosophies on OR, I sat there intending to be critical. Instead, I was pleased that it told where OR fits into the concept formulation, what questions are asked along the way, and what questions OR must address itself to. I thought that session was very well done. If we have the Symposium again next year, which I hope we will, I would suggest another session like this, with a special invitation to people who are not familiar with various aspects of OR in the development cycle. We had a Panel, "OR in Developing Countries", and for me personally that was highly enlightening. It was a wonderful demonstration of what people can do. We had a session on Simulation Methodology, as opposed to a technical paper session. We had a new innovation, "What Are We Doing?" papers. I think these are excellent ideas. That is, we know what has gone on in the past, or we can get that kind of information from DDC. But what are people currently doing, and what are they interested in doing? I would make one suggestion for those sessions, that they spend more time discussing the military problem they are going to attack and less time discussing the promises on what methodologies they're going to use. More time should be devoted to identifying the military problem with the idea of recognizing analogous ones--all of which might be resolved by a common methodology.

I thought the themes of the individual sessions were well integrated, and the sessions were well organized. One in particular was interesting, Strategic Mobility. That was really one paper, I think, instead of three. The sessions were well integrated and organized because the session chairmen were allowed to organize their own sessions. They personally invited the speakers. Even the "What Are You Doing?" sessions were fairly well integrated. What was lacking was inter-session coordination. I saw the same "What is CDC and its Function?" in about four papers from different sessions. I think we should try to eliminate some of this redundancy between sessions, if possible.

I think we need more time for the papers. It is very difficult to develop the technical aspects of a paper in twenty minutes and still leave time for discussion. Usually the papers were given sequentially, with no time for questions after each paper. In this process, I forgot what questions I wanted to ask of a particular speaker while I was taking notes on another paper. Even if I had not had this problem, the question and answer period was usually absorbed in presenting the last paper. Where time permitted discussion, I was a little disappointed in that questions were taken somewhat antagonistically by the presenter. I don't think they were meant that way--we're all trying to learn something.

As to the discussion aspect of the audience participation, I would like to make a recommendation. I don't think discussion is sufficient participation by the audience. I sensed that some people wanted some more, and I talked to some who agreed. They wanted some more exchange between the individuals and technical sessions. In 1966, at the last symposium, Oscar Wells asked for more clinical sessions. We felt the need then for people to discuss their problems technically and present what they were doing. We need more participation, not just discussion. In previous years, some people have recommended the working group technique of MORS. I don't care what technique is used, but there has to be a mechanism, I think, for closer participation with everybody here. There has to be more activity than just some presenting and some listening. Going back to my comment about the distribution of personnel, we are actually working now and we should do some work together while we are here to improve Army Operations Research. I think we can do that by getting some more participation from the attending personnel.

The next major heading was papers. First let us consider the number of papers. There were invited and contributed papers (46 invited). I included just about everything as a paper, even parts of the Panel. There were some briefing and position papers, roughly 14 of these. I recognize that I have made the decision on what is a briefing and position paper and what is a study or a technical paper. There were 12 "What Are You Doing?" papers and 20 technical presentations about OR studies--studies that were hopefully recently completed. There were 9 contributed papers that fall into the technical paper area, but they were separated because they were contributed, as opposed to invited. This is quite an increase over the number of last year's papers. Maybe this increase is not effective, since it leaves less time per paper.

The papers do not necessarily align with what the paper or the session title said it was. Some papers in sessions didn't really coincide with the title. For example, Emery Atkins' session of papers were listed as Air Defense. I don't think they were. They were about concept formulation, independent of Air Defense, therefore I took them out of Air Defense. It is interesting to note that there are zero entries in the Missile and Air Defense category at this Army OR Symposium.

Next, in looking at the papers, I tried to break these down into the time frame that the paper examined--either current operations or planning. I listed 43 papers out of the total 55 papers where I could really find out what they were talking about in terms of either operations or planning. There are only 17% devoted to current operations; 83% are devoted to planning, which I further partitioned into planning for forces and planning for weapons. As best I could determine, roughly half of the papers were devoted to planning for weapons systems, and 27% were planning for forces. I think that, significantly, there were only 2% that did both. This was rather surprising to me. It seems that future weapons for the Army are very much related to what the forces should be. In fact, Jim McLynn made that comment this morning in a roundabout way. He said, "Logistics are related to what the forces are." But logistics are also related to what the weapons are. These are very closely interrelated subjects, and, while I realize that we have to partition somewhere, I was merely surprised that we did not have more studies which looked at both problems in planning. I classified the three in the Panel Session on OR in Developing Countries along with the 17% that dealt with current operations.

There was very little study of operations. I am surprised at this since we have to look at the future when we plan something. To do this you need predictive models. Analysis of Operations is an estimation problem. Call it operational inference, if you want to give it a name. To develop predictive models you need data about current systems. Somebody made the comment that we do not want to look at exercise or operational data because it will be history tomorrow. I don't see how we ever develop a science unless we look at data today. There is no such thing as future data. Data is what we have today, and we have to correlate and extrapolate that for the future.

The next aspect of the papers is the methodologies that were employed. I could identify, in 35 papers, what methodology the authors were either using or planning to use in their studies: 7% were experimental approaches to a problem, 61% were war gaming or simulation and 32% were mathematical approaches or purely mathematical kinds of activities. Let me discuss these in reverse order of their frequency of use. This is what was given in the papers--I cannot infer what I think they did by things they didn't say. There may be lots of experimental work, but I didn't hear it. In my opinion, we don't do enough experimental work. In 1963, Ed Paxon from the RAND Corporation leveled this criticism at Army OR. Bob Thrall did this in one of his two critiques, and many of you, I think, feel the same way. I have heard remarks similar to this throughout the whole Symposium. We need more experimentation both for use in the development of models and for their verification.

Consider next the analytic or mathematical approaches. I divide mathematics into two kinds of activities: one is algebra, a la programming and input-output analysis, and the other is analytic, looking at the problem and using mathematics to model the process. I think we tend to do more algebra. That is surprising for a process oriented discipline. Since we are looking at military dynamics and military processes, I think we ought to be more analytic than algebraic. In terms of the analytics that we do, there is insufficient concern or responsibility about how we get the input data. Can we measure the required inputs for our models? I heard a comment made at the Symposium that we apply sophisticated mathematics to poor guesses. An OR philosopher once said, "We have to subject the heated anxiety of the mathematician to the cool spray of data." I think he is right. We are all too anxious to go out and mathematize something and model it without worrying about where the input data is coming from. I think there was evidence of this in the Symposium.

I have seen instances in this symposium and in other symposia that I have attended, in which we re-invent the wheel. At a recent symposium, I heard one man give a paper on Army Operations Research in which he rediscovered the binomial distribution. I am suggesting here that, before we jump into a problem and try to mathematize something or model it in any way, we should take a hard look at the literature. We have done a lot of work in over twenty years; let's find out if similar problems have been attacked, if similar methodologies have already been developed. We might save time and money and lots of frustration if we look at the literature more often. It seems to me that every study should begin with a good search of the literature in detail.

The next part of the methodology, after analytic, is war gaming and simulation. In 1963 Ed Paxon said that of 3000 papers produced every year, 25% are simulation papers. At this symposium we have exceeded that percentage. I am concerned, and I am sure many of the other people here are concerned, with the use of simulation as a substitute for very good hard thinking. That is not to say that when you do simulation you do not think at all. I personally have looked at some of the reports of the MICV-70 study that was reported here and that was a good job of thinking. All too often we jump into a problem and say, "It's complex, so we'll simulate it." I don't think we should do this all the time. One of the reasons we do this, I think, is that a simulation can be completed in a specified period of time. It may be a bad one, but it can be finished in eight or nine months or two years, whatever the time period may be. Additionally, I think it is easier for the sponsor to understand the simulation because it looks like his system rather than some other, perhaps mathematical, model which does not look exactly like his system. It is easier for a sponsor to accept a simulation because he recognizes all the elements in the physical process as being there. That is good for the sponsor, but I think at times it forces the analyst to simulate too often. Here again, I am expressing comments that were made by the people in the simulation technique session.

We need not simulate everything completely isomorphic with the real world. If we do, it is not simulation. The point is, we only want those factors that are relevant to the problems we're looking at. Dr. Schorr pointed this out in his paper. Those of you who are aeronautical engineers know full well that in wind tunnels we do not simulate the whole wing. The detail that we do put in, of course, leads to well recognized problems. First of all, it is extremely difficult to analyze the output. Last summer I ran a conference in military OR, and I had two practitioners in the field of simulation give four lectures. At one of these lectures, I asked them to please tell me what they did with the output of the simulation. They refused. They said, "We don't know what to say in an hour, or in an infinite amount of time for that matter, to really tell you how to analyze data that comes off the simulator."

There are many other problems, among them the application problem--the difficulty of getting good input data. The more detail you get, the more input data you need in the simulation, and it is difficult to get even relatively straightforward data. And probably the most important in simulation, because they are usually so big and because we use it to project into the future, we cannot verify it experimentally, nor run a sensitivity analysis. The bigger it gets, the more unfeasible it becomes to use correctly. We have a paradox.

When it is necessary to resort to a simulation, it would be nice if we did not build a new one every time, for every problem. It seems to me, we could probably get some standard simulations in certain areas by building a good one for each area of concern. I hope we will do this at some time in the future. I am referring to standard models. For example, in the last six months, George Nicholson conducted a study for the Department of Defense (with Emery Atkins and others in the field) on Models of Optically Directed Gun Anti-Aircraft Systems to find what was available and to determine if we could get some standardization of the models. Hopefully, this activity will be performed in other areas.

Oftentimes the underlying complexity of a process will allow you to use a simple model. What I am implying here is the limiting effects of something like the Central Limit Theorem (sums of normal inputs give you a normal output). Sometimes the complexity allows you to make a very simple model of the process you are looking at. Clint Ancker made a statement that was related to this: "When you have a very complex system, use an expected value model; only when it is a very simple system do you want to use a probablistic model--a stochastic simulation." He made this comment last year. I would like to add another to it. Why don't we try taking some of the sub-models in a big simulation and make them analytic? That is, take some known analytic results and use them as sub-models. Let me cite the example that immediately comes to mind. In armored combat simulations we fire a round, we time its flight, the other side fires a round, etc., and we do this back and forth, sampling hit probabilities and kill probabilities to determine when events occur. After 20 random numbers, we find out who killed whom in a little fire duel. Why don't we use a methodology like stochastic duels as a sub-model for this process? This procedure would reduce the running time and the complexity in a simulation. I am suggesting that we can do this for many of the processes in a simulation.

Let us now discuss the content of the papers where consideration was given to 27 of the papers. I made subjective estimates of quality, and by that I mean, does the paper have a proper definition of the military problem, does it develop a model of the phenomena, does it use data? If it does not use any data, does it do any sensitivity analysis? Does it come up with meaningful conclusions and recommendations? I had a hard time on many of the papers figuring out what they were trying to do. Most of them developed models in the papers. 45% of the papers used data, 37% of which was used in model development. I found very little use of data, not for testing purposes, but input data used for running the model. 8% used data for model verification. 22% of the 27 papers did some sensitivity analysis. If these results are indicative, I think we should be very wary of the output of some of the studies we are conducting.

More important for this symposium is the fact that 22% of the 27 papers, roughly five papers, presented some conclusions and recommendations. I would make a recommendation to the Planning Committee that we have more completed studies presented at future symposia. I think promises belong in the "What Are You Doing?" papers. The technical presentations should be completed or nearly completed studies.

In the development of the problem definition, I found very little attention given to the military objectives. I am concerned that we don't spend enough time studying measures in terms of the sensitivity of the measures and in terms of the statistical characteristics of the measures. Remember, measures of effectiveness of a simulation are statistics.

I did not see where many of the models developed contributed knowledge of Army Operations Research processes. That is, the models were not used to determine the dynamics of military processes.

In summary of the papers, there was very little use of the collection of data, very little sensitivity analysis, and too few conclusions and recommendations. I thought the presentations per se were the finest I have ever seen at a symposium. People presented their material well and you could read what was on the slides. I think we have to do some work in the other areas, however.

At this time I would like to make some comments regarding Army Operations Research in general. Last night, General Clark defined Operations Research for us. He had two definitions, as you remember. (Hopefully, we would strive for the first of these two and not the second.) In the first definition, he stated that Operations Research is a science of interactions. Unfortunately, I don't see very much science in the Military Operations Research area. Let me preface this comment--I think we are relatively young as a profession. Physical sciences are 200 years old, and physics is 300 years old. I hope we can make it sooner than that. Let me say what I mean when I say I don't see much science yet. I have already noted the lack of a data base. It seems to me that most of our efforts are devoted to two things: specific problem solution today about some problem (the problem may be a problem of the future), or concern with technique development--and here I'm speaking of the OR community at large. I don't see any Reynolds numbers of military processes. I don't see any analogue to thermodynamics in military processes. I don't see any physics. By military process I am referring to combat dynamics, R&D, logistics, etc. I think, however, that we are on the fringe of this knowledge. In the MICV study, there was a conclusion which implied you should attack fast, but the benefit of increased speed has decreasing marginal value. In other words, the faster you go, the smaller the marginal benefit you derive. This is some fundamental knowledge about the process. I am suggesting that we spend more time on this activity. I recognize that we have to solve problems as well--we have to do both. I agree with Foster Weldon that the inventors do an awful lot and I think we are in the inventive stage. But we have to progress beyond the stage of invention. We have to understand something about the processes we are concerned with. Dr. Cleland said, "Give us the wisdom to know the why and the wherefore." Not does it work, but why? If we can learn why these things occur, why speed is so good and what the trade-offs are between firepower and mobility and protection (and we try to do this in every study), then our weapon evaluations and our problem solving might be more efficient.

Related to my comments earlier about the re-invention of the wheel, I would like to see some organization accept a long range responsibility to accumulate some of the knowledge that is developed in particular studies, fundamental knowledge of the processes we are concerned with. Let's not only accumulate this knowledge, but also make it available, along with some standard procedures, for those who have specific problems in particular areas. This will reduce the inefficiency of continual relearning to solve particular problems.

My next general comment is about Army ORSA as a profession. I think we are well recognized. We now have an ORSA specialist program. We have 60 working level military personnel at this symposium. This is indicative of the fact that the Army is truly concerned and interested in the area. One of the points raised in the first Panel session was that we need better enticements to get more OR analysts working on Army problems. I am not sure that is a correct statement; there are already lots of enticements. I don't believe there is sufficient input to the career field. I think we need more trained analysts as input, which leads me to my last general observation, that of education of military OR analysts in general.

I am concerned about our ability to educate people, not to train them for today's problems, but to educate them to analyze tomorrow's problems. We spend too much time at the universities teaching techniques (that is, linear programming, dynamic programming, queueing theory, etc.). We don't spend enough time teaching process modeling. I would like to see courses in logistics and courses in R&D dynamics. Dr. Dean implied that there were some fundamental concepts in R&D and that these could and should be taught. I would like to see military students at the universities get more experience in the problem areas as opposed to a ditty bag of techniques. I think we have to show them how to structure a problem and analyze it--and you can only do that by experience. I am suggesting the following kind of activity. After their first year at the university, let the students spend two or three months during the summer at an organization working in some area, defining a meaningful problem, perhaps for their thesis. It should be a problem which is not already well structured and one in which the variables are not already defined. In most classical textbook problems, you are given the variables, the problem is defined, and you know the techniques to employ because the problem is at the end of a chapter which describes the particular technique. We have to teach prospective analysts to look at the problems and structure the processes as needed.

Let me summarize in closing. I said that our objective was to improve Army OR and, as I pointed out earlier, it is worth improving. I have pointed out in this session, that there are areas which have to be improved. I am convinced that the capability to improve exists. I think it will grow.

One last closing comment: for those people who would like to critique the Critique, I suggest that next year the Critique be given before the Symposium.

Let me take a moment now to call upon the chairmen. I asked the chairmen to answer two questions about their sessions. One, what was learned about the subject area? Secondly, what do you, as chairmen, see as major problems in this subject area?

Mr. Roepcke: Where have we come in the last year in the area of resource allocation in R&D, particularly research and exploratory development? Concerning the last year's activities as presented by the three papers in my session, we have available models that have been tested in a limited nature, but which need a lot more extensive testing to determine their adequacy. These models are useable if they turn out to be as useful as their proponents believe, at the service level, at a major command level, and at lab levels. We find interest in and emphasis on a more optimal way of recommending how to allocate resources in research and exploratory development. The competing models that we heard about, which are the result of the last year's effort, stress balanced allocation on a marginal dollar investment technique, the maximum military worth under the various constraints, and technological value to the organization through optimization of the dollars and personnel invested in it. The problems are large. The basic one, of course, OR analysts cannot solve. This is the distrust of computer programs handling such subjective values as military value, the cost of technical efforts (technical risk) and the fear that wrong solutions are somehow in the black boxes and might come out. Hence, the decision maker makes the wrong decisions because the decision was reached erroneously someplace in the "innards" of the ADP. It's a major problem, but I don't know how to solve it.

Another problem is structuring the operational capabilities so that their relative worths are ordered and have additive properties as was indicated. They may not even have the same metrics, and this may be a difficult problem to solve. Many factors of R&D resource allocation are not covered by the models that I have been referring to, such as maintaining a technical ability in a laboratory complex someplace, to be able to aid in making many other decisions than just building equipment. The use of sophisticated models somehow has the connotation to most laboratory people of a cold, unemotional device which puts out pink slips that say, "You're Fired," or something like that. Again, this is a climate that the OR analyst has been facing for many years, and in resource allocation it rears its ugly head too. The models did not handle the problem of setting up facilities, maintaining the current facilities, or seeing that the personnel required to operate them are available.

There was one thing that was not evident from the papers and is, in essence, something that I'm greatly familiar with. I might just as well present this as a problem from my own knowledge rather than from the papers. The DDR&E Project TALK and the Case Institute Model (and I think to some extent the RAC Model) are a one-year allocation technique, and yet RDT&E of the character we're talking about in research and exploratory development is multi-year. We need some way of modifying these to that end.

Dr. Bonder: The subject of Colonel Callahan's session was "Helicopter in Limited War." His general observations: there was relatively little commonality of war games scenarios and situations, definitions of terms, objectives, or collection of data in these four studies. In the AAFSS study, the cost data was generally collected independently of the performance model and this required an unnecessary secondary collection effort. None of the studies presented actually reported final results. They re-emphasized the need for clearly bounded objectives, constraints, data analysis, and conclusions. Suggestions for future improvement are: there is a need for better establishment of bounds, terms, and data collection means for studies related to solutions of the same general type of problems. Study models must provide the basis for specific formats used in the collection of cost data as well as performance measures. There is a need for increased attention to OR management, i.e., planning, organizing, directing, and controls for studies in related areas. A management system should at a minimum include a PERT type network in which the objectives, terms, analytical procedures, and data collection which at a minimum should include planning, organizing, directing, and control. This procedure should be directed at initiation and scheduling of parallel study efforts such as those characterized by this session.

The next session was "Strategic Mobility", chaired by Mr. Lee Stoneback. He points out how pleased he was with the integration of papers in the session. Let me read his comments at the end: "In general, the papers indicated that the bulk of the work now being done is concerned with the inter-theater part of strategic mobility systems. The importance of the CONUS and theater ends of this system is recognized. There has not been sufficient work to gain an adequate understanding of these parts of the system. The general concensus is that increased efforts should be devoted to determining how the CONUS and theater sub-system interact with and affect the intra-theater sub-system. It is also recognized that further effort is required to get a better handle at costing strategic mobility sub-systems."

COL Burton: I think that the "What Are You Doing?" session, at least the one that I chaired, was really quite unstructured. It did have a rationale to it. All the papers dealt somehow with the human factor. But what I heard may not necessarily have been what others heard, nor how they interpreted it. This was a mixed audience. I do know, I think, that we have a problem in what does YOU mean? "What Are YOU Doing?" I had interpreted that to mean that the speaker was going to give a highly personalized account of his involvement in something. However, he gave it from an organizational viewpoint (I guess all of us are good organization men). Essentially, he told what his organization was doing. I don't believe this negated the work of the papers at all; I think the speakers are to be complimented, particularly considering the time pressure that we had to operate under. We really "buzzed" through it, and I'd like to apologize for perhaps having pushed some of them a little too much.

There were three papers which were concerned with people and fitting people into these systems that we are talking about. One was the human allocation problem to meet the requirements. Another dealt with the man-machine system. A third was vitally interested in social aspects particularly of different cultures. Two of the papers considered educational problems. I submit that this is a problem in itself. We sit here at fairly high levels in a very complex Army System which is getting more complex all the time. And yet, what we do eventually has to make sense to the man down there in the field. This is an educational problem. That man may wonder, for example, why knobs are like this and why they feel like this and are placed such and so. He may wonder about the positioning of the crews, in terms of man-machine systems. He may wonder about personnel policy: why does it result in his getting new training and of moving every six months to some far distant place. It is very easy to get lost in a theoretical type of problem without looking at the realities of what can result from that study. It has got to make sense to the man down on the business end. This is like the inventory problem. When you are out of stock, you don't really know what the costs are and you make some wild guess. But let me tell you, when the man down in the field is out of ammunition and somebody is shooting at him, he knows what the costs are. And all your solutions will never seem reasonable to him, even if they are statistically sound.

A major problem that we have in this OR business is to carry it through. Two of the papers in my session dealt with education. We are trying to give the graduates of the Military Academy at least some appreciation for the power and substance of Operations Research. We can't do it very well. We need to carry it on down in some way; how this is to be done I do not know. Of course, the allocation problem in the face of changing requirements is an enormous problem. When you introduce new systems you create new training requirements and need new skills and new inputs. This is a continuing problem which we all have.

I thought my session was a very good session. I would hope that next time we can decide on what "What Are You Doing" means so that we are all on a common footing.

Dr. Bonder: The next session, Effectiveness of Barrier Systems", was chaired by Mr. Martin Chase. He said, "The arsenal of probability models for assessing casualties suffered in traversing mine fields appears to be adequate and these models can be combined with appropriate cost models to permit cost effectiveness analysis of mine fields. Similarly, there are a number of models of terrain which permit evaluation of terrain as a barrier to vehicle movement. Application of all of the models is hampered by lack of reliable data on terrain characteristics and on vehicle performance as a function of terrain characteristics. The interactions between varied offences and other tactical actions (artilleries, artillery support, close air support, defensive barriers, etc.) are very important, and strongly affect evaluation of barriers. As in most fields of military OR, the major content problems have to do with the lack of real data."

Mr. Hardison: All of the comments that I have were made by either COL Billingsley or Dr. Bonder. That was that the difference between the time that proved to be available and the sums of the times that I had allocated to the speakers was negative.

COL Ostrom: I think that the Panel Session served more to demonstrate the breadth of the problems that were open to attack than it did to teach any specific lessons. Two points did come out as specific lessons which a great many people have learned before, but which bear reiterating.

One point is that when you are trying to get a native population, or some fraction of it to become involved in the execution of a plan on a permanent basis, you had better get them in it early and get them involved deeply. Otherwise, when you turn your back, you are going to find that things evaporate just about as fast as you walk away.

The second point is that the interpreter, when you've got any kind of a language barrier, is very much a key to your whole study, and you had better pay a great deal of attention to your interpreter or translator problems before you attempt to move any further.

More generally, I think that the session showed that the OR in which you are likely to become involved is going to be oriented to the social sciences rather than to materiel. The state of development of this kind of OR is such that you are going to spend about half your time defining the problem; you've got a feed-back loop, or a number of feed-back loops, that come far back toward the beginnings of your study. You may find that you are modifying your inputs in the process of also modifying your models. Under these conditions, of course, measures of effectiveness are going to be vague. As I said before, these statements merely reiterate what is already common opinion, if not common knowledge, that the social sciences are not nearly so well quantified at this point in time as are the physical and life sciences. So far as problems are concerned, the Army (and now we're getting to personal observations) is a member of the country team. It makes no difference whether it is a leader of the country team or a subordinate member. The Army is going to become involved in this kind of OR, whether it likes it or not. The greater the degree of involvement of the United States in developing countries, the more inevitable is going to be the requirement for this type of Operations Research. I see a two-headed problem. One is selling the necessity for the social science oriented studies to the senior levels of the executive department and also to Congress. The other is selling the notion that we have got to become involved in this kind of Operations Research to the uniformed fraction of the Army at a minimum.

Mr. Atkins: My observations on our particular session are actually a little biased. The feeling that I gained from our session is that we tackled much too broad a subject for the short period of time which was alloted. As a result of the discussion of some of the participants, I also got the feeling of what I would call a "delayed reaction". There were more questions on the session quite a while after it occured than there were during the session.

We need cooperation or coordination between the multiple groups (CDC, AMC, the contractor, etc.). The fact is that if all of us do not work together, we will not deliver effective systems.

LTC Travis: In our session, we looked at simulation and the uses of simulation. I think the problems that are faced were brought out perfectly by Mr. Weinberg last night. In the military we are probably at the same stage that industry was at just after World War II. We face the same situation. We have men, data, and machines. Now, the data may be furthest down the road. We can probably get it today. The machines still have to come. I question whether you can take, as Dan Malone suggested, tactical automation (machinery) and apply it to logistics problems.

As for the men, as Dr. Bonder has already mentioned, we are concerned with our education program, and I think that in our session and in other sessions you got a fairly good idea of the steps that we are taking to close this particular gap. I think Mr. Weinberg hit it perfectly. We are at the same stage as industry in the late 1940's.

LTC Mears: I chaired a Contributed Paper Session consisting of three seemingly unrelated papers. The first two, were, in my opinion, finished, or almost finished products. The first had to do with the use of a model to predict friendly casualties in a chemical-biological environment, and from this model predict the force structure of our medical units in the future. This model is practically finished; it will be up to the Army to take it over and use it.

The next paper had to do with a technique of computer application to the correlation of aerial photographs. This model is complete and the presenter did a fine job of selling it to the Army. Again, it is up to us to pick it up and use it.

The third paper, I would say, was in the pre-pre-problem definition phase. It had to do with the need for the OR application to military police techniques. It pointed out that we have not yet even defined our measures of effectiveness. I believe that the problem here is for us to realize that we have the problem and to use what resources we can to its solution. We should also be looking at the results of the Department of Justice with regard to this problem.

Dr. Parrish: At the last minute, I asked everybody in the audience at my session to think about ways our session could have been improved. I got two or three responses. One concerned the technical versus the general type comments. An individual expressed the feeling that in a "What Are You Doing?" session, we should not go into technical details to any extent. He felt that there was insufficient time to develop that aspect, and that it would be better to stick to an overall description of the functions which the individual was performing.

Another comment I got, which applied to other sessions as well as mine, was that we should not spend so much time on the biographies of the speakers. It is not necessary, for example, to know where each of them was educated.

Finally, I would like to comment that in my session there was not enough time per paper to develop even the general comments. We had six papers in an hour and a half, and that comes out to 15 minutes per paper. It was hard to get through in the alloted time. Possibly, four or five papers in a 90 minute period would be more appropriate.

I also believe that we should have abstracts of all the speeches available, or at least a brief outline of the points that will be covered.

Dr. Bryson: Being a Toastmaster, it has been awfully hard on me to sit around for three days when everybody else is talking and not speak myself. I would like to thank the people who assisted us on this Symposium. It is the first one of the six that has really satisfied me. And I think that any individual is probably his own worst critic. There are two people that I particularly want to thank whose names did not appear on the program: that is, our own Commanding Officer, Major Al Thompson, and our liaison man in the Army Research Office in Washington, LTC Joe Mears. I thank you gentlemen for coming. I especially want to thank the session organizers. I think they've done a wonderful job. This is why I believe this symposium has been pleasing to me. I will now ask Colonel Billingsley to say a final word.

COL Billingsley: I think I can speak for all of those who have attended this Symposium in expressing our appreciation and thanks to our wonderful host and all of the people here at the Army Research Office-Durham, who have certainly made this a very successful and smooth operation. Much to my amazement, I haven't heard a "gripe" about any administrative arrangement that has been made. I think that getting lost when going to the first luncheon was the only "booboo." So please, Major Thompson, if you will accept the appreciation of the attendees, I will declare this Symposium closed.

CRITIQUE

Attendance

Organization

Papers

- number
- subject
- operations/planning
- methodology
- quality

General Observations

Chairman's Comments

INVITED PAPERS 46

Briefing/Position	14
"What are you Doing"	12
Technical Study	20

CONTRIBUTED PAPERS 9

total 55

SUBJECT	% SURVEY	% AORS
COST EFF & S/A	22	9
COUNTERINSURGENCY	15	15
COMBAT MODELS	11	0
WEAPON PLANNING & EVALUATION	10	24
WAR GAMING & SIM.	9	9
INTELL & THREAT MODELING	9	6
MISSILE & AIR DEFENSE	8	0
LOGISTICS & MOBILITY	7	15
COMMAND, CONTROL & COMMO	6	4
EDUCATION OF OR PERS.	2	4
MANAGING OR/SA EFFORTS		6
PERSONNEL & HUMAN FACTORS		8

Time Frame (43)

Current Operations 17 %

Planning 83 %

forces 27%

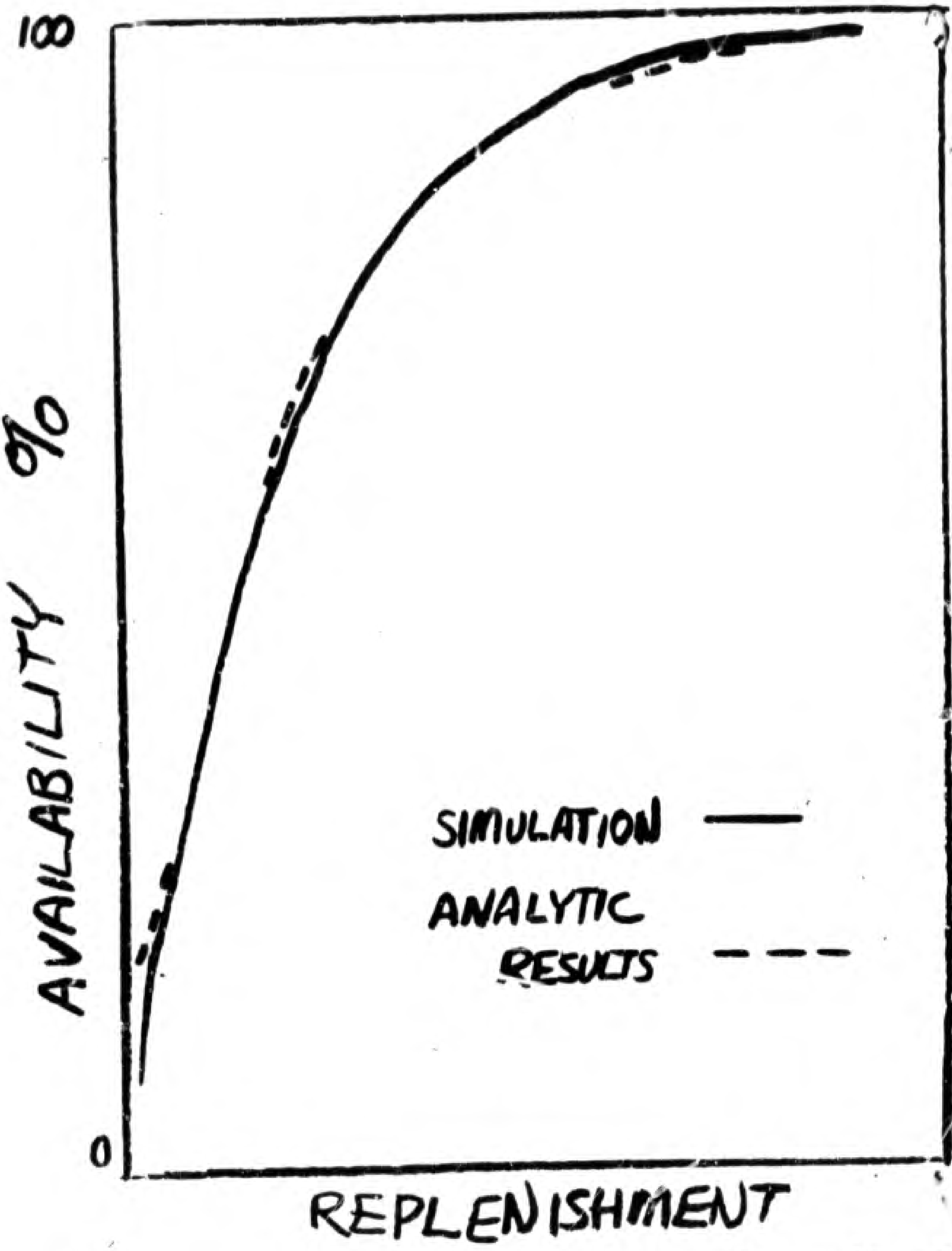
weapons & equip 49%

Methodology (35)

Experiment 7%

War Game / Simulation 61 %

Analytic 32%

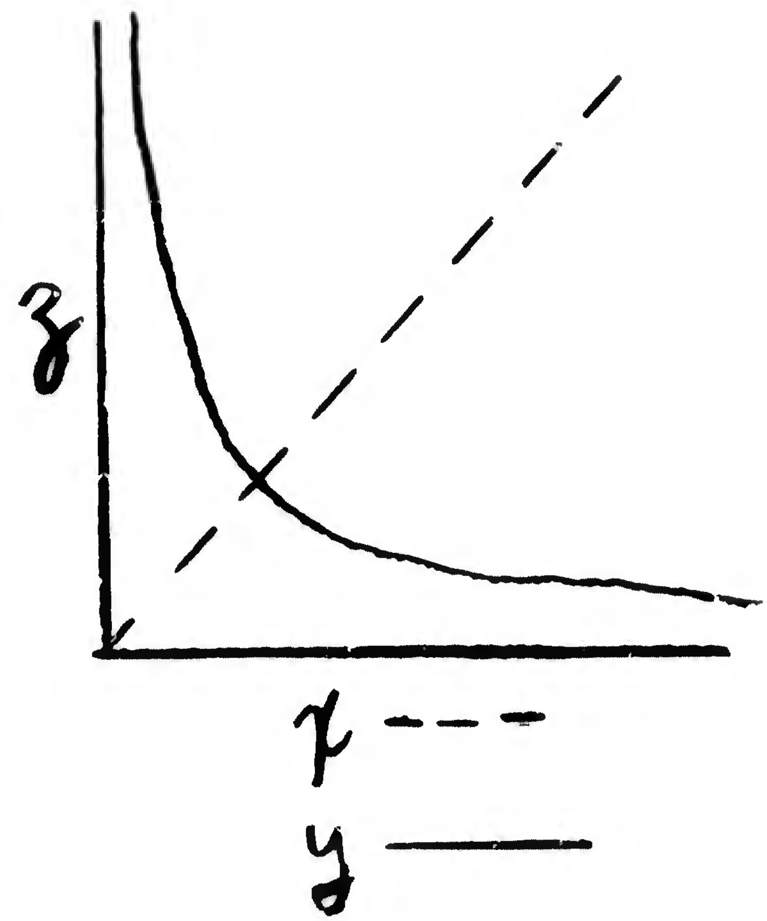

100
0
AVAILABILITY %
REPLENISHMENT
SIMULATION
ANALYTIC RESULTS

Content (27)

Problem Definition	
Model Development	74%
Use of Data	45%
model Development	37%
Input	
Verification	8%
Sensitivity Analysis	22%
Conclusions & Recommendations	22%

RATIO MEASURES of EFFECTIVENESS

$z = x/y$



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13. ABSTRACT
This volume contains all invited and contributed papers and major addresses which were presented in the unclassified sessions at the U. S. Army Operations Research Symposium, 24-26 May 1967. The 35 papers include such topics as research planning, resource allocation, war game analysis, anti-aircraft effectiveness and research management. The theme of this year's symposium is "Uses of Operations Research in Developing Countries."

14. KEY WORDS
Operations research
personnel study
resource allocation
counterinsurgency
cost-effectiveness
concept formulation
timing systems
security
RECAP
SYMWAR
tactical optimization
systems analysis
research planning
war game analysis
anti-aircraft effectiveness
non-linear simulation
logistics
input-output technique
environment
weapons systems
aircraft replacement
police techniques

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