48 (2)

AD669751

AD 669 751

MANAGEMENT AND THE SYSTEMS ANALYSIS MYSTIQUE

Paul L. Peck, Jr.

Army Materiel Command
Washington, D. C.

1968

33

Foreword

It has become evident to most managers that a capability in systems analysis is a prerequisite of success. Not only is systems analysis useful in decision making and problem solving, but it has become the leading buzzword of the day. This can be seen by the fame or notoriety of the DOD systems analysis group developed by Robert McNamara, the fact that the management science groups of most universities stress systems analysis in their brochures, and the salary wars being waged to hire systems analysts.

This paper is designed to penetrate the mystique which surrounds systems analysis. In addition to defining systems analysis, the advantages and limitations of this technique are discussed, a general purpose methodology is developed, and a description of one application of the methodology is provided.

The opinions expressed in the paper are those of the author and not those of AMC.

"Management and the Systems Analysis Mystique"

LT Paul L. Peck, Jr.
Headquarters, Army Materiel Command

Introduction

To be successful, the modern manager must be able to assimilate large quantities of data. It has been said that our knowledge has doubled in the past twenty years and it is estimated that it will double again in the next ten years. Not only does this affect the scientific community but it affects all of us. Every day new developments occur which generate reams of data which are later grouped, analyzed, and published. As a result, the modern manager finds himself confronted with an ever increasing amount of useless data. Surrounded by data on every conceivable facet of his operation, the manager diligently searches for a method of separating information from chaff. During this search, the concept of systems analysis is first discovered. An aura of contentment now settles about our executive as the mystique of systems analysis exerts its influence. Unfortunately, the decision maker often finds that systems analysis has provided additional data, but no additional information. Since so much controversy surrounds this subject, an intensive examination of the nature, value, and limitations of systems analysis is needed.

Definition

Systems Analysis is defined as a systematic approach to problem solving which utilizes quantitative management science techniques to develop and evaluate a spectrum of solutions to long range problems. The length of the effort does not determine if something is to be classified as a "systems analysis study." If all steps in the enclosed methodology have not been properly considered, this effort is merely an evaluation based on expertise. Unfortunately, too many incomplete efforts, which can lead to poor decisions, have been termed "systems analysis studies." To arrive at an optimum solution, either the effectiveness of the system should be maximized or the costs minimized. Systems analysis can be applied to materiel effectiveness, organizational structure, and product mix problems. During the conduct of a systems analysis study, alternatives are developed to meet specific requirements for a variety of environments; then the alternative is selected which best satisfies these requirements.

System & Subsystem Relationship

Systems analysis is applicable to any type of problem if the technique is adapted to take into account the individual aspects of each problem. If the systems analysis effort is to be productive, it is vital that the system under consideration be carefully defined. A system is composed of men, material, and machines; and the limits, relationships, and effects of each part of the system must be explicitly separated from the environment, which is defined as everything outside the system. Furthermore, each subsystem must be clearly defined and its relation to other subsystems and the system established. In practice, defining the subsystem boundaries and determining the interface coefficients is extremely difficult. After developing the subsystem relationships, the value of each parameter must be related to overall effectiveness. If a systems analysis effort is to be successful, a clear distinction must be made between each subsystem, the system and the environment.

A final source of difficulty arises if past studies have been conducted to optimize certain technical characteristics of the system and an attempt is made to sum the results of these technical subsystem studies into a system study. The results of these subsystem effectiveness studies cannot simply be summed to give total effectiveness because the objectives of the system study are not necessarily the same as the objectives of the past subsystem studies. Furthermore, the system operates under different constraints than the subsystems. Realizing that a systems analysis study is composed of a number of subsystem studies, both common constraints and a method of assigning relative weights to the results of each subsystem study must be developed. If the above factors are not considered, a less-than-optimal solution will be obtained.

Time Frame

One of the more important points illustrated by the definition of systems analysis is that long range problems are specified. Does this mean that short range problems must be solved using other techniques? A review of current operations research publications indicates that short range problems are handled by resource analysis techniques, however, resource analysis is essentially the same as systems analysis. The only difference between these analytical approaches is that cost is usually not the most important factor in the short run. For example, it might be demonstrated that a particular alternative is much cheaper than other alternatives, but personnel or special material requirements of this alternative might negate its use in the short run.

Continuing Process

It has been asserted that systems analysis is used for both long and short range problems. Systems analysis is a continuing effort from the concept formulation stage, through feasibility testing, through all development stages, into production and throughout the life of the product or the idea. At each stage, information which is both more pertinent and more reliable becomes available to the analyst. Since the analyst is continually acquiring information, the decision maker or a member of his staff must maintain close contact with the study to verify that the current facts and assumptions are valid. By monitoring each phase of the study, time and money can be saved because the manager will be able to make good timely decisions and eliminate alternatives which could never be implemented.

Since systems analysis is a continuing process and since the manager is continuously involved, it becomes evident that present decisions may be exactly opposite to decisions made in the past. This is natural because as time passes the goals, alternatives, criteria, and environment change; necessitating a complete re-evaluation of the entire project.

The Computer

Much has been written about Robert McNamara, systems analysis, and computers. Since these subjects are often discussed in the same article, the reader often associates systems analysis with computers. This association is not justified. Systems analysis is a technique while the computer is a tool utilized by systems analysts. In fact, a computer is not necessary for systems analysis; it merely speeds calculations which the systems analyst has determined are necessary to solve the problem. Once the analyst has determined what must be calculated it is relatively easy to program this so it can be run on a computer.

Value and Use of Systems Analysis

Systems analysis is a tool of the manager which enables him to avoid broad generalizations. This tool is used by the manager to allocate resources, to optimize under a particular set of circumstances, to compare alternatives and to establish requirements. In comparing alternatives, in order to make a decision, the manager is interested in differences, not similarities, among alternatives. The real value of systems analysis lies in the fact that it is a systematic approach which forces a manager to structure his thinking to the problem at hand. By forcing differentiation of qualitative and quantitative variables and by listing the assumptions, techniques, and limitations of the study; the problem areas are highlighted. In other words, at this point the manager finally knows what must be decided.

This author believes that the present day manager, who most theorists assume is interested in making an optimum decision, is actually interested in eliminating the alternatives which could prove disastrous. Since only the results of the one alternative selected by the decision maker can be observed, the decision maker is sitting pretty if he can avoid obviously poor decisions. The reason for this is that once a decision has been made, even if the best alternative has not been selected, the manager can make this solution work.

Another advantage of systems analysis is that it may demonstrate to the manager that a decision may be postponed. The point will not be belabored that choosing to do nothing is a decision. If a decision can be postponed, the study can be revised to take advantage of more accurate and timely information, which increases the usefulness of the study. In addition, since every manager operates in a dynamic environment, this means that the competition has less time to react to the decision. This holds true when possible strategies of the United States are being considered, when a manufacturer is engaged in negotiating a union contract or when developing optimum organization techniques. The importance of delaying a decision until it is needed is evident when past prognostications of the future are evaluated against reality.

Cost-effectiveness studies are also a good source of documentation. The subjects which should be discussed in the summary of the cost-effectiveness study (FIGURE 1) enable the manager and future users to analyze the value of the effort. In addition, the progress of a study can be ascertained by determining whether or not the steps in the general methodology (FIGURE 2) are being followed.

Limitations of Systems Analysis

Like everything else, systems analysis has its limitations. In systems analysis, the real world is represented by a model. Since a model is one level removed from reality, an optimum solution to the problem, as defined in the model, may not work in the real world. Furthermore, a good systems analysis study requires a great deal of effort which means that both competent people and the necessary time must be available. If either of these factors is missing, the resultant effort will be either poor or incomplete. If an incomplete effort is submitted as a "systems analysis study", an unearned air of respectability accompanies the submission. The false confidence inspired by this incomplete effort may lead to poor decisions in the future.

A second problem arises when data is not available or only low confidence values can be placed on this data. The value of good relevant data cannot be overstated. The last factor to be considered is the effect of a good decision based on a successful study. As was discussed, a decision is valuable for a certain time frame. After this time period, the environment changes of its own accord or the competition moves to change the environment so that another systems analysis effort must be prepared for the new problem.

General Methodology

Fortunately for systems analysts, no cut and dried method of performing these studies exists. Each problem is different, each environment is different and the techniques of systems analysis are constantly changing. The problem tells the system analyst the direction to follow. For these reasons it is easy to see that the systems analyst must be both ingenious and flexible, but it also seems reasonable that some way should be developed to take advantage of any similarities. For this reason, a general methodology (FIGURE 2) has been developed. Each of the steps in the methodology will now be discussed.

Defining the Problem

As has often been said, defining the problem is the most important part of any study effort. If the problem is not clearly defined and the scope of the effort spelled out, interface problems and suboptimization may result.

Problem definition, which should therefore be the first part of any study, begins with some statement of general objectives, such as, "this Army will have the best possible communications" or "this company will operate so that each person receives quality merchandise and good service for a reasonable amount of money". These abstract goals must now be turned into specific realistic requirements which is extremely difficult in practice. The first question encountered deals with the scope of the problem. Do we mean that we will provide communications under all possible conditions? How is communications defined? What do we mean by the "best possible" communications? In considering the business concern, how do we define quality and good service, what is a reasonable amount of money, and are we talking about all products we sell or only those which we produce and sell?

During this translation of the abstract to the realizable goal, the decision maker must participate because all alternatives will be evaluated against this requirement. This aspect of the methodology assumes greater importance when it is remembered that certain aspects of systems operation can be improved without improving the overall efficiency of the system. Furthermore, if the requirements are set too high, the system may be overdesigned. Even though overdesign increases the cost and effort involved in product development, the initial phase of problem definition is often summarily concluded. To avoid this problem, both minimum and maximum requirements should be set. Specific requirements are often expressed in terms of quantitative standards, but qualitative requirements are often forgotten. Representative qualitative requirements must be developed and should be listed separately from the quantitative requirements. For example, requirements for personnel with certain skills and special time constraints must be spelled out.

Since these requirements are to be used for evaluation, it is important that no alternatives are precluded by the definition of the problem. The different levels of problem definition must be considered. For example, if one radio is simply to be compared against another radio for communication over a certain distance, it is relatively easy to develop a requirement for this. Note how problem definition becomes more difficult as the radio is compared with another means of communication such as cable to determine which provides the best communication. Now expand the problem so that you compare this radio versus an improved weapon to determine when overall combat effectiveness has improved. In order to take into account all state-of-the-art advances, and to guard against overdesign, a significant amount of time should be spent defining the problem.

Defining the Environment and the Mission Mix

For a product to be profitable, the proper market for this product must be determined. Similarly if a weapon system is to be effective, it must be able to meet a certain threat. However, the extent of the value of this weapon system also depends on how often the threat materializes. For these reasons, it is evident that systems analysis cannot be performed in a vacuum. The conditions under which the system will operate and the number of times this system is needed must be defined.

If the objectives are to be realized, a clearly defined mission mix must be provided. The type of mission and the frequency of occurrence of each mission must be determined. Although this appears obvious, a review of many systems analysis studies shows that it may not be so obvious. For example, real time computer capability is extremely advantageous to a manager. With such a system, a manager could develop a program so that he could receive an immediate printout on the background of each employee. However, how often does the manager need this information immediately? What percentage of the personnel decisions which a manager makes require immediate information? Granted the manager has received information faster, but has he increased the effectiveness of the personnel system? Another example of this concept is the development of a system which is to perform two or more functions. To develop the best system the relative need for each function must be known.

If the environment is to be realistic, close attention must be given to the time factor. If a product is needed in four years but development of the item requires eight years, it would be a waste of time to develop the original item. The operational situation must be timely. It must reflect the conditions under which the product will be utilized. Furthermore, if the product is to operate over a certain period of time, provision for change must be built into the environmental section of the study. If a product has a life cycle of ten years and requires eight years to develop, the scenario, which provides background information, should reflect the conditions eight years from now to eighteen years in the future. State-of-the-art advances must be considered.

Suppose all the above factors have been considered, one factor still remains. How are these missions to be weighted relative to one another? One thing is certain, all missions will not have the same amount of importance; therefore, if an optimum product is to be developed, weights must be assigned to each mission. Who assigns these weights? One of the better methods of assigning relative values is to bring together a number of experts with different backgrounds. These experts, without benefit of discussion, are then asked to rank the missions in order of importance. After listing these missions in order of importance, the five or six most important missions are considered by the group. Since these five or six missions will probably cover 90% of all missions, the experts then assign percentage values to each of these missions. After normalizing these figures, a relative mission mix will have been developed. This mix provides a beginning. In the analytical section of the methodology, it will be demonstrated how this relative mission mix can be easily modified or other missions added to determine the effect on the outcome of the study.

Developing the Criteria

The criteria is an approximation of the objective. It serves as the standard against which the alternatives are compared. Since there are many types of objectives, there will be many types of criteria. For example, a go/no go criterion is valid for some types of studies while degrees of success must be considered in other studies. The problem indicates to the study group what type of criteria to develop.

In many cases, subjective considerations become the critical factors in the selection process. For example, how will morale or coordination be affected by each alternative? Since it is obvious that each person will weight these factors differently, they should be listed as factors affecting the decision. (Note how these factors differ from the qualitative requirements discussed previously.) One other way of handling these qualitative factors might be considered. A group could be set up to apply quantitative values to each qualitative factor. The major shortcoming of this approach is that these quantitative estimates of qualitative factors must now be combined with pure quantitative factors.

The criterion is usually expressed in the following manner: provide the same level of effectiveness for all alternatives; then select the one with the least cost or vice versa. As can be imagined, this comparison can be performed for many different cost or effectiveness levels and different results will probably be obtained at each level. Since this doesn't help the decision maker, maximum and minimum standards for cost and effectiveness should be developed to reduce the scope of the problem and incremental analysis techniques should be used to show when the cost of additional effectiveness becomes prohibitive. After utilizing these aids in developing quantitative measures of effectiveness, the qualitative factors or subjective considerations often become the deciding factor.

Having considered both cost and effectiveness (the derivation of the name cost-effectiveness study), it would appear logical to develop a cost-effectiveness ratio. However, such a ratio is misleading for the following reasons: (1) the cost of an item depends on the quantity produced; therefore, the C/E ratio will vary depending on the amount, (2) the ratio is affected by changes in either the numerator or the denominator, (3) the level of effectiveness may not reach the minimum level, yet a good ratio could exist. The first two problems can be eliminated if either cost or effectiveness is held constant and the development of a minimum standard will eliminate the third problem. Therefore, a C/E ratio can be useful if the criteria standards discussed above are implemented.

To conclude this section, importance factors will be discussed. The importance factor is the value of one system parameter relative to other parameters. This concept is easily understood if it is recalled that effectiveness depends on a number of things. For example, the effectiveness of a plane is dependent upon speed, range, maneuverability, availability and many other factors. But how are these factors related to overall effectiveness? Does speed contribute 30% to total effectiveness? Is speed twice as important as range? This weighting problem was discussed earlier in the paper and the use of a group of experts to develop these importance factors still appears to be the most promising solution. After the study has been completed, a sensitivity analysis can be run on each factor to determine how it affects the results of the study.

Determining the Alternatives

Having defined the problem and developed the selection criteria, all alternatives which may satisfy the requirements should be listed. The problem must be stated in general terms so that no alternatives are precluded. Ingenious people with broad backgrounds must determine these alternatives, for only then can the decision maker be certain that all alternatives have been considered.

In addition, the internal and external tradeoffs for each alternative must be considered. For example, if the objective is to destroy an enemy position, combat troops may be aided by either tactical air support, ground fire support, or a combination of the two. But many types of air and ground fire support exist. For instance, tanks, artillery, mortars and vehicular mounted weapons provide ground fire support and each of these categories can be further divided. Artillery could be divided into 105mm guns, 155mm guns, and 175mm guns. Once a weapons system has been selected, its effectiveness can be changed by varying its performance or its availability characteristics. Availability is determined by intrinsic availability and operational availability, and intrinsic availability is dependent upon reliability and maintainability.

As illustrated above, differences in degree and in kind exist at each level of the system.

Determining the Relevant Variables, Assumptions and Facts

Due to cultural and educational differences, the same word can have many different meanings. Not only will people disagree on the definition of a word but they will disagree on the importance of the concept which the word represents. Since these concepts have not been universally defined, it becomes even more difficult to measure them. Therefore, each concept and characteristic must be explicitly defined if a cost-effectiveness study is to be meaningful.

Since a study is conducted to determine solutions to an existing problem, a clear differentiation must be made between assumptions and facts and each assumption and fact must be listed for the decision maker. In addition, the source of each fact and the reason for each assumption should be noted. Only in this way can the decision maker check the reasonableness of the study and ascertain if the real problem is being attacked.

The factors which will make up the effectiveness value are then selected by a group of experts. To do this all factors which are thought to affect the effectiveness value are determined. After structuring these variables according to importance, the six most pertinent are selected. The reason for selecting six variables is that the author believes that 90% of total effectiveness is determined by these variables. If this surmise is wrong, no damage has been done because the effect of other variables may be tested by sensitivity analysis. After selecting these variables, the group of experts assigns weights to these factors. These variables must be chosen so that any significant change to the system will be immediately evident in the model results.

Generating the Data

At this stage of the study plan, the problem, criteria, and alternatives will have been defined and the problem will indicate to the study group what data is needed. Data is needed on both the cost and effectiveness aspects of the study, but the necessary data in the proper form is difficult to obtain. Even though the time, effort and cost involved in gathering data is high, confidence in the validity of the data is often low. There is no simple solution to this problem, and a number of articles have been written on data collection, but it should again be stressed that a study will not be successful unless a sufficient amount of money and talent are committed to this step.

Developing the Model

It becomes obvious in this section that model development and data generation should take place concurrently because a continuous feedback loop exists between these 2 phases. Gene A. Markel defines a model as follows, "A model is a representation of a thing; the more important parts of the real thing are incorporated into the model, and appropriate analogs are used to replicate essential structural and functional characteristics." The model abstracts only those parts which are important to the problem. This means that no model is completely realistic, because many intangibles and concepts which are difficult to define are neglected. However, the value of a model depends on its ability to indicate the merit of various alternatives, not on how accurately the model is a reproduction of the real world.[1]

Any model chosen must illustrate the tradeoffs between effectiveness gained and resources utilized. For this reason, effectiveness and cost submodels are developed. The effectiveness submodel is divided into performance and availability submodels, and the cost model is broken into research and development, initial investment, and operating and maintenance submodels (FIGURES 3, 4 & 5). Each of these submodels is further divided into its elements as illustrated in the area communications example. What this means is that just as a system is a hierarchy of subsystems, so a model is a hierarchy of submodels where each submodel is composed of a number of algorithms. Furthermore, just as subsystems must be integrated into the system so must submodels be integrated into the model. This is a difficult task for the model builder who must develop and interface each level of the model.

Modular design is the tool which enables the designer to build a multi-level model. In a modular model, the failure of an element on a certain level does not affect other elements on the same level. This concept enables the system designer to localize cause and effect relationships. As utopian as this idea sounds, it does not hold completely true in the design of a model because submodels are not independent of each other. Therefore, the relationship of each element to other elements and to the next higher level must be clearly defined. This is extremely difficult. The amount of detail in each submodel and the degree of detail to which the interfaces are stated is dependent upon the time, money and expertise available. Expertise is the greatest limiting factor.

It is easy to see that continual feedback is necessary in model

[1] G. A. Markel, "A Concept for Modeling and Evaluating Information-Producing Systems," DDC publication AD 628495 (January 1966), p. 6.

development. Each submodel is related to the model and other submodels and a continuous exchange of ideas is necessary so that a complete description of all interface algorithms is developed. In addition, the decision maker must be continually briefed because he will be called upon to provide further guidance for submodel developers and to insure that the correct problem is still being attacked by the model builder.

Effectiveness Model

Having introduced the concept of modular design of submodels, the effectiveness and cost models will now be discussed. An overview of these models is shown in figure 3. Many different groups have developed methods of estimating effectiveness. The Weapons System Industry Advisory Committee (WSIAC) appears to have been the first group to establish a method of establishing effectiveness. To determine system effectiveness, this group used a matrix concept which represents effectiveness in terms of capability, availability, and dependability of the equipment. It appears that a simpler method of determining effectiveness exists. Total effectiveness is determined by manipulation of the performance and availability submodels.

Performance Model

There are no general elements which I can group under this heading because each problem has different measures of performance. For example, speed and maneuverability are extremely important when considering the measure of performance of an interceptor airplane, however, they are of no concern when considering the measures of performance of a manpack radio. The problem indicates the important parameters and an example of this is provided in the area communications example. (Appendix 1)

Availability Model

It is much easier to develop a general model of availability. As can be seen from figure 4, availability is dependent upon two primary factors, intrinsic availability and operational availability. Availability is the probability that the system is able to function satisfactorily at any point in time when used under stated conditions, where the total time considered includes operating time and repair time. (Repair time is further divided into active repair time, administrative time and logistics time.) Intrinsic availability is a function of reliability and maintainability only. As can be imagined, the best way to improve the availability of equipment is to increase intrinsic availability. This can be achieved only if a major reliability and maintainability effort is begun early in the design stage.

The other major factor influencing availability is operational availability. From figure 4, it can be seen that two primary factors determine operational availability. These two factors are attrition rate and repair time. Repair time is determined by serviceability, logistic time, administrative time, and failure rate.

Undoubtedly, the reader is happy to know the factors which determine availability, but he would probably be happier if the interrelationships were shown. Three levels of detail are shown in the availability model. Algorithms must be developed which show how elements are combined to form submodels and how submodels are combined in the model. For example, design reliability and design maintainability are combined to give the value of intrinsic availability. Intrinsic availability and operational availability are now combined to give a measure of availability.

Since submodels are not independent of other submodels, additional algorithms must be generated which show these relationships. For example, design maintainability is a determining factor of availability, but it also affects repair time.

Cost Model

The life cycle costing concept considers R&D, initial investment, and operating and maintenance costs over the total useful life of the system. In the R&D category, all stages of development should be considered. Figure 5 illustrates the basic phases of development in the R&D cycle. The R&D cycle begins with the exploration development stage in which the feasibility of a product is tested, and ends with operational systems development. During the development phases, various systems development approaches are evaluated and the best approach selected and implemented. The costs which are found in each of these stages have been examined in detail and many check lists have been developed.

The investment costs involve all costs expended to manufacture a product. A summary of the major elements is given in Figure 5. In this phase, the costs of production facilities, labor, and materiel are considered. Production testing and quality assurance costs are also considered here. Two other high cost factors are the cost of the initial supply of repair parts and the cost of government furnished equipment.

The last cost category is operating and maintenance costs. Operating costs and maintenance costs provide the bulk of these costs. The other major factors are personnel and training costs, and supply operations costs. An example of the cost of supply operations is the cost associated with running a depot or maintaining a headquarters.

Each of these submodels has been extensively described. Military Standard 881, which has not been approved, provides the standard DOD work breakdown structures for eight types of hardware systems and defines which costs fit into each category. In addition, completed cost-effectiveness studies provide further documentation.

Having determined the cost categories to be used, the remaining problem is to gather the costs. Since most studies are performed on systems in the experimental stage, it is soon discovered that no cost information is available. This means that a relationship between the desired cost and some known physical or performance characteristic of the system must be found. Then an algorithm is developed which relates cost to the value of this characteristic. For example, the Air Force has effectively used aircraft weight to predict airframe cost and recently a relationship has been found between truck weight and fuel consumption. In these cases, regression analyses were performed on historical data from existing similar systems. Regression analysis is a statistical technique which illustrates mathematically the relationship between two or more variables and assigns confidence levels to those relationships. After production costs are estimated, learning curve theory shows how these production costs decrease as experience is gained.

There are other factors to be considered while gathering costs. Basically, the costs which are the same for all alternatives (fixed costs) are only valuable for determining whether the cost ceilings have been pierced. In addition, all money that has been obligated or spent is a sunk cost and should not be considered because systems analysis can demonstrate when past decisions should be changed, but it cannot bring this money back. Since the objective of the study is to select the best alternative, only costs which are different for each alternative should be considered. This is differential cost theory.

There are certain military policies such as procurement and overhaul policies which must be considered when designing the overall cost equation. The problem tells the analyst how to combine all relevant costs. For example, a general unit life cycle cost for a system would follow this form:

$$\text{UNIT COST} = \frac{\text{R\&D costs} + \text{initial investment} + \text{life cycle operating and maintenance costs}}{N} \quad \begin{pmatrix}\text{where N is the}\\ \text{number of units}\end{pmatrix}$$

Algorithms must be developed to relate all elements in each category. As seen in Figure 5, the total R&D cost is found by adding exploratory development, advanced development, engineering development and operational systems development costs.

Another element to be considered is that the value of money changes with time. This can be seen by checking the interest you have received in the past year. Since the normal life cycle of a system is approximately ten years, different amounts of money will be spent during each year of the life cycle. If two alternatives have the same effectiveness, but one requires a large initial investment while the cost of the other is spread equally over a number of years, the second alternative is cheaper. How much cheaper depends on the discount rate assigned for the study. This issue has generated a lot of controversy because no two people agree on the discount rate to be utilized or on the estimated useful life of the product. To solve this problem a number of discount rates should be used and the effect on total cost evaluated.

Exercising the Model

After the model has been developed, it must be manipulated to provide information on each alternative. If the problem is simple the manipulation can be done by hand, otherwise a computer is utilized. Simulation is often utilized in systems analysis because it provides quantitative answers to specific questions which do not require the participation of a decision maker. The great time compressions and control conditions obtainable with computer simulation provide data which is useful for more quantitative and rigorous analysis. This time compression is due to the fact that either probabilistic or deterministic decision rules are written into the simulation. The problems that are best studied by computer simulation are those which require large sample sizes in order to perform adequate statistical tests.

To gain the most from the use of simulation, the program must be written so that the variation of the critical parameters can be easily detected. If parameters become less important, they are modelled as environmental conditions. However, as a variable becomes a limiting factor in the results, it is modelled in more detail.[2] The model is continually being modified because data may not be available, because additional knowledge indicates that some data may not be relevant, or because some parameters become less critical to the analysis.

As with other computer programs, the cost of designing and running the simulation is proportional to the length of the program and the complexity involved.

Analytical Effort

In this stage, all alternatives are compared against the standard and against each other. Three levels of analysis should be performed in any cost-effectiveness study. The initial analysis should be general in nature and is designed to eliminate all alternatives which cannot meet the minimum requirements or the cost ceilings. Next, an intensive analysis is performed in which detailed cost and effectiveness estimates for each remaining alternative are developed. At this point, some additional alternatives will probably be eliminated. An incremental analysis (marginal analysis) is then performed on the remaining alternatives. This analysis will show any break-points which may exist. Since the additional effectiveness for a fixed amount of investment will markedly decrease beyond this point, this test provides another indication as to which alternative should be selected. The results and confidence coefficients for the detailed analysis and the incremental analysis, along with subjective considerations should now be presented to the decision maker.

Sensitivity Analysis

Even though he has continually participated in the conduct of the study, the decision maker may be plagued by a series of "what if" questions. Since data is generated with different levels of confidence and since the use of expert judgment was utilized extensively in this methodology the manager must be provided with some type of validity check. A sensitivity analysis provides this check and helps to eliminate some uncertainty. In sensitivity analysis, certain variables or environmental factors are changed so that the effect on the results may be determined. Using this type of analysis, the contribution of each variable to total effectiveness can be determined. The importance of a sensitivity analysis in the systems analysis effort cannot be overstressed. This technique provides the

[2] M. A. Geisler, "Man-Machine Simulation Experience," Rand publication P3214 (August 1965), p. 5.

means of changing assumptions, varying decision rules, modifying environmental conditions and considering the reaction of the competition. If the study were not structured so that sensitivity analyses could be performed, the study would be useful for only one set of assumptions and environmental conditions. Since the world is changing rapidly, the results of the analysis would be outdated by the time the study was completed.

Each submodel should be developed so that mathematical programming techniques can be utilized. To use mathematical programming an objective function, mathematical function, and the constraints and restrictions on variables must be defined. Mathematical programming techniques enable the analyst to optimize under certain restrictions which is exactly what we are trying to accomplish with a systems analysis study. Mathematical programming techniques make it easier to perform sensitivity analyses.

The concept of sensitivity analysis becomes even more valuable when it is recalled that the specific requirements which we have satisfied are only an approximation of the objective. Thus, sensitivity analysis enables us to determine if the proper problem was solved. Sensitivity analysis also enables us to determine maximum capabilities under fixed conditions. This is simply a modification of the basic technique in which time, materiel or personnel requirements act as a limiting factor in the short run. In all cases, systems analysis should be conducted for both the most important and the most prevalent conditions. The question of what to vary and how much to vary must be considered because of the cost of the additional runs required for sensitivity analysis. Since the cost varies with the number of variations run, an experienced analyst must decide which parameters are to be varied and what degree of variation is needed.

Presenting the Results

The results of the study must be perfectly clear and understandable, because only this finished product is transmitted through the different levels of management. The elements which should be contained in the final report are shown in figure 1. In order to make certain that these factors are clearly discussed, the final report should contain a short summary which considers each of these elements. Since the report contains two levels of detail, the reader can first read the summary; then turn to the detailed discussion of the parts that interest him.

Two points should now be made. In the section in which the results of the study effort are presented, the benefits of the selected alternative should be discussed and possible problem areas highlighted. Since some controversy exists about whether or not recommendations should be included in the final report, it is shown in the figure as an optional section.

Conclusions

In this paper, the nature, value, and limitations of systems analysis were discussed, a general purpose methodology developed, and this methodology applied to an area communications problem. In addition, the continuing nature of systems analysis and the requirement for the close participation of the decision maker has been stressed. Systems analysis provides answers to two types of questions. In the first type, a certain level of effectiveness is required and the alternative selected is the one which costs least. Systems analysis is also used to determine the worth of additional capability.

Systems analysis was defined as a systematic approach to problem solving which utilizes quantitative management science techniques to develop and evaluate a spectrum of solutions to long range problems. However, this concept can be applied to short run problems if it is recalled that time or personnel considerations may be more important than money in the short run. Since a system is composed of men, machines, and materiel; a careful differentiation between the system and the environment is necessary.

Systems analysis is valuable, not because it places quantitative values on variables, but because it forces the designer to organize his thinking. If the procedures and the results of this systematic approach to problem solving are presented to the decision maker, the issues can be clarified; then, the manager will know what types of decisions must be made.

Appendix 1

AACCMS High Capacity Subsystem Example

General Objective

The proposed Army Area Communications High Capacity Subsystem is to be an integrated system composed of multi-channel field Army communications equipment which will provide secure high quality circuits capable of telephone, teletype, facsimile and data communication via radio and cable. This system is to provide line-of-sight communications to other Army area signal centers (30 mile radius), provide increased channel capacity and provide improved reliability and maintainability.

The technical control facility at the transmission center will have the capability of patching 600 channels, and the technical control facility of the operations center will have the capability of patching 300 channels. This system should be 100% mobile and shall be available to meet tactical field Army requirements in 1970.

To find additional general objectives, Army doctrine should be reviewed. The above was written to provide an example of what is meant by the term general objectives.

Specific Requirements

The charter authorizing the AACCMS system is very vague. In addition, even though qualitative materiel requirements (QMR's) exist for individual system components, no QMR has been developed for the system. Therefore, a QMR must be developed for the system; then specific requirements developed from the general objectives.

Representative requirements for the high capacity subsystem follow:

1. Capacity per Army Area Signal Center

   Transmission - 600 channels composed of combinations of 96 channel groups and 48 channel groups

   Operations - 300 channels composed of combinations of 96 channel groups and various smaller groups (presently under dispute)

2. Security. Different levels of security are possible. Either of the following could be designated as the requirement.

a. Secure from operational center to operational center.

b. Secure from transmission center to transmission center.

c. Secure from subscriber to subscriber.

Note that the first decision is whether or not there should be security. The second question is whether both tactical and administrative messages should be secure.

3. Range: 30 miles. (According to present Army doctrine, Army area communications centers will be located 30 miles apart.)

4. Availability. There shall be a 90% probability that the equipment will be operational 90% of the time.

5. Information rate: 19.2 or 38.4 KBS. (A multiple of 75×2^n so that this system will interface with other communications systems.)

6. Validity of Information. An acceptable error rate for digital communications or a postdetection signal/noise ratio for analog communications must be specified.

A representative group of experts who are cognizant of the objectives and familiar with the state-of-the-art of communications must be gathered together to develop the exact requirements for the system.

Environment and Mission Mix

Environment

1. Either a colocated operations and transmission center or separate operations and transmission centers must be specified.

2. Geographic and climatic conditions. In what areas of the world will this equipment be used? Various areas must be chosen and probabilities assigned to each area. Only in this way can equipment be developed to operate in a representative environment. For example: Southeast Asia is hot and humid while Europe is colder and not as humid. Even though the same circuitry would be used, the equipment package depends on the environment.

Mission Mix

It must be determined what specific requirements are required for what percentage of the total time. For example:

x range)
y security) needed for H% of the time
z availability)
.
.
.

A range)
B security) needed for J% of the time
C availability)
.
.
.
etc.

Both the representative environment and the mission mix must be determined by a group of experts.

Criterion

A minimum level of effectiveness must be determined and a cost ceiling must be set.

Basic Criteria

1. After setting the effectiveness of all alternatives to the same level, the alternative with the least cost is chosen or vice versa (as long as the minimum level of effectiveness and the cost ceiling are not exceeded.)

2. Qualitative requirements must be set. Any special requirements such as time and personnel should be set. For example:

a. No more than a signal company should be needed to man each Army Area Signal Center.

b. The cancellation clauses on some component contracts should be considered.

3. A list of qualitative factors which may influence the decision must be developed.

In this section, the method of evaluating the alternatives which exceed the minimum value should be determined, e.g. if the range requirement = 30 miles, how valuable is 40 miles of range or 50 miles of range?

Again, a group of experts should be utilized.

<u>Alternatives</u>

1. The existing system should be used as a benchmark alternative against which the other alternatives are compared. This comparison is made in addition to the comparison against the criteria.

2. Primary alternatives:

a. Method of patching — audio; audio/video

b. Channel groupings — 4, 6, 8, 12, 48 or combinations

c. Various levels of security

d. Cable or radio down the hill

e. Levels of system control

The alternatives are all combinations of A, B, C, D & E.

Note the internal tradeoffs of the above factors, e.g. intrinsic availability depends upon both reliability and maintainability. The external tradeoffs should first be considered. After determining the best solution, then the internal considerations should be optimized.

<u>Assumptions and Reasons</u>

1. For all alternatives which utilize audio-video patching, it is

assumed that the Department of the Army will authorize procurement of new security devices. This assumption is made because the needed security devices do not presently exist.

2. The year when the equipment will be fielded must be estimated.

3. Enemy capability and the state-of-the-art of communications in the pertinent time frame must be estimated.

4. The extent of interface required with other systems such as MALLARD and TACSATCOM and other subsystems such as the low, medium and troposcatter subsystems must be estimated.

5. The number of area signal centers must be estimated.

6. All other data and model assumptions must also be stated.

Facts and Documentation

1. The existing force structure as defined by CDC will be in effect in the proper time frame, e.g. signal centers will be located 30 miles apart and a signal company will man each signal center.

2. Pulse code modulation will be used.

3. Any other technical and administrative facts and the source of this information must be stated.

Relevant Variables

Performance:

a. Channel groupings

b. Security

c. Information rate

d. Validity of information (error rate (patching (multiplexers

e. System control (complexity (personnel requirements

Availability:

Intrinsic Availability (reliability
(maintainability

Operational Availability

1. Attrition rate

   a. Failure rate (all vulnerabilities

   b. Survivability (mobility
   (silhouette

2. Repair time

   a. Failure rate

   b. Serviceability

   c. Logistic time

   d. Administrative time

The systematic use of expert judgment is necessary if variables which are representative of the requirements are to be chosen.

The last stages of the study process are covered in the methodology. I will conclude this example at this point by stressing that the validity and the source of the data must be stated and it must be recognized that model development and data generation affect each other. In the analytical effort, the importance of sensitivity analysis should again be stressed. The problem will indicate which variables should be changed and by how much.

In conclusion, figures 3, 4, 5 & 6 should again be reviewed.

REFERENCES AND BIBLIOGRAPHY

1. Russell L. Ackoff, Management Misinformation Systems, Management Science, Volume 14, No. 4, December 1967

2. Charles B. Barfoot, A Preliminary Cost-Effectiveness Handbook, DDC, Cameron Station, Alexandria, Virginia, 15 November 1963

3. Alfred Blumstein, The Choice of Analytical Techniques in Cost-Effectiveness Analysis, Institute of Defense Analyses, Arlington, Virginia, October 1965

4. Oliver Bryk, Models in Cost-Effectiveness Analysis: An Example, RAC, McLean, Virginia, June 1965

5. W. R. Gishong, Jr., et al., Cost-Effectiveness Analysis Applied to HF Communications Link, DDC, Cameron Station, Alexandria, Virginia, 4 January 1967

6. Peter C. Fishburn, Evaluation of Multiple-Criteria Alternatives Using Additive Utility Measures, RAC, McLean, Virginia, March 1966

7. George R. Fitzpatrick, et al., A Programming Model for Determining the Least-Cost Mix of Air and Sealift Forces for Rapid Deployment, RAC, McLean, Virginia, July 1966

8. Murray A. Geisler, et al., Man-Machine Simulation Experience, DDC, Cameron Station, Alexandria, Virginia, August 1965

9. J. Kagdis, M. R. Lackner, The Modeling of Management Control, DDC, Cameron Station, Alexandria, Virginia, 30 December 1963

10. Herbert W. Karr, et al., Simoptimization Research Phase I, DDC, Cameron Station, Alexandria, Virginia, 1 November 1965

11. Klaus Knoor, On the Cost-Effectiveness Approach to Military R&D: A Critique, Rand Corporation, Santa Monica, California, June 1966

12. Donald Macko, Hierarchial & Multilevel Systems, DDC, Cameron Station, Alexandria, Virginia, 11 October 1967

13. Gene A. Markel, A Concept for Modeling and Evaluating Information-Producing Systems, DDC, Cameron Station, Alexandria, Virginia, 28 January 1967

14. National Military Command System Support Center, Programs System Division, Program Design Approach, DDC, Cameron Station, Alexandria, Virginia, 31 January 1967

15. E. S. Quade, Military Analysis, Rand Corporation, Santa Monica, California, November 1965

16. E. S. Quade, Cost Effectiveness: Some Trends in Analysis, Rand Corporation, Santa Monica, California, March 1967

17. James R. Schlesinger, Organizational Structures & Planning, DDC, Cameron Station, Alexandria, Virginia, 25 February 1966

18. James R. Schlesinger, The Changing Environment for Systems Analysis, Rand Corporation, Santa Monica, California, December 1965

19. William H. Sutherland, A Primer of Cost Effectiveness, RAC, McLean, Virginia, April 1967

20. Eugene P. Visco, A Beginning to Cost-Effectiveness Analysis, RAC, McLean, Virginia, August 1963

21. Julius Widrewitz, Concepts Relative to System Effectiveness, DDC, Cameron Station, Alexandria, Virginia, June 1964

ELEMENTS OF THE FINAL REPORT & THE REPORT SUMMARY

1. General objectives
2. Specific requirements
3. Background information
4. The environment and mission mix
5. Facts
6. Assumptions
7. Reasons for assumptions
8. Decision criteria
9. Analytical techniques
10. Conditions under which these analytical techniques can be used
11. The alternatives
12. Results of the study effort
13. Recommendations (optional)
14. Documentation

FIGURE 1

STEPS IN GENERAL METHODOLOGY

1. Define the problem

   a. Define the objectives

   b. Turn general objectives into specific requirements

2. Define the environment and the mission mix

3. Develop the criteria to be used

4. Determine the alternatives

5. Determine the relevant variables, assumptions, and facts

6. Generate the data

7. Develop the model

8. Exercise the model

9. Analyze the results of the model

10. Present the results of the study effort

FIGURE 2

COST EFFECTIVENESS DETERMINANTS

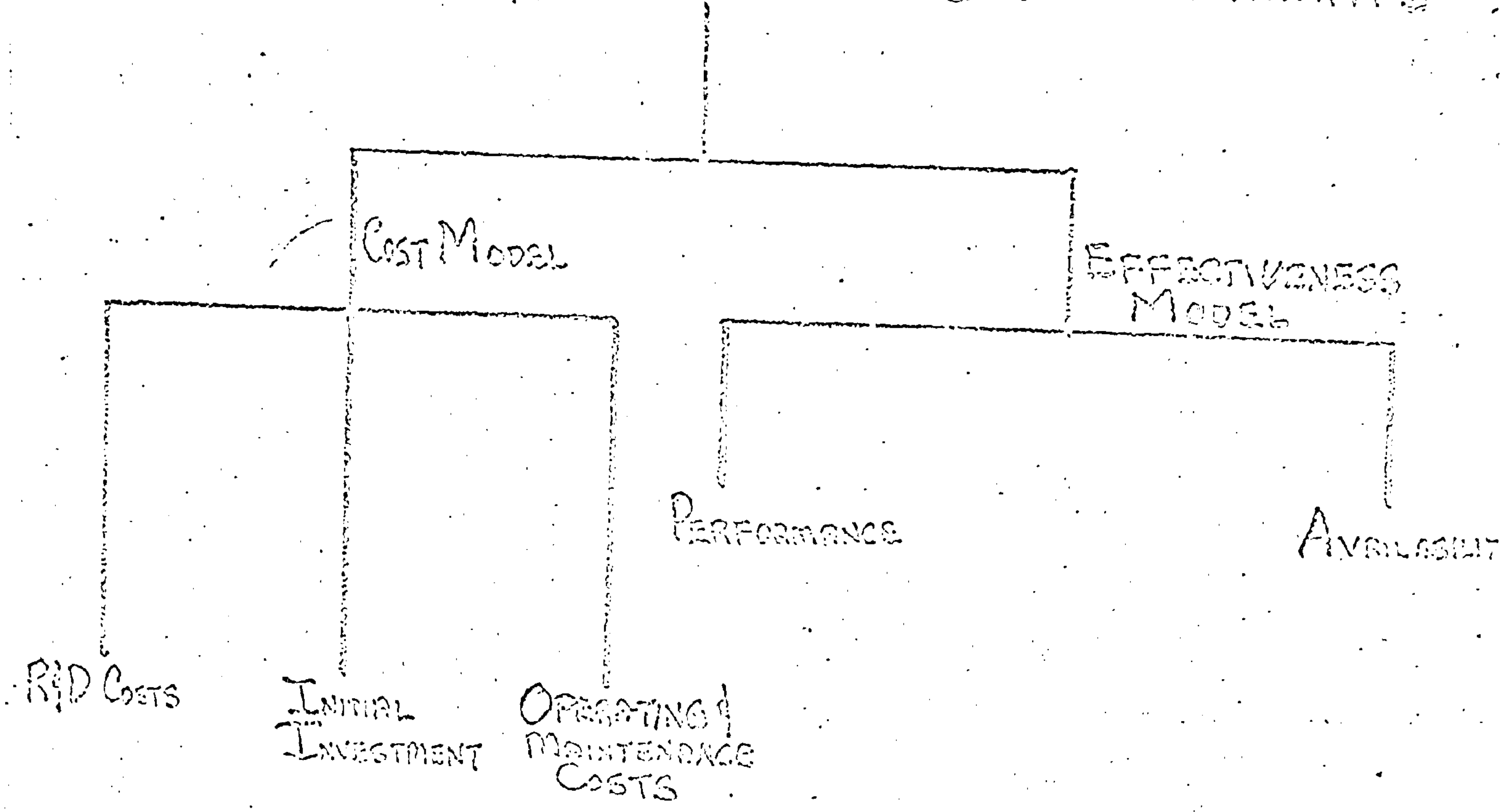
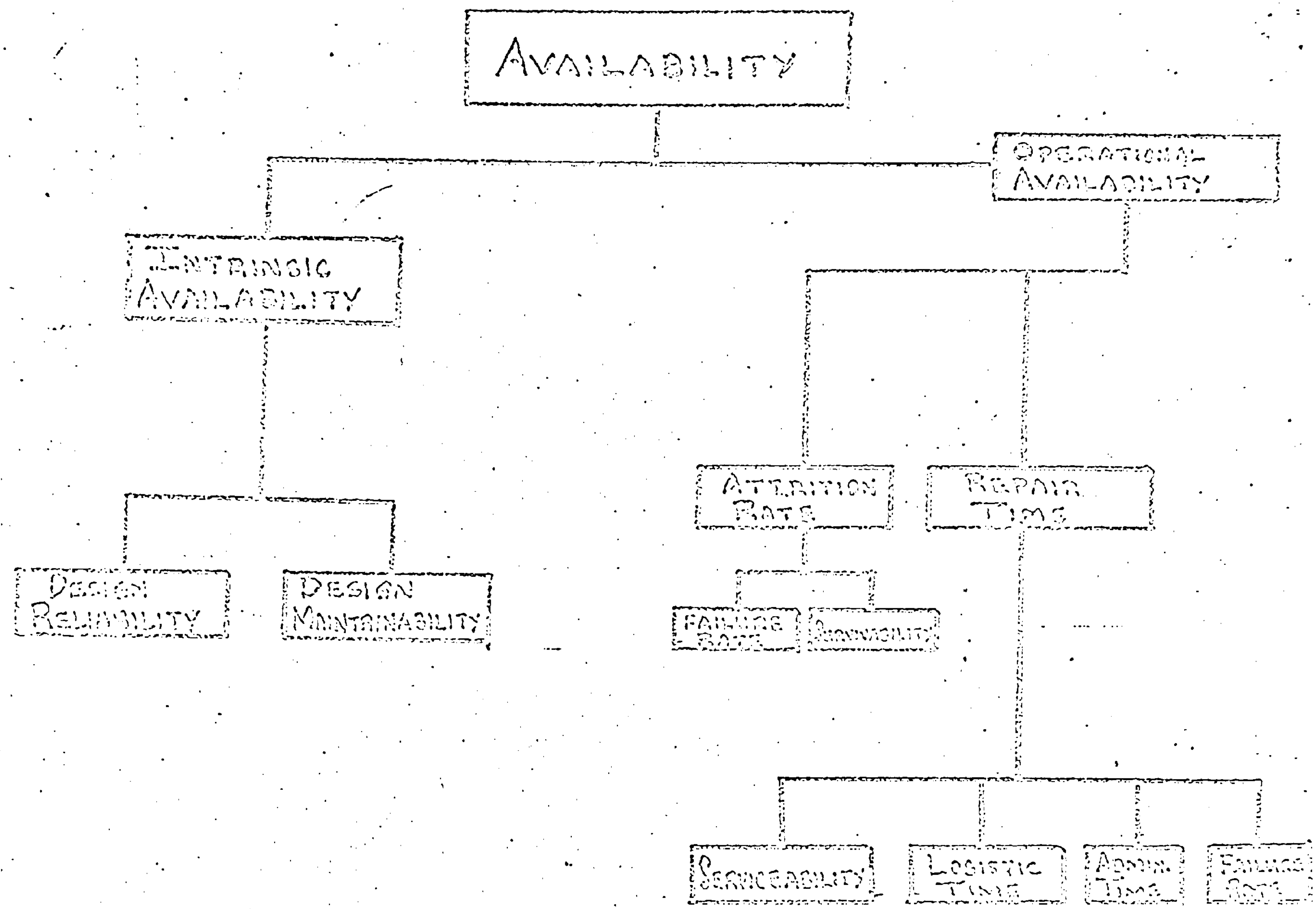


FIGURE 3



AVAILABILITY
OPERATIONAL AVAILABILITY
INTRINSIC AVAILABILITY
DESIGN RELIABILITY
DESIGN MAINTAINABILITY
ATTRITION RATE
REPAIR TIME
FAILURE RATE
SERVICEABILITY
LOGISTIC TIME

FIGURE 1

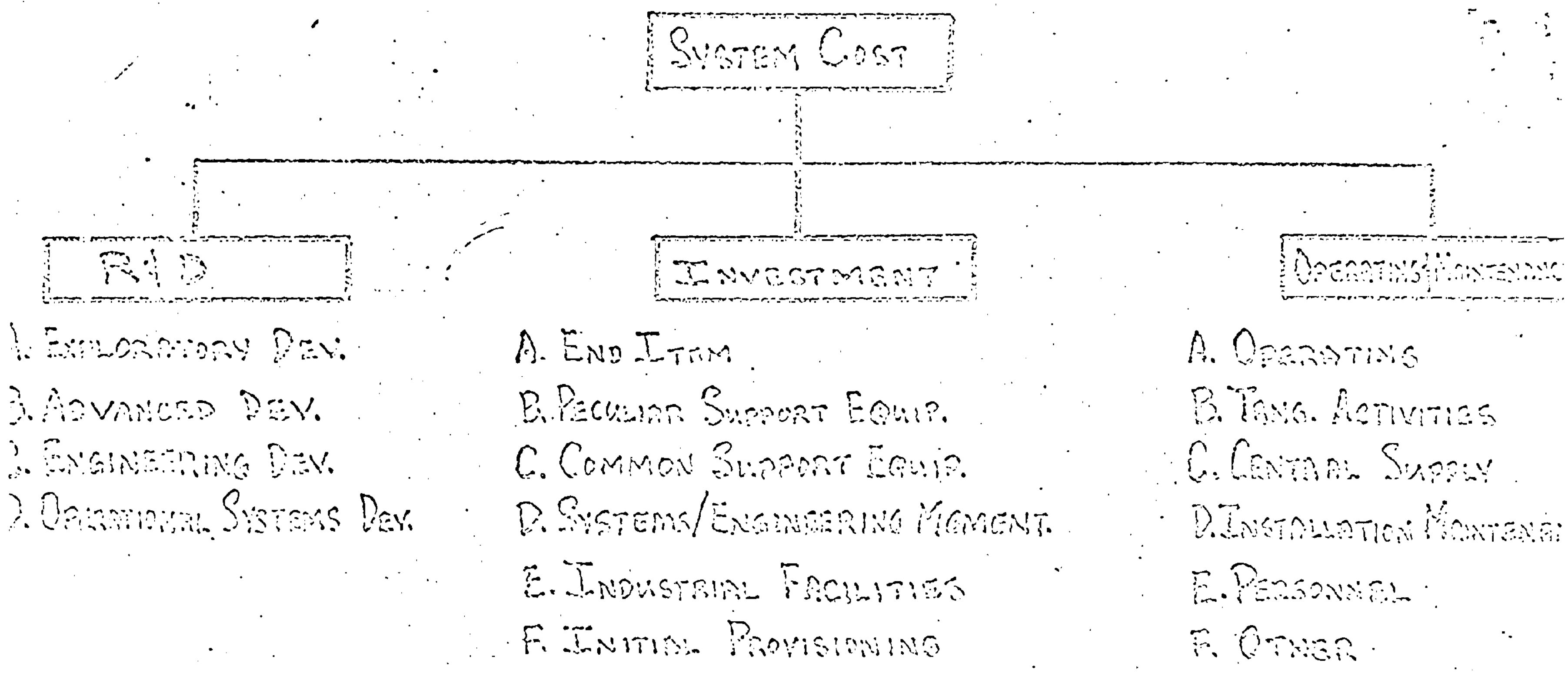

System Cost
R&D
Investment
Operating&Maintenance
1. Exploratory Dev.
3. Advanced Dev.
2. Engineering Dev.
2. Operational Systems Dev.
A. End Item
B. Peculiar Support Equip.
C. Common Support Equip.
D. Systems/Engineering Mgment.
E. Industrial Facilities
F. Initial Provisioning
A. Operating
B. Trng. Activities
C. Central Supply
D. Installation Maintenance
E. Personnel
F. Other

Figure 5