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# NAVY SYSTEMS PERFORMANCE EFFECTIVENESS MANUAL

NAVMAT P3941



May 1967

HEADQUARTERS, NAVAL MATERIAL COMMAND

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**NAVY  
SYSTEMS PERFORMANCE EFFECTIVENESS  
MANUAL**

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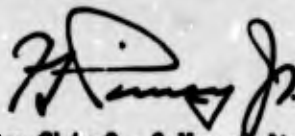
**HEADQUARTERS, NAVAL MATERIAL COMMAND**

## FOREWORD

The effective performance of Navy systems in Fleet use is essential to successful Naval operations. With the increasing complexity of Naval systems, the achievement of an acceptable level of performance effectiveness has become increasingly difficult. An extensive effort to develop the ways and means to improve performance effectiveness of Fleet systems was initiated about three years ago and useful techniques are now evolving from this continuing program.

The purpose of this manual is to describe the techniques developed under the System Performance Effectiveness (SPE) program. Navy program managers, project managers and project engineers are urged to use this manual as appropriate in the development of systems to assure the maximum feasible effectiveness. Distribution of this manual to industrial organizations as necessary and appropriate is authorized.

It is intended that this manual will be periodically revised and updated to meet the varied needs of groups within the Naval Material Command. In view of this fact, comments or recommendations concerning the content of this manual should be forwarded to the Chief of Naval Material at any time for consideration. This publication has been reviewed and approved in compliance with SECNAVINST 5600.16.



Deputy Chief of Naval Material for  
Development/Chief of Naval Development

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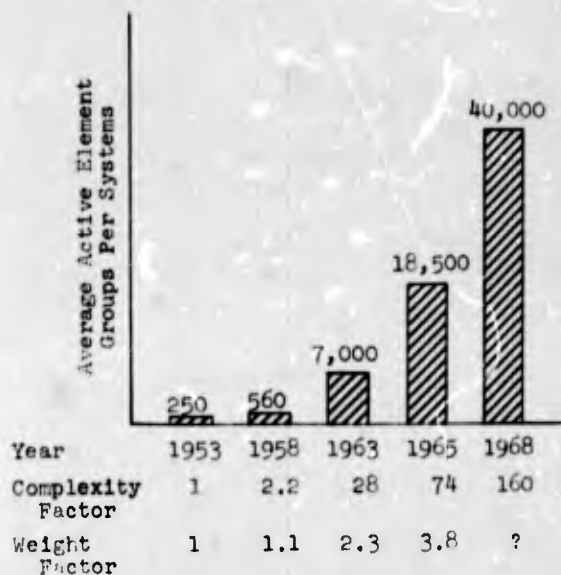
# AN INTRODUCTION TO SYSTEMS PERFORMANCE EFFECTIVENESS

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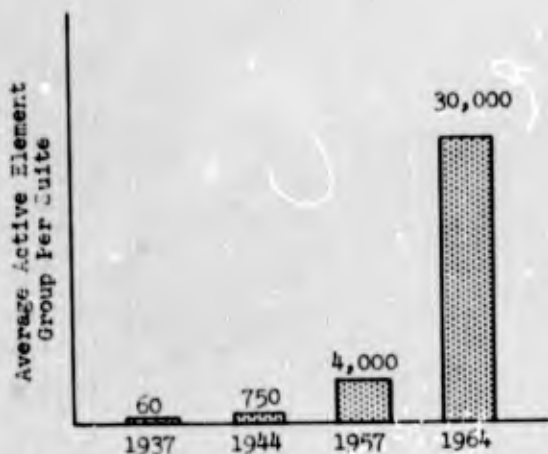
## 1.1 BACKGROUND

The effective performance of systems in the Fleet has always been an important factor in the successful accomplishment of the Navy's missions. In recent years, however, the tremendous growth in system complexity, due to more

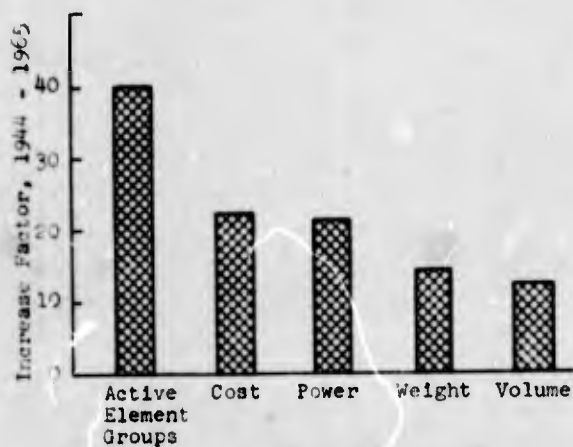
complex and demanding operational requirements and to rapidly advancing technology, has magnified the problem of obtaining effective performance from the new systems being delivered. For example, Figure 1-1 depicts the rapid growth of aircraft electronics, measured in terms of active element groups (diodes, transistors, and vacuum tubes, together with their associated passive components). In the 12 years from 1953 to 1965 the complexity of avionic systems increased by a factor of 74, although improvements in technology and techniques permitted the attainment of this complexity with a weight-increase factor of only 3.8. A large avionic system now planned for 1968 will be 160 times more complex than a 1953 avionic system.



**FIGURE 1-1**  
**COMPLEXITY INCREASE, AVIONICS SYSTEMS**



**FIGURE 1-2**  
**COMPLEXITY INCREASE, DESTROYER ELECTRONICS SUITS**



**FIGURE 1-3**  
**INCREASES IN CHARACTERISTICS OF DESTROYER ELECTRONIC SUITS**

A similar increase in complexity is evident in shipboard electronics, as illustrated in Figure 1-2. The figure shows the increase in system complexity--measured by the number of active element groups--in destroyer "electronics suits" over the period 1937 to 1964. Figure 1-3 relates this increase over the last twenty years to the corresponding increases in cost, power, weight, and volume. It is interesting to note that although complexity has increased by a factor of 40, technological progress has resulted in smaller increases in the other factors: a factor of 21 for cost, 20 for power, 14 for weight, and 12 for volume.

The complexity explosion has not been restricted to electronic systems, however. Threats are more complex, decision time is reduced, tactical decisions are more critical, available reaction time is reduced; all these 'squeeze' factors tend to require increased complexity in all the systems that combine to form a capability. The seemingly simple task of collecting feedback data, for example, has escalated to a point where the complex Naval Tactical Data System is required.

More complex systems in turn generate greater technical and operational interface problems. Consequently, the achievement of satisfactory systems performance effectiveness in the Fleet has challenged the ingenuity of the scientist, the engineer, and the technical manager, and has influenced trends in all the engineering and management disciplines.

Although special attention during the past several years to such areas critical to systems performance effectiveness as reliability, maintainability, performance, operability, quality, human factors, safety, and value has provided some measure of improvement in each area, further improvements in these techniques and the development of methods for efficiently integrating them into an effectiveness discipline are essential.

## 1.2 DEFINITION AND AIMS OF SYSTEMS PERFORMANCE EFFECTIVENESS

Systems performance effectiveness can be defined as, "A measure of the extent to which a system can be expected to complete its assigned mission within an established time frame under stated environmental conditions"\*. This definition has received general acceptance, and accurately establishes the scope and context of the discipline. Although the word "measure" is ambiguous--here assumed to imply a standard of comparison or judgement--the other terms clearly indicate that effects of mission environment and the time demands of system operation are an integral part of the systems performance effectiveness concept.

A meaningful concept, however, requires more than acceptable definitions. To provide an analysis capability, a structure or frame of reference is required for the principle elements of the concept; the nature of the interrelationships among the elements must be identified; and a set of techniques must be developed. Rules and procedures for applying the techniques are desirable.

The purpose of this manual is to present the concept and highlights of systems performance effectiveness and the steps required for implementation. In general, there is a growing volume of literature on systems effectiveness. Some important reference sources are cited at appropriate points in the manual.

Appendix A contains a description of the nature of the acquisition process--the process for which systems performance effectiveness serves as a measure and a tool. The role and utility of systems performance effectiveness modeling techniques during various phases of the acquisition process is also discussed in this appendix. Considerations relating to characteristics and attributes of analytic models, and discussions on the formulation of an appropriate analysis framework for systems performance effectiveness are presented in Appendix B.

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\* System Effectiveness, compiled by Systems Effectiveness Branch, Office of Naval Material, January 1965.

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# IMPLEMENTATION OF SYSTEMS PERFORMANCE EFFECTIVENESS

T W O

Several technical disciplines are involved in implementing a disciplined approach to achieving satisfactory systems performance effectiveness. In general they include technical documentation, data acquisition and reduction, system evaluation, analysis, and systems engineering.

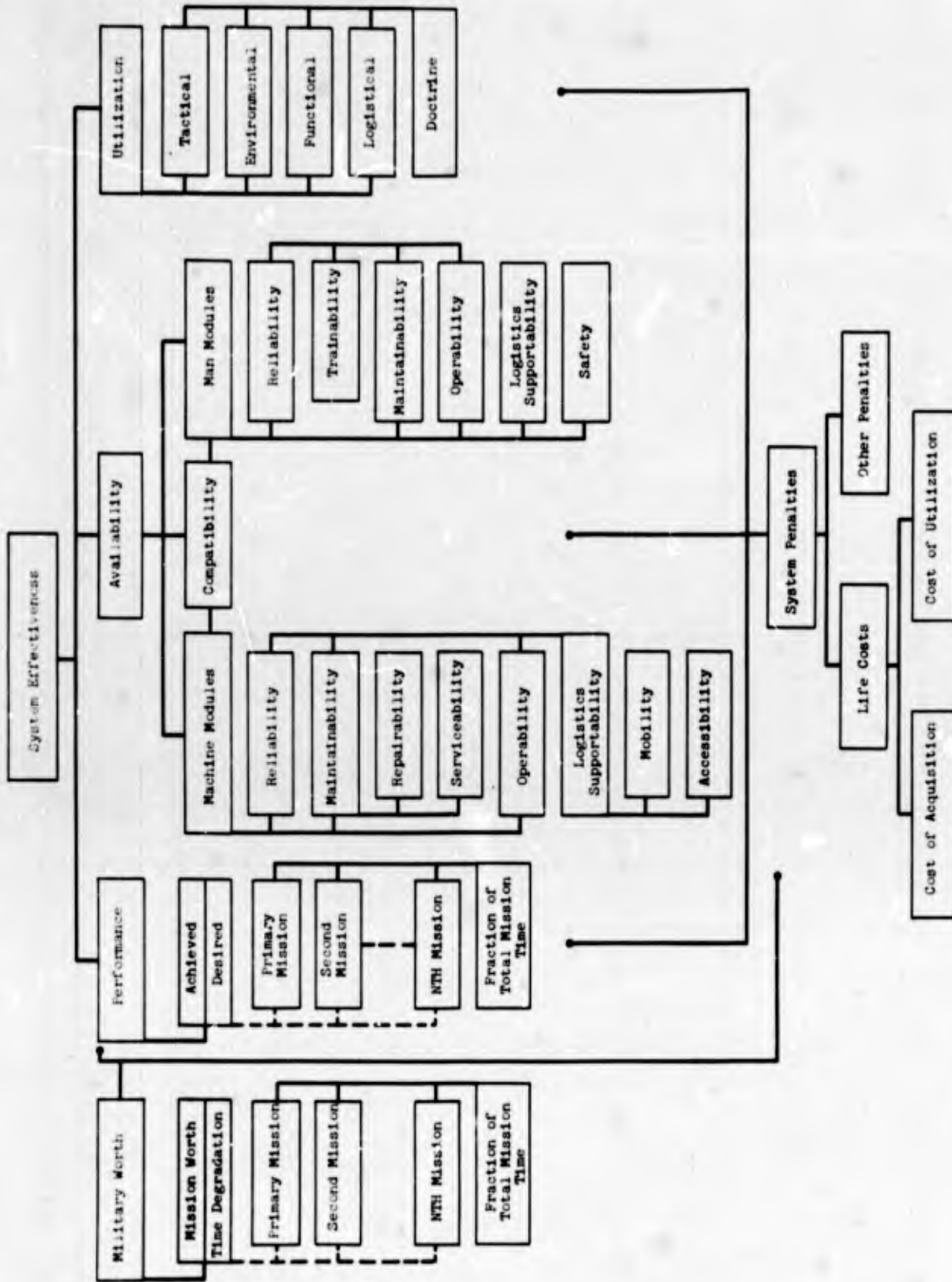
The natural tendency to seek a uniform, optimum criteria for system development actually may not be the best approach.\* The systems performance effectiveness model can take several forms; depending on the mission requirements, complexity, and development status of the system or equipment in question. The problem, then, can be stated as follows: How is effective systems engineering performed in a real-world environment? The techniques of systems performance effectiveness have evolved from the endeavors to answer this question.

## 2.1 SYSTEMS PERFORMANCE EFFECTIVENESS FACTORS

The use of an effectiveness framework permits a multiplicity of missions, functional considerations, and resource considerations to be analyzed within a common frame of reference. The elements from which the Navy's PAU effectiveness framework is synthesized is illustrated in Figure 2-1; the framework is described in detail in Appendix B. Figure 2-1 indicates the structural relationships

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\*"We cannot and should not expect ever to develop a complete set of numerical criteria to measure military effectiveness", from a McNamara-Hitch-Enthoven Anthology, A Modern Design for Defense Decision, p. 174, Industrial College of the Armed Forces, July 1966.



**FIGURE 2-1**  
**SYSTEM EFFECTIVENESS FACTORS**

among the PAU elements and the number of factors each contains. The inclusion of elements relating to military worth and system penalties allows the structure to be expanded to higher levels. For the purposes of a systems performance effectiveness analysis, Figure 2-1 basically serves as a checklist for identifying the particular set of factors of concern for a given problem; the significance of each factor will vary from problem to problem. The framework provides initial perspective and organizes information to be used in subsequent analysis.

If the system performance effectiveness discipline is to represent a useful solution to the project manager's problems, performance parameters that are specified in procurement contracts and the associated effectiveness factors must be related to system needs. Thus, the planning sequence must lead to a definition of critical performance parameters such that the requirements developed during Concept Formulation and Contract Definition are compatible with the technical system design and can be analyzed by a systems performance effectiveness model.

## 2.2 DEVELOPMENT OF EFFECTIVENESS CRITERIA

Conversion of the systems performance effectiveness structure into a practical technique is discussed in this section. Considerations and procedures leading to a formulation of effectiveness criteria and characteristics and appropriate levels of abstractions to be used in generating the criteria are discussed.

Figure 2-2 outlines the complexity of developing systems performance effectiveness criteria for a particular system. In threat analysis the project manager must consider that both weapon-system technology and threat capability are in a dynamic state.

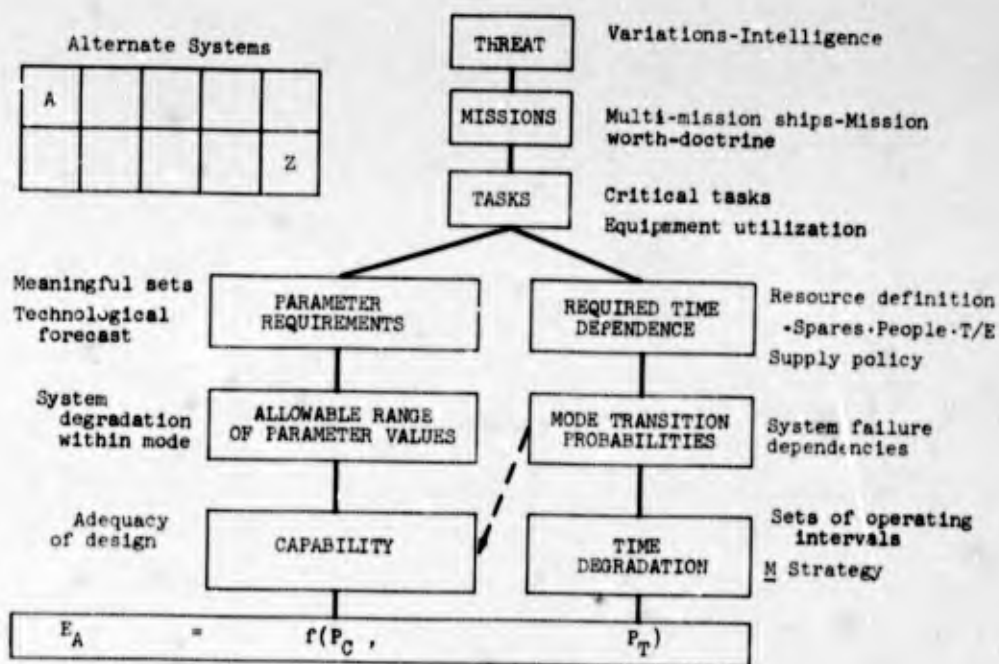


FIGURE 2-2  
CRITERIA DEVELOPMENT

Simulation is therefore a useful tool for modeling the problem. Inputs associated with the user play a significant role in the analysis, and special agencies such as the Center for Naval Analyses are employed to provide operations-research (OR) analyses. In mission analysis the manager must make subjective decisions to reduce the problem to manageable levels without causing loss of significance in the results. The tasks he selected for inclusion in the model must be those whose successful performance accurately represents mission success. Furthermore, some of the tasks should use most of the equipment in the weapon system or ship so that complete cost, personnel, and other data can be predicted.

It is important that the user, producer, and review agency all agree on the functional requirements specified in the task descriptions. These task descriptions form the basis of effectiveness analysis. Parameter requirements that allow successful performance of the task are generated: the parameters form the basis for analytic modeling to measure sensitivities to resources, failures, logistics, degradation, time demands, etc. Technological forecasting is used to provide inputs for measuring predicted performance parameters against task requirements. Thus, a mix of simulation and analytic modeling is used to generate and evaluate alternative systems and specific designs within systems. The bottom line of Figure 2-2 expresses analytically the performance capability ( $P_C$ ) and the detailed time-dependency of performance ( $P_T$ ).  $P_T$  adds a time dimension to performance and allows reliability, maintainability, availability, etc., to be treated as modifiers of performance. Effectiveness then can be analytically measured as a function of  $P_C$  and  $P_T$ . The effectiveness criteria ultimately selected must meet the following requirements:

- They must be quantitative.
- They must be sufficiently meaningful to the system designer and system analyst to permit their use as design and evaluation criteria for a given system.
- They must be sufficiently meaningful to the user and mission analyst to permit their value to be specified and interpreted in terms of the mission.

An important stage in the development of effectiveness criteria is the estimating of the resource constraints for each system. These are treated in three distinct but logical ways by the project manager.

First, he places absolute upper limits on the particular constraints that are specified. For example, Program A may have a two-year lead time as an absolute requirement; Program B may have certain size and weight constraints because of payload restrictions, etc. These limits are treated in a go/no-go sense: only systems which satisfy these requirements can be candidates.

Second, the constraints are treated as design parameters, and the impact of each is measured where possible as a change in  $f(P_C, P_T)$ . For example, employment of technicians in the higher skill brackets reduces downtime and therefore affects  $P_T$ ; provision of ample lead time reduces development risk, allows advanced technology to be employed, and therefore affects  $P_C$ .

Finally, the constraints are treated as quantitative attributes of the system in their own right, and specific values are estimated in terms of years and dollars for each design approach. Figure 2-3 gives an overview of the use of  $(P_C, P_T)$  effectiveness criteria used in developing resources as a function of the Maintenance Engineering Analysis in the Integrated Logistic Support Planning procedure.

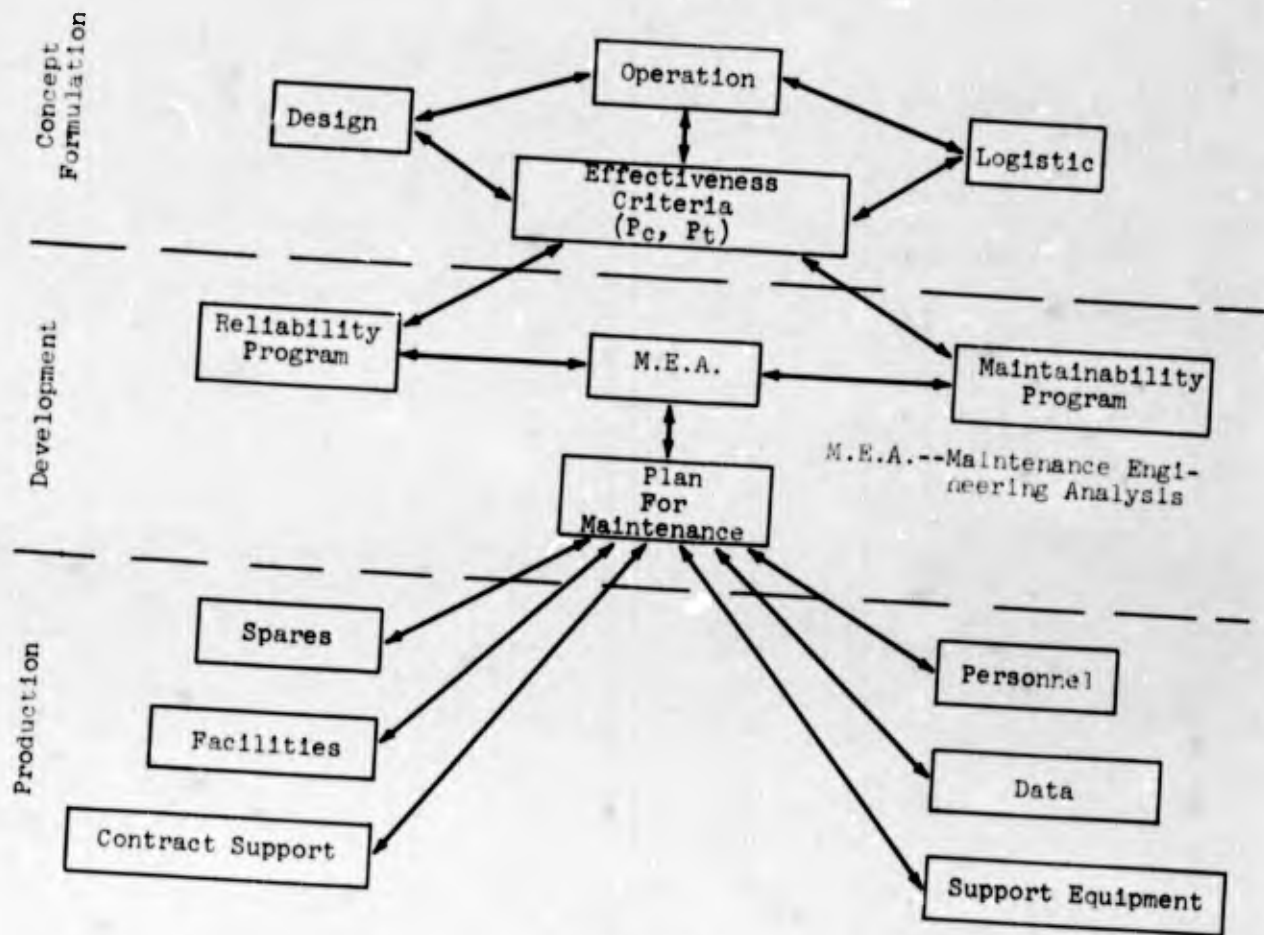


FIGURE 2-3  
EFFECTIVENESS CRITERIA ( $P_C, P_T$ ) FOR ILS\*

\*NAVMAT INST. 4000.20, Integrated Logistic Support Manning Procedures, August 1966.

The attempt to combine effectiveness measures into a single figure of merit poses a question currently receiving much attention: To what level should the elements be combined? For example, if a relative value can be placed on cost versus manpower skills, size, etc., it is possible to combine the elements into a single cost figure of merit. In general, however, a better approach is not to combine data beyond the point at which useful information is lost. For instance, the ability to study systems from the viewpoint of individually estimated resource constraints permits analysis to reflect change in emphasis at any point in time. Figure 2-4 is a symbolic presentation of system effectiveness for

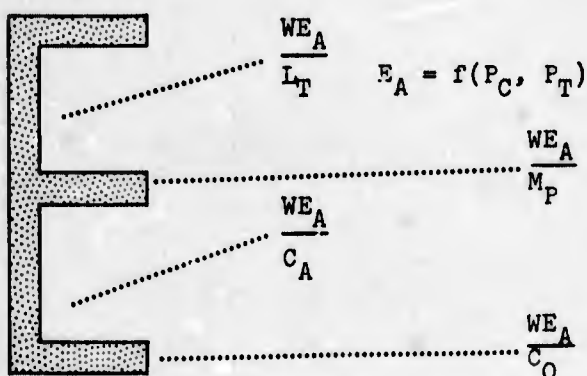


FIGURE 2-4

**ANALYTIC REPRESENTATION OF NAVY MODEL**

a large system: effectiveness appears in a series of relationships that show the lead time ( $L_T$ ), manpower ( $M_P$ ), acquisition cost ( $C_A$ ), ownership cost ( $C_O$ ), etc., as modifiers of an analytic representation of effectiveness. The factor  $W$ , a measure of mission worth, is introduced to illustrate that even this general form is subject to additional variation depending on whether the tasks of multitask missions are treated independently or in a combined form.

**2.3 TECHNICAL COMMUNICATIONS AND ANALYSIS**

An analogy can be drawn between the PAU framework and associated factors, and the  $P_C, P_T$  expression and its associated techniques. The techniques associated with the  $P_C, P_T$  expression, however encompass not only elements of analysis--such as prediction, assessment, trade-off, and optimization routines--but deal with methods that have been developed to help achieve adequate technical communications among all system-acquisition participants.

The tools needed for meaningful implementation of systems performance effectiveness, then, may be divided into two broad categories. Those in the first category provide the means of achieving adequate technical communications among all participants in a system's acquisition; those in the second category provide the means for performing systems performance effectiveness analysis. These elements have been the objects of comprehensive studies leading to the development of

techniques which, when used in combination, provide some of the basic ingredients of the practical systems performance effectiveness methodology known as Generalized Effectiveness Methodology (GEM). GEM, shown in schematic form in Figure 2-5, is basically an analytic method of addressing the systems performance effectiveness problem.\* The organization, logic, current status of development, and capabilities of GEM are described in Section 2.3.2. While GEM has been specifically designed for easy access and use, caution must be exercised in the use of its more specialized features. In some cases it may be necessary to verify that the problem to be solved and a particular GEM technique are compatible. It is recommended that only experienced personnel make this determination.\*\*

The two broad aspects of systems performance effectiveness--Technical Communications and Analysis--are discussed in Sections 2.3.1 and 2.3.2 respectively.

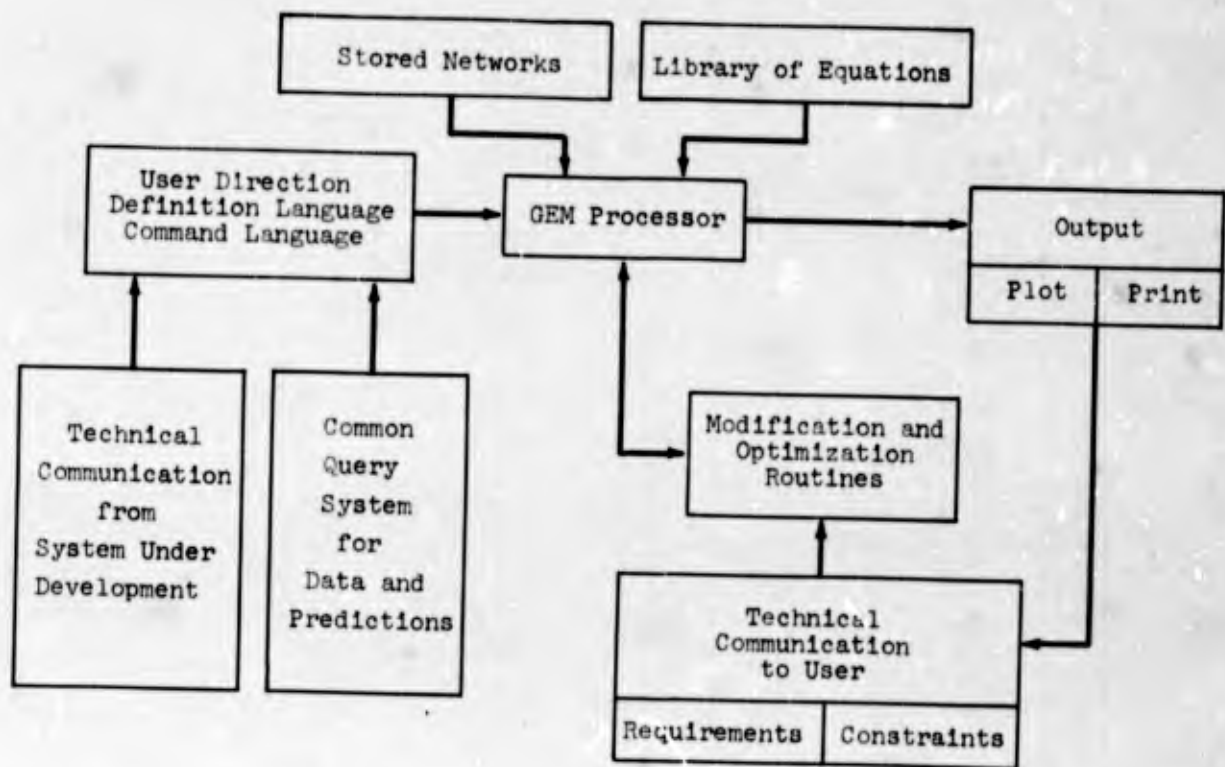


FIGURE 2-5  
GENERALIZED EFFECTIVENESS METHODOLOGY

\*U. S. Naval Applied Science Laboratory, System Effectiveness Branch, Brooklyn, New York 11251.

\*\*Some major components of GEM have been implemented on a CDC 6600 computer currently housed at the Courant Institute, New York.

### 2.3.1 Technical Communications

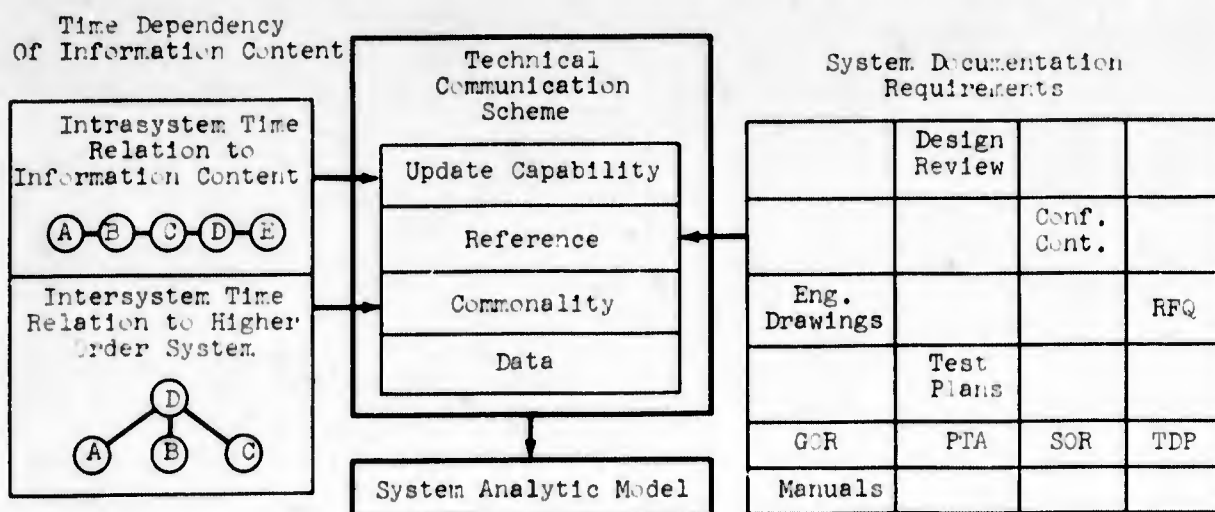
#### The Need

Technical communications probably form the most important requirement for a successful system-development program: criteria development emerges as primarily a dialogue between user and producer (see Appendix A). The establishment of formal concept-formulation and contract-definition outputs, whose content is specified in documents such as DOD Directive 3200.9, are based upon this need.

The diversity in the size and complexity of equipments purchased by the Navy requires a corresponding diversity in acquisition-management structures. In turn, technical communication must be geared to accommodate these diversities. Information-disclosure formats, therefore, must have sufficient commonality to permit structuring of various subsystem organizations for various management levels. Furthermore, since system acquisition is time dependent, technical communications must be geared to the development cycle and grow with the system. If communication is not adequate, high system complexity and the depth of the organization required to manage the program will result in allocation of goals and sub-optimization of goals without the benefit of the total systems approach. The communications requirement, therefore, must be specifically defined in terms of what is to be communicated and how it is to be communicated.

The requirement is illustrated in Figure 2-6 and may be summarized as follows:

- The ability to handle change (update capability)
- The ability to sort information (reference)
- The ability to integrate information at different levels and from different sources (commonality)
- The ability to provide critical inputs to the modeling effort (data)



**FIGURE 2-6**  
**TECHNICAL COMMUNICATION FOR SYSTEM DEVELOPMENT**

### A Method: The Design Disclosure Standard

A technical-communications scheme called the Design Disclosure Standard (DDS) is now under development by the Naval Ship Systems Command in response to the need described above. It provides for the transfer of design and development information from the function and hardware designers to the system designers, system analysts, mission analyst, and users. For this purpose it specifies the use of four information-transfer structures: detailed block diagrams, blocked schematics, blocked texts, and design outlines.

The detailed block diagrams and the blocked schematics define the boundaries off functional and hardware entities. The blocked-texts structure is an economical way of increasing management control and understanding; it presents theory, performance data, goals, etc., on a page facing the detailed block diagrams and blocked schematics. The information--in detail applicable to the particular level--is inserted appropriately in blocks which comprise a mirror image of the detailed block diagram and blocked schematics. Lastly, the design outline presents all the time and information dependencies at any level for all the hardware and functional entities in all operating modes.

Figure 2-7 is an overall summary of the acquisition adaptation of the DDS.

### 2.3.2 Analysis: The GEM Program

In this discussion, analysis is interpreted as a procedure for "providing the best possible estimate of the effects of selecting various courses of action"\*. While there are many reasonable courses of action within the framework of system performance effectiveness, the approach selected attempts should incorporate as much problem solving capability as is consistent with the current state of the art. Furthermore, it maintains a sufficiently flexible structure and logic in the model to allow for further expansion and introduction of additional capability when new techniques are developed and their impact on systems performance effectiveness has been ascertained. Figure 2-5 showed the logic and main components of the approach selected: the Generalized Effectiveness Methodology (GEM). The various elements depicted in the figure are discussed below.

#### User Directions

The user directions (1) provide the means for describing the system (Definition Language) and (2) direct modifications and evaluation of the model (Command Language).

Definition Language - The definition language is used to describe the system (network or block diagram). The system may contain combinations of series parallel configurations; shared elements or bridge networks may be

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\* Hitch, Decision Making for Defense, University of California Press, Los Angeles, 1965.

described by Boolean (logical) functions. The processor program\*, in association with the description, generates the system model and a computer program to evaluate the model.

Command Language - The command language is used to direct evaluation of a system in terms of any or all the variables that have been indicated in the system definition. Also provided in this language are commands which are used to modify the system definition, evaluate the resulting definition, and thereby generate alternatives to the original system.

By means of the commands--ADD, DELETE, REPLACE, ALTER, VARY--the user is able to add, delete, or replace items in the system configuration; alter any formula reference; and vary any single argument value or set of argument values throughout the system. The command "VARY" permits the user to generate automatically the information needed for a sensitivity analysis.

#### Technical Communications for Systems Under Development

The system that is being analyzed must be described in terms appropriate to the analysis to be performed (e.g., reliability analysis requires a reliability network of the system). Currently this represents a complex and tedious procedure involving the services of specialists from diverse disciplines. Use of a DDS description of the system and methods for extracting the information pertinent to the particular analysis under study, will simplify and expedite the task. The information extracted can then be coded, either manually or semi-automatically, into GEM language and made to represent the required input to the program.

#### Library of Equations

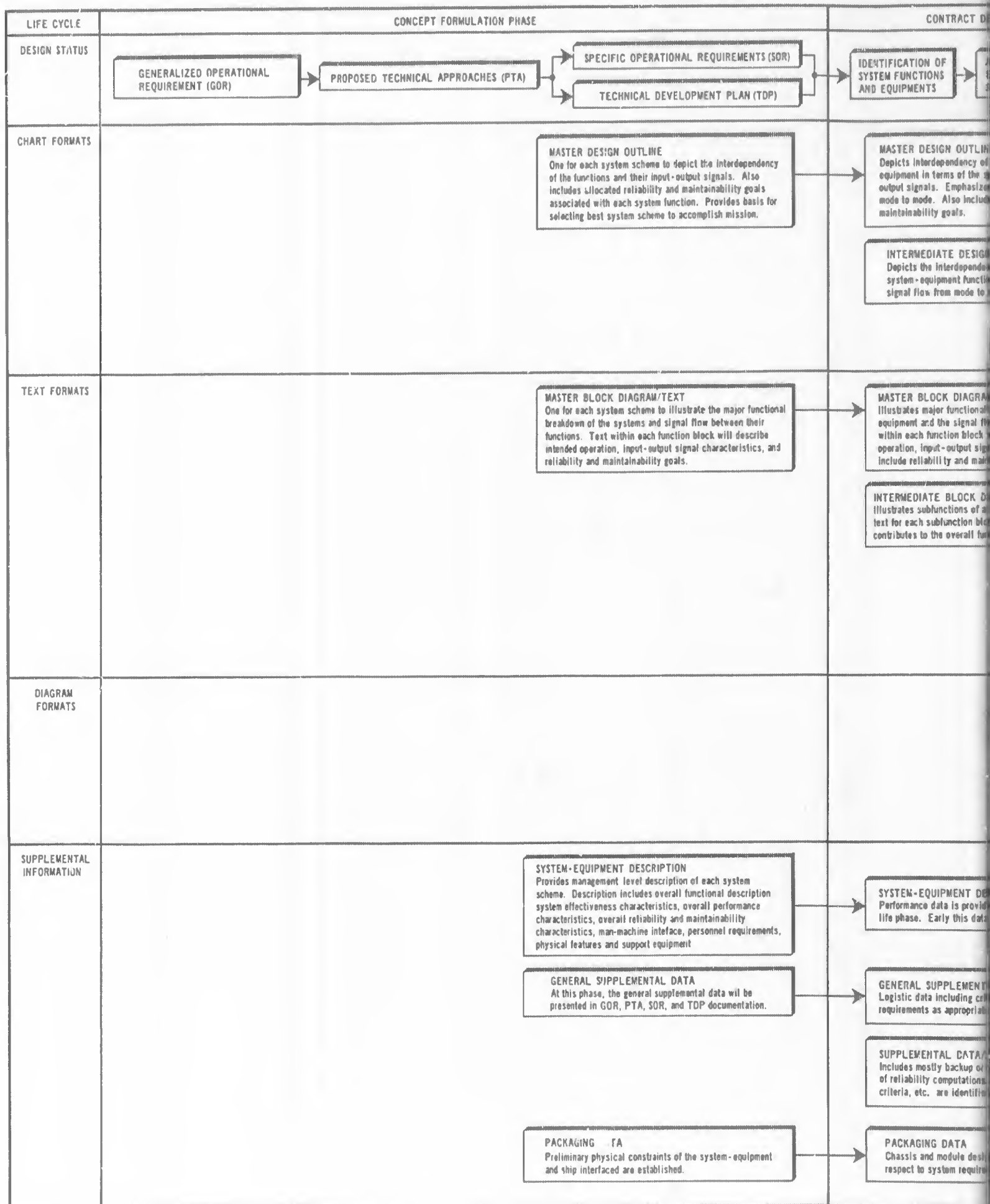
The library of equations (formula library) consists of a set of computer programs for evaluating the functions most frequently used when the variables pertinent to systems performance effectiveness are described.

The equations that are now available will enable the program manager to compute the following parameters:

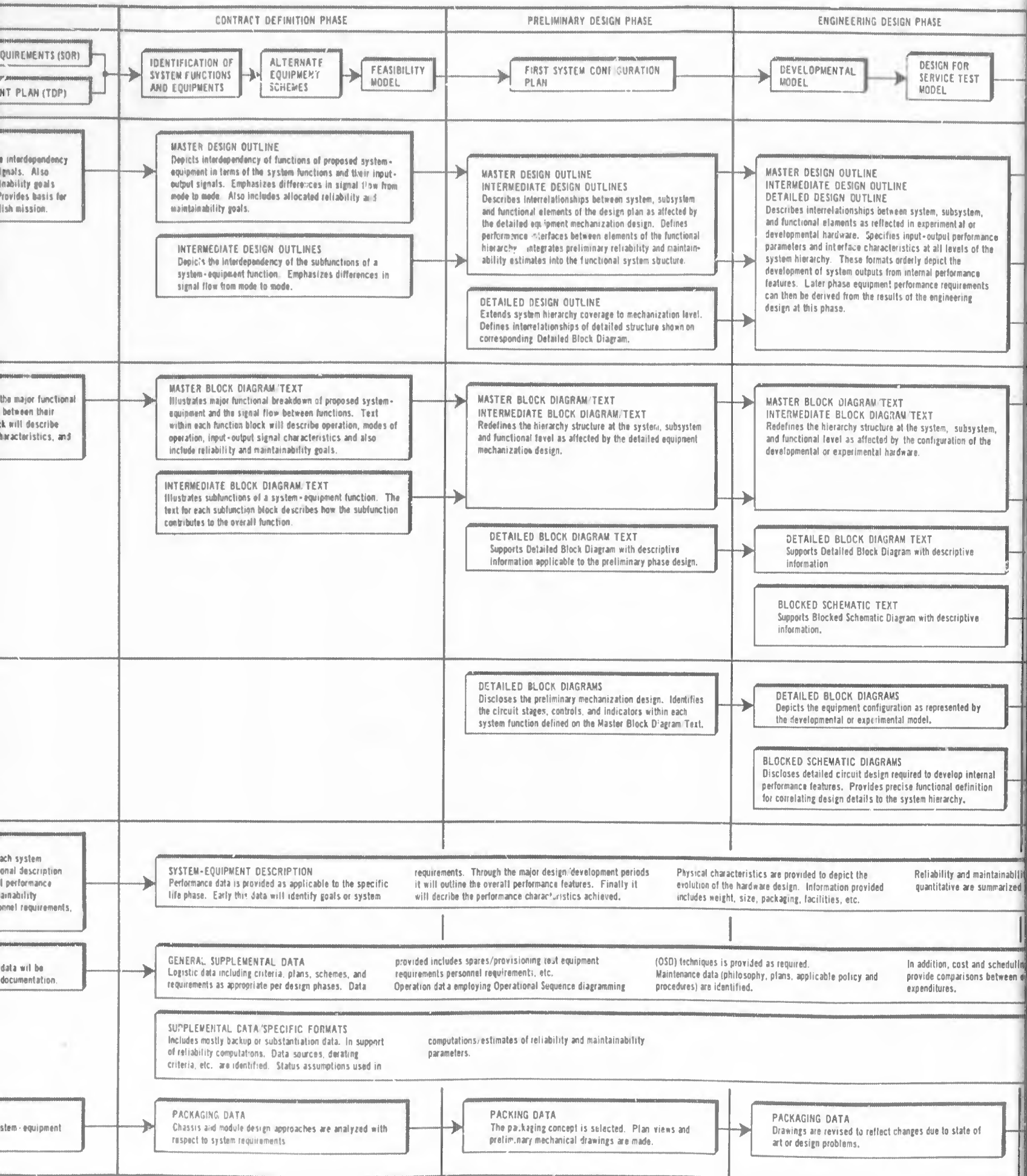
##### (1) Reliability Without Repair

- In general, the reliability-without-repair parameter can be calculated for exponential, Weibull, gamma, log-normal, and truncated normal failure distributions.
- For parallel-standby configurations, the reliability-without-repair parameter can be computed for exponential and Weibull failure distributions.
- The reliability-without-repair parameter can be computed for a system that comprises several identical elements arranged linearly or in a circular pattern (such as in a cylindrical sonar transducer).

\*See GEM Processor, page 18



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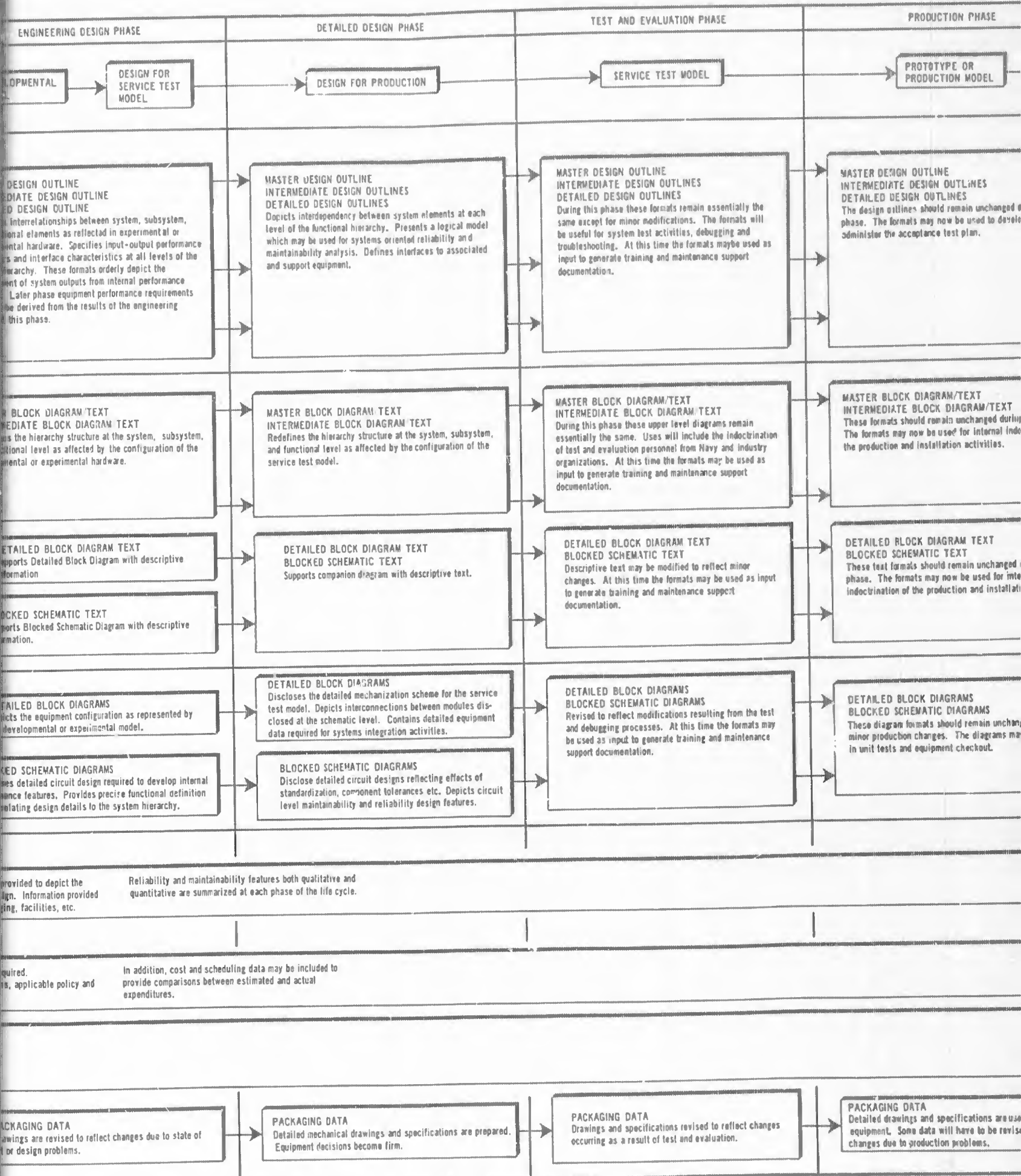


FIGURE 2-7 DE

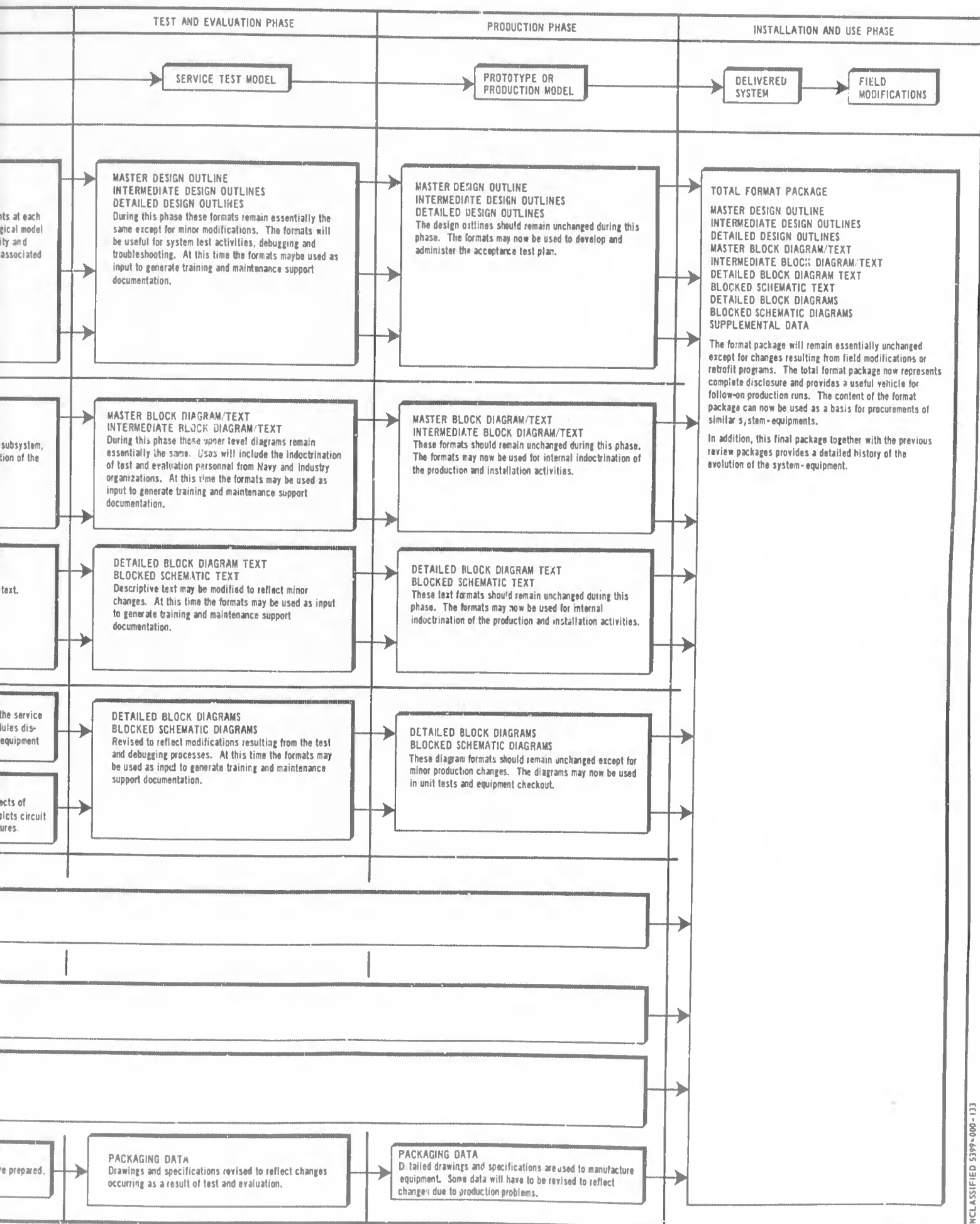


FIGURE 2-7 DESIGN DISCLOSURE STANDARD LIFE CYCLE ADAPTATION

(2) Reliability With Repair

The reliability-with-repair parameter can be computed for the following combinations of failure and repair distributions:

- Exponential failure - exponential repair
- Weibull failure - exponential repair
- Weibull failure - lognormal repair

Under the exponential-exponential condition, the program will also account for the following circumstances:

- Limited number of repairmen and a repair priority
- Limited number of spares assigned to specific equipments or pooled among equipments
- Combinations of the above.

In the cases of Weibull failure and Exponential or Lognormal repair, there are several equipment-configuration and maintenance-personnel restrictions imposed.

(3) Availability

The availability parameter can be computed for the following combinations of failure and repair distributions: [see restrictions under (2)]

- Exponential failure - exponential repair
- Weibull failure - exponential repair
- Weibull failure - lognormal repair

(4) Interval Reliability

Interval Reliability is a major component of the measure of effectiveness. It is defined as the probability that the system is in satisfactory condition at some time,  $t_1$ , (mission start) and does not fail during a time interval,  $t$ , following  $t_1$ . The interval reliability of a system can be calculated for conditions identical to those described under Reliability with Repair and Availability.

(5) Steady State Availability

The steady state availability of a system can be calculated for the combination of exponential failure and exponential repair only.

(6) Mission Availability

The mission availability of a system can be calculated for the combination of exponential failure and exponential repair only.

(7) Mean Life

The mean-life-without-repair parameter can be calculated for any combination of failure and repair distribution. The mean-life-with-repair parameter can be calculated only for the combination of exponential failure and exponential repair.

An update program for the equation library is also provided so that the user can incorporate new formulas into the library and delete ones no longer of interest. In addition to expanding the set of formulas related to systems performance effectiveness variables, new variables may be named and formulas related to these variables may be added. Thus, when quantitative relationships for variables such as maintainability are developed, they can be added to the equation library.

#### GEM Processor

The GEM processor is a computer program which generates the mathematical model(s) for the systems and its alternatives, and executes the coded program. If any item has been described by a Boolean formula, the processor will generate the appropriate probability formula for use in the model, and provide, as a separate output, the program by which the formula was calculated. The program may then be incorporated into the equation library.

#### Stored Networks

Any system description which has been processed by GEM can be stored and subsequently retrieved. The stored-networks library provides a fast-access record of all analyzed systems.

An update program for the stored-networks library is also provided to generate, update, and maintain a System Library free from error. The update program provides the user with the following capabilities:

- Rename a present system in the library (RENAME)
- Delete a present system from the library (ERASE)
- Add a new system to the library (COPY)
- Delete variable(s) from a present system in the library (EXCLUDE)
- Add a new variable(s) to a system in the library (INCLUDE)

#### Common Query System

Having established the system description and defined the appropriate measures, it is necessary to introduce data to obtain quantitative estimates. In the past decade, the availability of reasonable data has improved considerably. Methods of storing and retrieving information have advanced, and determined efforts have been made to collect accurate design and operational data. In addition to collecting performance, reliability, and maintainability information, data banks are now collecting information on items, such as costs and personnel. Another important data trend has been the collation of data from diverse sources into common pools. This is leading toward universal applicability of the data and the ability to compare alternative systems with equity. MIL-STD-217 is an example of such a data pool; it is frequently specified in contractual documents as the prime data source.

Details of all the data programs will not be specified in this manual since there is ample literature available. In addition, there is the Navy-wide Maintenance Data Collection System (MDCS), the NASA PRINCE (Parts Reliability Information Central) program, the Air Force's Reliability Central at Rome Air Development Center (RADC), and many industrial data banks including those of ARINC Research Corporation, Electronic Industries Association, Federal Electric, General Electric, Martin, Radio Corporation of America, etc.

To apply the needed data to GEM, a procedure is required to translate data requirements into queries in the languages of the existing data systems, and to provide methods for retrieving and forwarding the information. The procedure, designated the Common Query System, is still under development, but the basic work of defining the problem and establishing initial ground rules has been completed\*.

#### Optimization Routines

Optimization routines are programs which evaluate and select from alternatives the system which is considered best in terms of specified objectives and constraints. The art of optimization requires the matching of techniques and model forms. It appears that no single optimization technique will solve all problems.

There are several optimization programs that are not currently part of the GEM package, but which could be used when appropriate. (These techniques are highly specialized and should be used only after appropriate analysis by personnel familiar with their use.) Descriptions and details of currently available computer programs in the optimization area as well as in other systems performance effectiveness areas such as cost, maintainability, logistics, etc. are included in an interim report of Naval Applied Science Laboratory (NASL)\*\*. In addition, a Department of Defense report, Survey of Studies and Computer Programming Efforts for Reliability, Maintainability and Effectiveness, AD-622676, September 1965, provides additional information on these subjects.

#### Output to User

The normal output from the GEM processor presents the results of systems performance effectiveness calculations in a standardized printed format that can be understood and be useful to the program office. Another form of output presents calculated results graphically in the form of a plotted curve. The formats of the graphic outputs clearly indicate the behavior of a systems performance effectiveness variable as a function of time and provides information necessary for decision making.

\*C. W. Duke, et al, Reliability and Maintainability Data Source Guide, ARINC Research Corporation, Report Number 527-10-9-725, January, 1967.

\*\*A. C. Nelson, et al, Evaluation of Computer Programs for System Performance Effectiveness, Research Triangle Institute, October, 1966.

For example, the reliability parameter can be described by a curve that shows interval reliability under particular conditions. The user can then fit his mission profile to the curve and extract specific data necessary to calculate effectiveness as defined for his system. Figure 2-8 shows a typical curve. The program manager can specify particular intervals of interest and indicate the policy and initial conditions to be considered for each interval.

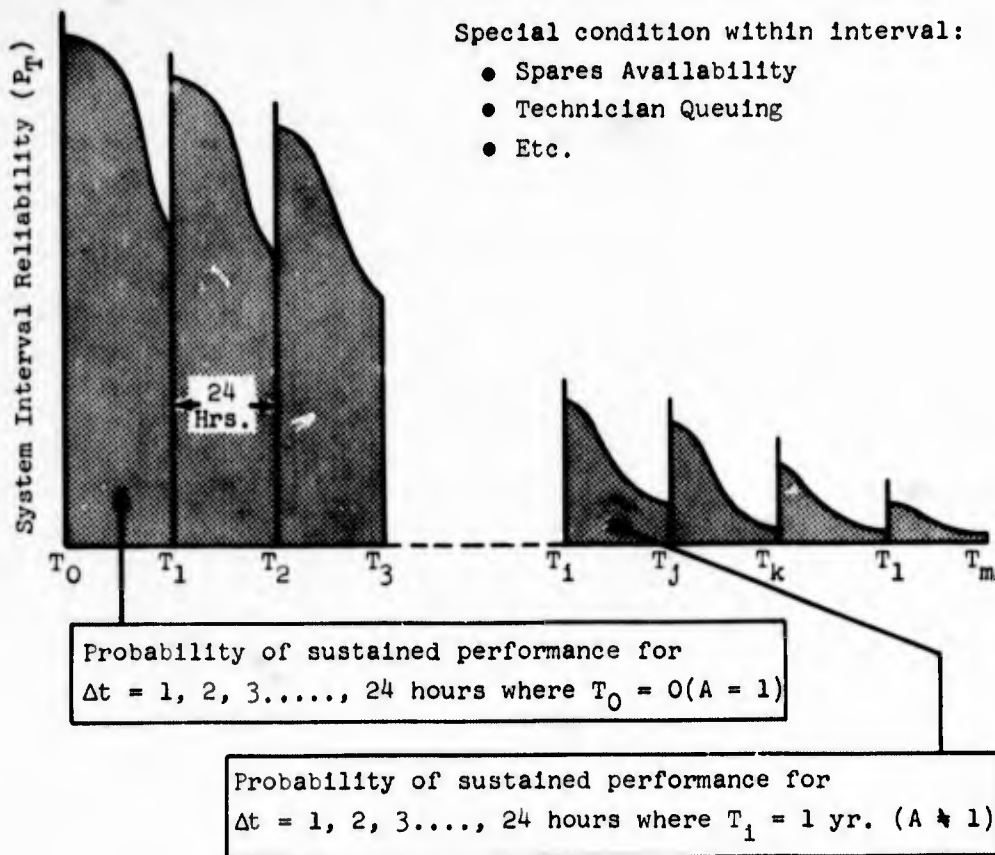


FIGURE 2-8  
PERFORMANCE TIME DEPENDENCIES

#### Summary of GEM

The techniques described in this section constitute the current capability of the Generalized Effectiveness Methodology (GEM). GEM will give project managers and design-and-development teams the capability to:

- Define system design and generate analytic models at various levels of complexity
- Specify changes in the design or analytic models and compute the effect of certain changes on system effectiveness and sensitivity
- Specify changes in specific design factors and compute the effect on other design factors.
- Store on tape complete details of analyzed systems and analytic models.

- Recall, update (expand, modify) and reevaluate any system or analytic model description stored in the system library
- Expand, at will, the set of computational equations stored in the equation library
- Request print-outs of trade-off curves illustrating the relationships between any combination of design factors, support-system characteristics, and systems performance effectiveness as a function of mission times

The following are specific advantages offered by GEM which result in cost savings:

- Separate programs need not be written to evaluate each specific design or analytic-model configuration.
- A system can be described directly in design-oriented language without the need for computer programming.
- Specific changes in design or analytic model can be made without extensive program revision or rewriting of programs.

## 2.4 PROBLEMS OF EFFECTIVENESS ANALYSIS

To emphasize the fact that systems performance effectiveness is an evolving discipline, several of its more important problems are described below.

### 2.4.1 Mission Analysis

Before analyzing a well-defined system, let alone developing a new one, it is necessary to know what the system is supposed to do, i.e., what mission(s) it must perform. It is relatively easy to establish performance envelopes for various subsystems that, in turn, enable the system to perform one task in one environment. The problem, however, becomes much more difficult if one must consider many tasks (e.g., defend other units, track a target without getting within vulnerable range, or attack a target) under many environments (calm sea, rough sea, or subzero weather).

One scheme often used is to develop figures of merit. This scheme weights the effectiveness figure for each task by the frequency with which the system may be called upon to perform each task. However, systems are developed to satisfy specific mission requirements that have been formulated on the basis of specific threats. The best system selected in accordance with such a scheme may not, therefore, be capable of responding to a specific threat, which of itself may be extremely serious but also may occur very often. Thus a system may not be satisfactory from the standpoint of a specific threat.

It is possible, however, to alter the method by weighting the threats by their severity and expected frequency of occurrence and thus design the system for some other weighted average of threats. However, this does not solve the

problem either, since optimizing an answer to any average threat does not optimize the answer to each threat. Perhaps the solution is to develop a procedure to optimize the effectiveness of answering a suitable, chosen, average threat that is subject to the achievement of a given effectiveness figure against each specific threat.

On one hand, it makes little sense to speak about the average effectiveness, the average environment, or the average threat. On the other hand, one cannot optimize with respect to a single mission unless the system has only one task to perform. Such a procedure, therefore, leads to all the difficulties associated with suboptimization, which results when one tries to optimize a system by optimizing each subsystem.

#### 2.4.2 Figure of Merit

Perhaps the difficulty associated with the formulation of an appropriate figure of merit can be best explained by a discussion of the analogous problem encountered with the parameters of a frequency distribution. For example, with a distribution a population can be characterized by its mean; but this does not indicate the variability about this mean. A measure of variability, called the standard deviation can also be added to this characterization.

Yet there will be other properties of the population that are not pictured by any of these characterizations, e.g., the lack of symmetry. If the 10th and 90th percentiles are also given, however, a more complete picture of the population begins to take shape. Nevertheless, no finite set of parameters can ever completely describe a real population or its frequency distribution.

Similarly, if one wants to know the system-effectiveness figures in all situations, something analogous to the frequency distribution is needed. Although there may be a figure of merit analogous to the mean in the frequency-distribution example, it can never give all the information about the system.

#### 2.4.3 Degraded Performance

At the component level, degradation can be thought of as measured by the number of failed components. At the system level, however, degraded performance may refer to the probability of performing the mission. For example, the system might be designed to be capable of performing its mission 95% of the time in one environment. In another environment, however, it may have only a 90% capability, and this may be considered degraded performance.

On the other hand, consider a radar-weapons system. Its design performance consists of being able to pick up an object at a certain distance, and then being able to assign appropriate weapons once the object has been correctly classified. A probability is associated with each subsystem performance, and hence also with the system's performance. If the probability associated with any subsystem is

reduced, however, the probability of system performance will also be reduced, and this, too, can be considered degraded performance.

Models of degraded performance can also be modified so that they are time-variant. There are, moreover, many other possible definitions of degraded performance. The one to use, of course, is the one that is useful in assessing a system. Much current work is misunderstood because one group does not use the same concept of system degradation as another.

#### 2.4.4 Modeling Problems

Two facets of modeling that have not been referred to previously warrant discussion, since they present significant problems. They concern assumptions and human factors.

##### Assumptions of Independence

The most significant assumption made in the modeling process--and especially in reliability and availability modeling--is that units comprising the system fail and are repaired independently of each other. In some cases such an assumption may cause only a slight distortion in simulating the functioning of the system. On the other hand such assumptions may so simplify the problem that its solution, for all practical purposes, becomes trivial.

##### Human Factors

Navy concern for human factors falls into three major areas: life support, personnel and training, and human engineering. It is the goal of life support to maintain and protect the human by controlling his environment; the goal of personnel and training is to select, train, and assign the human for operational tasks; and human engineering provides the design engineer with the basis for the most effective utilization of the human component of the system. In short the discipline of human factors in systems performance effectiveness requires that the man module be considered just as a hardware component: to be evaluated for cost, reliability, maintainability, availability, and operability. In addition, the man module must be considered for trainability.

To achieve these goals in a disciplined fashion certain procedures must be followed. These procedures are not one-time events to be accomplished early in the development phase, but rather are iterative procedures that must be reviewed and changed where necessary just as design is reviewed and changed during an equipment's development.

Appendix G of Guide for Human Factors and Personnel Resources Program, NAVMAT Instruction 4000.20, Integrated Logistic Support Planning Procedures, contains an outline of the procedures to be followed in a human factors program, and lists a series of reference documents that should be utilized in such a program.

The text of NAVMAT Instruction 4000.20 may give the impression that implementation of its procedures will lead to the solution of all Human Factors problems. Unfortunately, this is not so. GEM has stressed and improved the equipment aspects of the effectiveness model, and similar stress must now be put on the human segment of the model. As with hardware models, models for human behavior are no better than the data inserted into them. Therefore, data must be collected which has applicability to the broad range of tasks and characteristics of the man element of GEM.

It must be kept in mind that the goal of an equipment-development project is not solely that of producing a tangible piece of hardware, but that of producing hardware that can be used and maintained by men to its fullest design capability.

#### 2.4.5 Data Problems

The quality of the data used to perform calculations during the course of a systems performance effectiveness analysis will have a significant effect on the accuracy and utility of the results. Unfortunately, the mathematical model that describes a system configuration and behavior often is far more precise than the input data available. If effectiveness values--obtained from an exercise of the system model--are used as relative rather than absolute values, the quality of the data is usually found to be adequate. As a general rule, such values are satisfactory when the analysis is performed to obtain comparisons between alternate designs, or to determine the effect of changes on a specific configuration. If absolute values are required, however, extreme care must be used in selecting the input data, and caution should be observed in interpreting the results.

## SUMMARY AND IMPLEMENTATION ACTIONS

### T H R E E

The systems performance effectiveness discipline is a new science which still requires refinement by supporting research personnel. This manual has described an approach which allows program personnel to make immediate use of effectiveness analysis techniques, while improvements in data, system descriptions, forecasting, and computer techniques are introduced in an evolutionary manner.

Problems have been identified for the following purposes:

- To emphasize that this manual presents a perspective of the current state of the art, and not a closed systems performance effectiveness doctrine
- To indicate where further investigations are required (and in some instances are now being carried out) to refine and solidify the art of controlling and managing systems performance effectiveness

Program managers, project managers, and project engineers should take the following actions in implementing systems performance effectiveness:

- Determine the underlying system performance effectiveness factors associated with the system as discussed in Sections 2.1 and 2.2; consider the life cycle status and acquisition planning as described in Appendix A.

- Develop a systems performance effectiveness model for the system as discussed in Chapter 1 and Appendix B.
- Develop Integrated Logistic Support aspects of the system as shown in Figure 2-3.
- Assure the maximum use of technical communications in systems performance effectiveness activities as described in Section 2.3.
- Make use of Generalized Effectiveness Methodology (GEM) for systems performance effectiveness analysis as described in Section 2.3. (Consultation may be required for the application of GEM--discussion with the U. S. Naval Applied Science Laboratory is recommended.)

Careful performance of these actions will assure acquisition of a system whose systems performance effectiveness characteristics are consistent with its mission objectives.

APPENDIX A

THE RELATION OF SYSTEMS PERFORMANCE EFFECTIVENESS TECHNIQUES  
TO THE RDT&E PLANNING AND ACQUISITION PROCESS

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APPENDIX A

THE RELATION OF SYSTEMS PERFORMANCE EFFECTIVENESS TECHNIQUES  
TO THE RDT&E PLANNING AND ACQUISITION PROCESS

1. The Steps in System Acquisition

1.1 Introduction

The system-acquisition process begins with the generation of a General Operating Requirement that defines a need for capability in a functional Naval warfare area. It progresses through Concept Formulation, Contract Definition, Engineering or Operational Development, and Production, and it terminates with the procurement of the last replacement part for the system that has been developed and produced to fulfill the need.

DOD Directive 3200.9, 1 July 1956, "Initiation of Engineering and Operational System Development," implemented by SECNAV Instruction 3900.23, 20 August 1965, establishes the phases of Concept Formulation (CF) and Contract Definition (CD) as prerequisites to undertaking full Engineering Development of major projects. (These phases replace the Project Definition Phase of DOD Directive 3200.9, 26 February 1964.) As shown in Figure A-1, Concept Formulation, which comes under the general classification of Exploratory or Advanced Development, includes the RDT&E Planning Dialogue between user and producer. Successful completion of Concept Formulation leads to Contract Definition, the first step in Engineering Development. In CD, generally, two or more competitive contractors, working closely with the Navy, develop concept, design approach, trade-off solutions, management plans, schedule, and overall cost. Satisfactory completion of CD is followed by System Development, Production, Installation, and Operation.

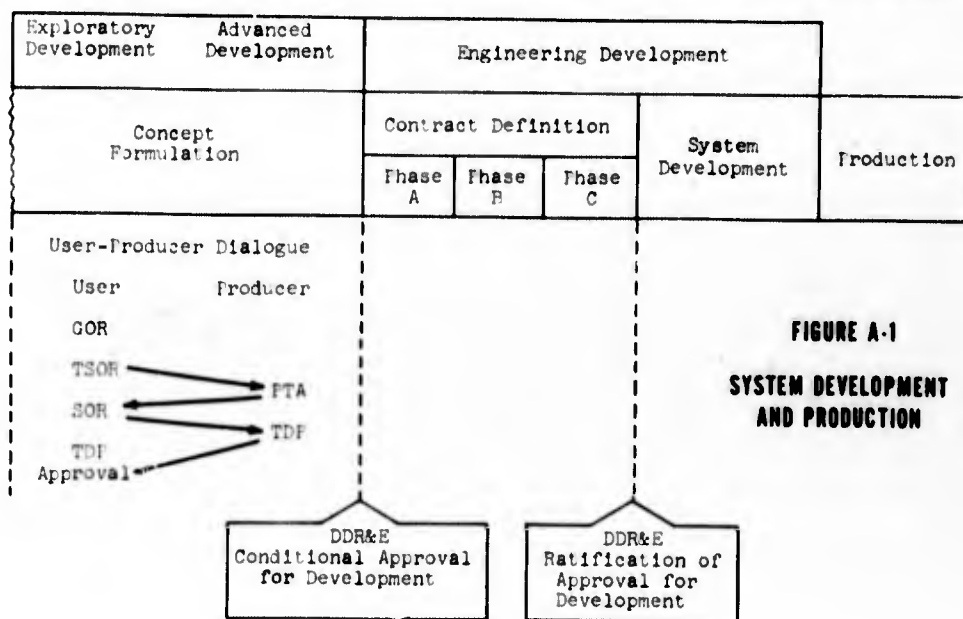
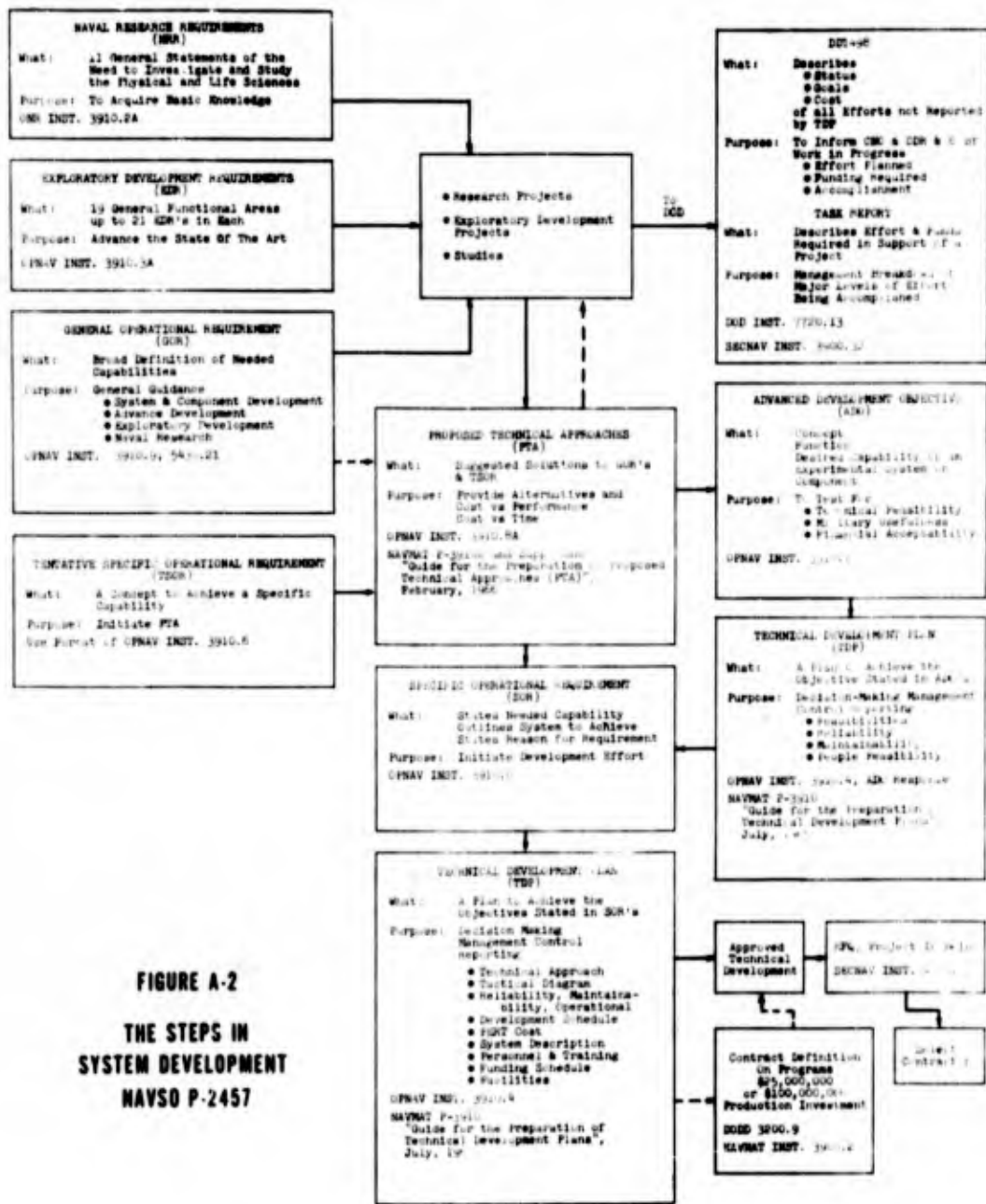


Figure A-2 lists the governing OPNAV, SECNAV, and OS directives for the steps in System Development, together with the Navy manuals developed to give guidance in the preparation of RDT&E planning documentation.

The actual system-acquisition process is not always as orderly as described above. Projects may leap-frog over Contract Definition, or they may retrogress from Engineering Development back to Advanced or Exploratory Development. Improvement programs for Fleet operational systems may appear to start life in the System Development Phase. It is important to realize, however, that although the formal acquisition-process terminology for the steps in system development may not always exist, these steps do take place in almost every program.



**FIGURE A-2**  
**THE STEPS IN**  
**SYSTEM DEVELOPMENT**  
**NAVSO P-2457**

## 1.2 The RDT&E Planning Dialogue

Concept Formulation begins with the RDT&E (Research, Development, Test, and Evaluation) Planning Dialogue, as defined in the 3910 series of OPNAV Instructions and the 3200 series of DOD Directives.

RDT&E planning within the Department of the Navy is characteristically conducted as a dialogue between the user interest and the producer interest. The user interest is represented by the Chief of Naval Operations and the Commandant of the Marine Corps, as spokesmen for the operation forces; and the producer interest is represented by the Chief of Naval Material speaking for the Naval Material Command. This user-producer relationship is more analogous to a relationship between cooperating independent business organizations than to traditional military relationships. Plans are the result of negotiation between the two interests. Through this process trade-offs are made that will result in the maximum military capability for the operating forces within the limits of the resources available.

The principal documents used in the user-producer dialogue are shown in Figure A-2 as the intermediate points in the flow diagram. At first glance the impression is that the user interest levies unilateral requirements--based on pure military necessity--on the producer interest. The actual process, however, involves a continuous interaction between operational requirements and their spokesman, and technical and scientific possibilities and their spokesman. It is a continuing, iterative interchange. New formal requirements for weapons hardware often have their genesis in new possibilities stemming from advancing knowledge and technology rather than from evolving military need or reassessment of old needs.

The Chief of Naval Operations is responsible for the preparation of a General Operational Requirement (GOR) for each functional warfare and support area. GOR's usually result from rather extensive long-range strategic and tactical studies. These documents state, in relatively broad but significant terms, the capabilities the Navy needs within each area. For guidance in making trade-offs in weapons design, the GOR should indicate the relative importance of the needed capabilities. In the past, performance capabilities have been adequately stated in the GOR's; however, other considerations that constitute system effectiveness--reliability, maintainability, etc.--have not always been given adequate attention. Systems performance effectiveness guidance must be provided for the entire system at the GOR stage, for here is where the thinking and planning for total system effectiveness begins.

In some cases the using agency issues a document concerning a narrower requirement, a Tentative Specific Operational Requirement (TSOR). This document states the need for achieving a particular operational capability and outlines the identifiable system characteristics necessary to fulfill the requirement. The TSOR

defines the desired performance goals and provides additional information needed to weigh alternatives and make the trade-offs required for an optimum system. The producer response to either the GOR or TSOR is a PTA (Proposed Technical Approach). PTA's are developed by the Naval Material Command to propose technically feasible alternative methods of accomplishing objectives set forth in a GOR or TSOR. The PTA should be fully responsive to the GOR or TSOR; therefore, the quality of the PTA depends directly on the quality of the GOR or TSOR. In addition to other mandatory requirements of the PTA, the governing OPNAV and DOD directives require that the PTA analyze and compare the operational effectiveness of the proposed alternate development approaches in terms of performance, reliability, operability, and maintainability, and clearly indicate the basis of the comparison, such as previous experiments, extrapolation, or conjecture.

The user reviews what is presented in the PTA and decides on one of the following alternatives:

1. Study the requirement further
2. Begin feasibility studies, further experimentation, or both
3. Begin an engineering or operational development effort
4. Terminate development effort in the specific area

If alternative 1 is chosen, the process returns to the strategic and tactical study phase and usually results in revisions to the GOR or TSOR. If alternative 2 is chosen, the user interests develop and promulgate an Advanced Development Objective (ADO). If alternative 3 is chosen, the user interests develop and promulgate a Specific Operational Requirement (SOR). In the case of alternative 4, all effort proposed in the PTA is terminated, which usually results in the action indicated for alternative 1, although on occasion the requirement will remain unmodified and essentially dormant until research effort develops new technical approaches to be incorporated in a superseding PTA.

If alternative 2 (ADO) or alternative 3 (SOR) is chosen, the producer prepares a Technical Development Plan (TDP). However, there is a distinct difference between a TDP that responds to an ADO and one that responds to an SOR. In the case of an ADO, the effort defined by the TDP is either directed toward demonstration of feasibility of approach(es) or experimentation at the breadboard level. This effort, if successful, leads to an SOR and a responding TDP.

The TDP responding to an SOR represents the essential completion of Concept Formulation (CF). The most important end product of CF, it comprises the complete and detailed plan for fulfilling the operational requirements of the user. The goal of a TDP is a balanced and integrated effort for optimizing operational effectiveness, total cost, and early availability.

With the development of the TDP, the necessary RDT&E Planning for the full-scale development phase of the system is established; if planning has been adequate, only a minimum of TDP updating will be required during the full-scale development phase.

2. Systems Performance Effectiveness and the System-Acquisition Process

2.1 The Discipline of Systems Performance Effectiveness Engineering

The role of systems performance effectiveness measures during the acquisition process is to enable the program manager to restructure the allocated goals to the system level, thereby allowing system decisions to be made by higher management. The allocation process is shown in Figure A-3, this ability adds a new dimension to management. Dynamic life cycle management and Integrated Logistics Support then become practical goals. The above structuring process is the systems performance effectiveness model, frequently discussed but too often not used until after the fact. Effectiveness models are described in Appendix B.

The following sections describe the application of the Systems Performance Effectiveness discipline to the System Acquisition process. It will be seen that systems performance effectiveness techniques are intended to aid the project manager in decision-making by presenting him with organized information, and to assist him in assigning task priorities by highlighting critical areas within his project. The discipline of Systems Performance Effectiveness is not a replacement for managerial judgment; rather, it supplies a basis for better and more timely decisions.

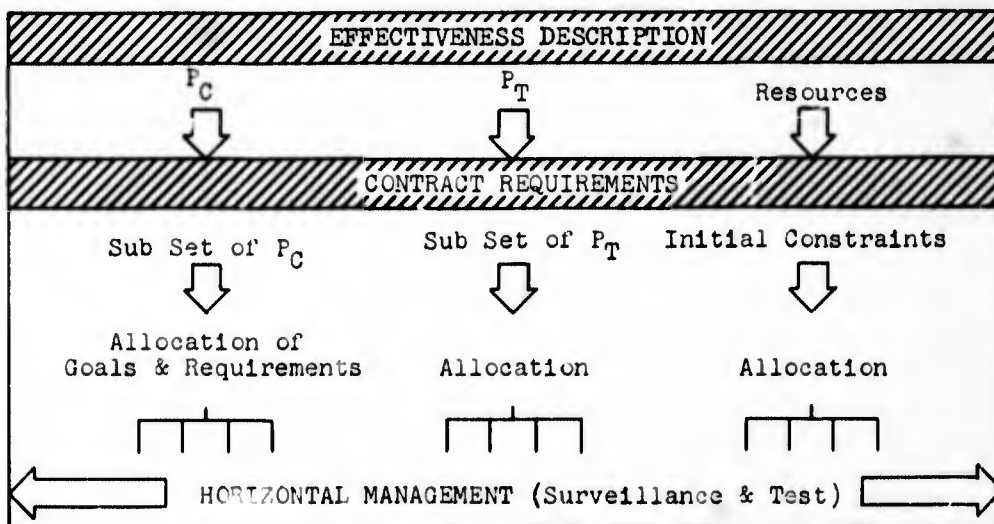


FIGURE A-3  
ALLOCATION PROCESS FOR LARGE SYSTEMS

## 2.2 Concept Formulation

"Concept Formulation describes the activities preceding a decision to carry out Engineering Development. These activities include accomplishment of comprehensive system studies and experimental hardware efforts under Exploratory and Advanced Development and are prerequisite to a decision to carry out Engineering Development."\*

The initiation of successful system development programs in the U. S. Navy is becoming increasingly difficult in view of the rapid technological changes to be coped with and the growth of required program documentation. Success depends upon many complex factors such as the following:

- Determination of threat profiles and their translation into system requirements and constraints
- Status and understanding of performance parameters, resource estimates, and error budgets of exploratory/advanced development projects
- Understanding of the activities required to satisfy the directives, requirements, and instructions of the DOD/Navy management system
- Availability of people, facilities, techniques, and data to support required activities

The integration of the above factors, and others, for the specific purpose of initiating an engineering development program is known as Concept Formulation. By definition then, Concept Formulation does not replace existing analyses or development activities but rather seeks to optimally integrate the outputs of such activities. Much work has to be done to provide efficient concept-formulation capability. A cohesive marriage of the design and analysis techniques is required. The results of concept-formulation studies will have a major impact upon the cost and responsiveness of future Naval systems.

### 2.2.1 Candidate-System Definition

In an ideal situation the process of Concept Formulation would progress from the recognition of a threat, to a number of approaches, to candidate concepts, and then to candidate systems. This idealized order is seldom realized. The lack of orderliness in the real-world evolution of the process can pose extreme problems if not approached in a disciplined manner.

Basic to a disciplined approach is the recognition that these stages of progress are simply differing degrees of precision in defining the system. In other words, the descriptive parameters become progressively better defined for each step in the evolution from approach to candidate system.

During the earlier stages, system functions are quite broadly defined. The gross functions are progressively structured as groups of subfunctions, each with

\*DOD Directive 3200.9 of 1 July 1965

its associated inputs and outputs. Structuring continues until the candidate system has been defined. This approach permits comparative evaluation of competing candidate systems, regardless of their relative stage of evolution.

### 2.2.2 Preferred-System Selection

The preferred-system selection process must take into account considerations other than systems performance effectiveness. Among these are cost-effectiveness and, in the Navy System Effectiveness/Cost-Effectiveness (SE/CE) method, what has been termed Defense Effectiveness.

The cost-effectiveness analysis is based on two cost estimates associated with each function in the systems performance effectiveness model. One estimate covers the cost of acquisition; the other, covers the cost of utilization or ownership. The former includes the RDT&E costs, prorated over the anticipated production quantity, as well as the production (and installation, when appropriate) cost per system. The latter includes all operating, maintenance, and support costs of the system. These costs can be used in connection with trade-off analyses, or they can be aggregated and associated with the systems performance effectiveness index and used as partial determinants in preferred-system selection. Other partial determinants useful in preferred-system selection are comparisons of systems performance effectiveness indexes with manpower and lead-time requirements.

The results of the effort to this point are formally organized as a PTA and submitted through appropriate channels to the Chief of Naval Operations for completion of Preferred System Selection.

The Defense Effectiveness methodology is based on the evaluation of military worth and its degradation as a function of the time taken to acquire the system. Neither of these factors is directly measurable. However, they can be assigned numeric judgment valuations by military experts. The military-worth index is an evaluation of the mission to be accomplished by the system. If all candidate systems accomplish identical missions, the military-worth valuation can be set at unity, and only the effect of time-to-acquire will be considered in the evaluation. On the other hand, if one or more of the candidate systems are capable of accomplishing additional missions or different combinations of missions, the indexes of military worth should reflect the differences as military judgment may deem appropriate. The net effect of the Defense Effectiveness methodology is to provide a military-judgment coefficient to assist in Preferred System Selection.

The actual selection is suggested by the candidate system with the highest index of Defense Effectiveness. However, this suggestion is not absolute. Modeling assists in the decision-making process and is not a substitute for managerial judgment. Indeed, judgment may result in a decision at this stage that more than one preferred system will enter Contract Definition.

The final action in the process of Preferred System Selection is taken by the Chief of Naval Operations. He expresses the decision through the issuance of an ADO or an SOR. If more than one Preferred System is indicated, an ADO is issued. (It should be noted that this is but one circumstance under which an ADO may be issued). If a single preferred system is indicated, an SOR is issued.

### 2.2.3 Approval to Enter Contract Definition

The preferred system(s) having been selected, one step remains prior to Contract Definition. To the project manager, this is one of the most critical steps, and his first major test as a manager. He must demonstrate that he has met all of the prerequisites\* to obtain SECDEF approval to enter into Contract Definition.

If not approached in a well-organized manner, this demonstration can be a time-consuming and frustrating exercise. However, the Navy SE/CE methodology, with its models (including the system model) provides the ordered approach and the demonstration vehicle. Using these models, the manager can define the preferred system(s) in terms of technical goals and criteria, trade-off evaluations, and priorities of effort, together with the associated confidence levels.

Application of the Navy SE/CE methodology throughout the Concept Formulation phase of the system's life cycle places the manager in an unambiguous position. If he can define his preferred system sufficiently well to exercise the models, it is probable that his system is soundly conceived and that the model completion in itself will demonstrate his meeting of the prerequisites for Contract Definition. On the other hand, inability to provide minimal input requirements for model analysis and/or to provide clear preferred-system definition is a strong indication that prerequisites have not been met.

Having successfully demonstrated accomplishment of prerequisites through Preferred System Definition, the manager uses the essential inputs to prepare the Request for Proposal (RFP) needed to cover the contracted effort.

### 2.3 Contract Definition

Contract Definition is a period of major concern to the project manager, although the burden of proving performance and responsiveness rests on the contractor (private industry or Government laboratory) who has been selected as a qualified participant essentially on the basis of proposals.

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\*OPNAV Publication 90 P-1, 11 June 1965.

In many respects the application of the Navy SE/CE methodology to Contract Definition parallels its application to Concept Formulation. There are, however, some significant differences. In time sequence, the application of the Navy SE/CE methodology under Concept Formulation, as discussed in Section 2.2, is applicable if the term "Contractor's Proposed System" is used in lieu of "Candidate System."

The preferred system(s) having been defined in the last step in Concept Formulation, a sensitivity analysis is performed with the effectiveness model. This analysis will indicate the limiting parameters and priorities for each element of the system model, which are expressed in terms of technical goals or requirements. The range of the permissive parameters, properly related to estimates of state-of-the-art capabilities, establishes the degree of criticality of the element.

The preferred-system(s) definition and the critical systems performance effectiveness parameters are incorporated into a Request for Proposal (RFP), which is transmitted to the contractor(s) as a guide for proposed approaches to Contract Definition. The preferred-system(s) definition provides for Phase A of Contract Definition, the equivalent of Candidate System Definition in Concept Formulation. In addition to guidance for the contractor(s), the definition of critical systems performance effectiveness parameters provides the criteria for evaluating contractor proposals under Phase A.

As with other aspects of the systems performance effectiveness discipline, the definition of critical systems performance effectiveness parameters is not static. The process of refinement started in Concept Formulation continues in Contract Definition. As a result of the analysis of proposals received under Phase A of Contract Definition, the preferred-system(s) definition is refined, and the critical parameters are better defined by the inputs received from the responses to the RFP. This sharpening becomes most important to the project manager during Phase C of Contract Definition.

The project manager exercises little control over the Contract Definition effort, which is largely in Phase B. However, progress reports under the contracts for Phase B do provide definition and validating data. As these data are received, reiterative exercise of the systems performance effectiveness model provides a significant measure of the progress being realized.

While the critical systems performance effectiveness parameters can be defined initially during the early phases of Concept Formulation, they reach their full definition during the latter stages of Phase B and during the analysis effort under Phase C of Contract Definition. They provide the essential framework for the decision to enter into Engineering Development.

The definition of these parameters at this point in the evolutionary cycle of a system must be sharpened to the point where the project manager can demonstrate the following within an 18-week period:

- The operational goals and technical goals are in agreement
- The technical, and hence operational, criteria can be met
- The financial and schedule factors are credible
- The development risks are acceptable
- A definitive contract can be entered into with the best-qualified contractor

To demonstrate the foregoing, not only must the parameters be clearly and concisely defined, but they must be quantitatively interrelated. This requires highly structured system models in terms of functional block diagrams with associated characteristics values (or, in some cases computer simulation models) and a completely structured SE/CE model with which to analyze and evaluate the system models. The former is an output of Phase B contractor efforts. The latter, however, is largely the result of the efforts of the project manager's staff.

The success or failure of Phase C will be determined by the degree of completeness of the model and the degree to which its structuring conforms to the real-world situation.

If the SE/CE model does approximate reality successfully, the parameters can be interrelated, and the exercise of the model for each of the competing systems produced by the CD contractors provides a framework for Source Selection and demonstrates the validity of entering into Engineering Development of the project, continuing with further definition or advanced development effort, or abandoning the project.

In addition to its use as a decision-making tool, the SE/CE model also serves another function during this period. The sharply defined Critical Effectiveness Parameters provide within the SE/CE model the checklist for completing the specification for the Engineering Development contract. This is particularly important in that one of the principal objectives of the Contract Definition process is to assure that a complete and unambiguous specification (definition) is developed for the Engineering Development effort.

#### 2.4 Engineering Development

Through the process of Contract Definition, the project manager has been establishing a frame of reference to define the system, its technical goals and criteria, and the measures by which its effectiveness in terms of its mission

life costs can be evaluated. Having established this frame of reference, he must now address himself to obtaining assurance of achieving an effective system.

The ultimate evaluation of the Engineering Development phase occurs during the test and evaluation of the developed system. If the simulated system model and systems performance effectiveness analytic model are valid and adequately defined, the system should meet its test and evaluation successfully, and the project manager will have been successful.

If the system is not satisfactory, the models have yet another function. The operational data accumulated during T&E should be inserted in the models. The models should then be exercised and the results analyzed to identify problem areas. These should then be recorded and made available to other project managers to assist them in avoiding similar errors. At the same time, a closed-loop management system should be implemented to correct the problems.

If the project is to be continued, whether or not the T&E is successful, the T&E data are inserted in the models to sharpen further the definition of technical goals and criteria and to validate the data for the production baseline and production specification. Here, again, the models serve to guide the effort and to assure the project manager that the baseline (specification) is complete and defined as sharply as the aggregate experience will permit. This is a necessary exercise, whether or not the R&D contractor is also the initial production contractor.

At this point, the project manager finds himself subjected to conflicting pressures. The extreme of one school of thought might insist that the design be frozen and production should proceed on essentially an exact-copy basis. The other extreme is to continue injecting all of the latest state-of-the-art improvements into production to ensure the maximum possible capabilities in the operating forces. There are too many factors external to the system itself to justify either of these positions.

However, two prerequisites to any decision are apparent. First, the project manager must have, with relative exactness, a complete definition of his system to serve as a baseline for a decision. Second, he must have a means for evaluating the relative impacts of the alternatives. The system model provides the former, and the analytic model provides the latter.

## 2.5 Production

When the system has passed the test and evaluation phase and has been approved for service use, the project manager must produce the system and introduce it into the operational forces. In the past, this transition from Research and Development to Production has meant turning the project over to a new team, all too frequently involving a great deal of learning for the new team, time losses, and a loss of experience and data.

Two factors could provide safeguards against these traditional difficulties. The first, the project-manager concept, includes provisions for keeping the management team intact. The same management team that was responsible for R&D should have some continuing responsibility for production. Thus the time loss involved in learning the system is eliminated. The second, use of both simulation and analytic models, provides a methodology for experience and data retention. The formal structuring and recording of data provide a high degree of assurance that both experience and data will be retained.

When viewed objectively, the demands placed on the project manager for changes in configuration, cost, and schedule differ little in concept from the trade-off analyses performed during concept formulation or the preferred-system selection performed during Contract Definition. Indeed, the same tools, the simulation model and the analytic model, can be used. Actually, since the model values have now been more sharply defined through the introduction of experimental data during Contract Definition, Engineering Development, and Test and Evaluation, the validity of the models as decision-making aids should be very high.

## 2.6 Fleet Operations

The most critical aspect of systems performance effectiveness during Fleet operations is the retrieval of data for future programs. One significant attempt to provide a portion of these data from operating units is the MDCS (Maintenance Data Collection System) carried out under the Navy 3M Program\*. Attempts are being made to structure the MDCS data formats in such a way that the requisite inputs to the systems performance effectiveness methodology can be obtained from the MDCS without additional reporting requirements. If these efforts are successful, the project manager will have available to him the main body of experimental data, which can then be introduced into the models.

These data are needed for two principal reasons:

- (1) They provide the real-life validating information on all of the project manager's past decisions. Through this validation effort he can determine the adequacy of weighting and other judgment factors that were applied during the preceding phases. An added return is the recording and sharing of these evaluations with project managers for other systems under development or for superseding systems. In this application of the systems performance effectiveness methodology, the Navy can receive substantial benefits in experience retention.
- (2) These data can also be used to establish a decision baseline for determining the need for so-called product improvements in operating

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\*OPNAVINST 4700.16B

systems, and for evaluating proposed changes. Costly changes and changes of questionable return may result from use of inadequate or incomplete data.

In the operational phase, as in the preceding phases, the discipline of the systems performance effectiveness methodology guards against making decisions on the basis of inadequate, incomplete, or unrelated data--principally through the visibility that the modeling techniques give to the ramifications of the variances in data inputs. While the systems performance effectiveness methodology is by no means a panacea and certainly not a substitute for sound judgment, it does provide a structured discipline that substantially increases the probability that the project manager will have as inputs to his deliberations all the factors necessary to assure that he makes the right decisions.

APPENDIX B  
CONSIDERATIONS FOR SYSTEMS PERFORMANCE  
EFFECTIVENESS MODELS

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EFFECTIVENESS MODELS

1. Analytic Models for Effectiveness Evaluation

Any meaningful application of the systems performance effectiveness concept to a particular project requires a quantitative methodology to evaluate the effectiveness of a proposed or actual system in terms of selected measures, requirements, and decision criteria. Until this is done, the concept of systems performance effectiveness for a project has little use--except perhaps as a rallying point for arguments about the advantages of System X over System Y. The need for a systems performance effectiveness evaluation methodology begins at the inception of the system life cycle and continues through the succeeding design, development, production, test, and operational phases. Despite the obvious differences in the depth of the analysis applicable to these phases, the need for a quantitative methodology applies throughout.

Evaluation methodologies for systems performance effectiveness characteristics can be broadly characterized in terms of two approaches: the empirical and the analytic.

An empirical methodology is one devoted to data collection and evaluation of existing systems. Thus it is possible to evaluate systems performance effectiveness by means of performance observations of systems in the field. While this approach is undoubtedly the most accurate, it is feasible only for systems or projects that are very far advanced in their life cycles.

An analytic methodology, on the other hand, is one that derives its results by inference, and uses a set of assumptions and procedures as a framework to compute an effectiveness description of the system in question. This descriptive system framework is called an analytic model, and the description of system "X" in these terms is called the analytic model of system "X".

Purely empirical or purely analytic methodologies are, of course, not very useful. The former yields highly authoritative data too late to be useful, while the latter yields answers unsupported by facts. In practice, a balance is sought. This balance will normally change during the life cycle of a system. As data about the behavior of the system become more available, the analytic model gradually merges into an empirical model; as the data become more available and as confidence in their value increases, statistical sample data supplant the assumptions.

Analytic models, moreover, usually remain useful even with regard to the empirical data obtained from system samples taken during acceptance tests. Also, these data often require interpretation simply because it is impractical to conduct tests that are sufficiently elaborate to yield statistically significant effectiveness data directly.

The need for analytic models to predict systems performance effectiveness thus emerges from the need to evaluate the effectiveness before the system has been at sea for many years. Since this manual is primarily concerned with systems performance effectiveness in its entire context, the following discussion considers the analytic models--with the understanding that empirical methods will always be required to provide inputs for the analysis.

## 2. Characteristics of an Effectiveness Model

There are certain general characteristics that any mathematical model should have in order to be a useful tool to predict effectiveness. Despite the fact that some of the points discussed below seem almost obvious in retrospect, a substantial number of existing models do not seem to possess these characteristics. Hence, the following discussion appears warranted:

### (1) Independence from Design Assumptions

If the concept of effectiveness is to be applied as a technical management tool, there is a demand that the effectiveness-analysis technique, and consequently the analytic model, be capable of evaluating alternative (or modified) system designs with respect to a fixed set of mission models and variables. To whatever extent the analytic model presupposes system design configurations or characteristics, the model is not able to evaluate alternate designs that are not within these constraints, and hence it may not provide a basis for comparison or optimization. For example, if the analytic model is built in terms of a given system-design configuration, other design configurations may be inequitably treated if subjected to the same analysis.

### (2) Usefulness Throughout the System Life Cycle

The analytic model should be one that can be used throughout the system life cycle. In the early stages of the cycle, relatively few data are available on the statistical or performance capability of the system, and a substantial number of assumptions must be made to permit the analysis. As the life cycle progresses through design, development, test, and implementation, additional design and sample test data ordinarily become available. The analytic model, therefore, should be designed to accommodate these changes in inputs, and yield successive systems performance effectiveness predictions throughout the life cycle, with increased confidence in the results.

(3) Realism in the Analytic Assumptions

The physical and mathematical assumptions upon which the model is founded must be realistic with respect to the expected characteristics of the mission and system operations. There is a great temptation to construct analytic models based more on mathematical elegance than on realism.

(4) Tractability of the Evaluation

For the model to be usable, it must give numerical answers when exercised. This implies the following:

- The model must be quantitative even in the face of limited data
- It must be amenable to computation.

Clearly, this model characteristic must be traded off against the characteristic of realism. The art of modeling consists, in large measure, of establishing this balance.

3. Selecting an Effectiveness Model

There appear to be three fundamental classes of considerations that enter into the selection of an appropriate effectiveness model: the outputs required for system management and optimization, the nature of the systems to be analyzed, and the mission characteristics to be employed.

3.1 Output Considerations

The definitions of the variables, requirements, and decision criteria influence the selection of an appropriate effectiveness model. The following questions are typical of those which must be answered:

- Can the system-oriented performance variables be identified with specific hardware, or are they more closely tied to overall system behavior, including software?
- Was an iterative methodology employed to establish the requirements and decision criteria? (The requirements on the model themselves could change during the iterative procedure, and these changes must be incorporated.)
- Is there one principal performance variable that corresponds to one principal system function, or is the system called upon to do many things?
- Will the utility and trade-off data permit the results of effectiveness analysis to be expressed in terms of discrete quantities, or will probability distributions be required to describe systems performance effectiveness adequately?
- Are the variables binary (success/failure) or multivalued?

### 3.2 System Considerations

System considerations concerning the choice of an effectiveness model have their greatest effect on the statistical and logical assumptions that underlie the model. In a given system, it may be uniquely possible to identify subsystems with their corresponding functions, and in such a case the effectiveness evaluation is simplified. On the other hand, if interaction of subsystem functions is expected, particularly with degraded modes of operation, the model must incorporate this flexibility of interaction. Additionally, the analytic model often incorporates assumptions concerning the statistical behavior of the system. These assumptions may or may not be valid for the system in question, and they may or may not be consistent with the available data. Finally, the scope and complexity of the system must be considered. The delicate balance between tractability and realism discussed above must be resolved in terms of anticipated system size (size being expressed in such terms as the number of components).

### 3.3 Mission Considerations

In addition to mission effects, described under the heading Output Considerations above, a series of representative mission profiles also must be examined as part of the model-selection process.

The results of the studies discussed elsewhere in this report are closely involved in this examination. For example, is the system operating in a steady-state environment, or are the missions short compared with other statistical time parameters? In the former case (e.g., a long cruising mission), an equilibrium or steady-state model may be employed. In the latter case, a mission-sensitive model is required in whole or in part.

Again, is the mission function carried out over a time segment (e.g., a hunter-killer exercise), or is a point mission involved (e.g., weapon launch)? Are there one or several critical mission segments? Do the requirements and decision criteria for systems performance effectiveness change with mission mode? Do the reliability and maintainability characteristics of the subsystems change as a function of a mission segment?

The answers to such questions will help shape the assumptions that are incorporated in the analytic model.

## 4. Analytic Frameworks for Effectiveness Models

The development of a model that satisfies the conditions cited in the preceding section is at best, a complicated task. However, even under the assumption that such a model is realizable, its range of application without some types of modification would be restricted. This is due to the nature of the requirements, diverse operating conditions, and use factors that generally are an integral part of military systems. To help solve this problem, an approach that uses a system

effectiveness framework has been developed. In this approach, the basic systems performance effectiveness elements remain constant for different system missions and use functions, although the more detailed factors underlying the basic elements are subject to change, depending on the particular problem analyzed.

Several systems performance effectiveness models have been developed. Table B-1 lists equations for the more general models used by the Armed Forces. All these equations concern systems performance effectiveness, but each approaches the subject in a different manner, reflecting the needs of the individual service.

In general, the Navy translates its terms PAU into the analytic terms  $P_C$  and  $P_T$ ; the terms PU and A are similar, respectively, to the WSEIAC terms C and AD. The following general equations are derived:

$$E_S = E_A \approx E$$

and

$$f(P,A,U) = f(P_C, P_T) \approx f(A,D,C)$$

It should be noted that properly constructed Navy and WSEIAC models of the same system carrying out the same mission will give the same evaluation, and may even be mathematically identical.

Although both the Navy PAU model and WSEIAC model are usually defined as equations, the basic Equations B-1 and B-5, given in Table B-1 can only be used for simple systems in simple missions, even if the equations are assumed to be in matrix form.

However, the Navy  $f(P_C, P_T)$  model is more adaptable to complex systems by virtue of its computerized treatment of the variable  $P_T$ .

Several systems performance effectiveness models are reviewed below. Emphasis has been placed on describing the framework of each model rather than on providing a detailed description. The referenced documents should be consulted for the latter.

#### 4.1 The Navy Model

The first term, Performance (P), in the Navy model (PAU)\* can be expressed within several frames of reference. In the single-mission system, the expression is derived from a variety of measurements, e.g., area destroyed, tons of cargo

\* System Effectiveness, Northeastern States R&D Clinic, Philadelphia, Pennsylvania, Department of Navy Office of Naval Material--Systems Effectiveness Branch, January 1965.

Proceedings of the NMSE Systems Performance Effectiveness Conference, the NMSE Systems Performance Effectiveness Steering Committee, April 1965.

Proceedings of the Second NMSE Systems Performance Effectiveness Conference, the NMSE Systems Performance Effectiveness Steering Committee, April 1966.

L. D. Whitelock and F. J. Giordano, The Navy's Systems Performance Effectiveness Program, Aeronautic and Space Engineering Manufacturing Meeting, Society of Automotive Engineers, October 1966.

**TABLE B-1**  
**EQUATIONS FOR SYSTEMS PERFORMANCE EFFECTIVENESS MODELS**

Title	Equation	Term	Explanation of Terms	
			Term	Explanation
Navy Systems Performance Effectiveness	$E_S = (PAU)$	(B-1)	$E_S$	Index of Systems Performance Effectiveness
	$E_S = f(P,A,U)$	(B-2)	P	Index of System Performance - a numerical index expressing system capability assuring a hypothetical 100% availability and utilization of performance capability in actual operation
			A	Index of System Availability - a numerical index of extent to which a system is ready and capable of fully performing its assigned mission(s)
			U	Index of System Utilization - a numerical index of the extent to which the performance capability of the system is utilized during the mission
Navy Analytic Systems Performance Effectiveness	$E_A = (P_C P_T)$	(B-3)	$E_A$	Systems Performance Effectiveness
	$E_A = f(P_C P_T)$	(B-4)	$P_C$	Measure of Performance Capability - a measure of adequacy of design and system degradation
			$P_T$	Measure of Detailed Time Dependency - a measure of availability with a given utilization.
WSEIAC System Effectiveness	$E = (ADC)$	(B-5)	E	Quantitative measure of systems performance effectiveness
	$E = f(A,D,C)$	(B-6)	A	Measure of Availability - a measure of the condition of a system at the start of a mission when the mission is called for at unknown (random) point in time.
			D	Measure of Dependability - a measure of the system condition during the performance of the mission given its condition (availability) at the start of the mission.
Navy Cost Effectiveness	$E_C = \frac{E_S}{C_a + C_o} = \frac{f(P,A,U)}{C_a + C_o}$	(B-7)	$E_C$	Index of Cost Effectiveness
			$C_a$	Cost of Acquisition - the aggregated costs of acquiring the system, including prorated development costs.
			$C_o$	Cost of Ownership - the aggregated costs of operating and maintaining the system.
Navy Defense Effectiveness	$E_d = \frac{W}{E_t} \quad E_o = \frac{W f(P,A,U)}{E_t(C_a + C_o)}$	(B-8)	$E_d$	Index of Defense Effectiveness
			W	Index of Military Worth
			$E_t$	Index of Time Effectiveness
Cost of Acquisition	$C_a = f(C_{at}, C_{am}, C_{af}, C_{as})$	(B-9)	$C_{at}$	Acquisition Time Costs - the calendar time required to acquire the system.
			$C_{am}$	Acquisition Manpower Costs - the manpower and skill levels required to acquire the system
			$C_{af}$	Acquisition Financial Costs (Dollar) - the dollar outlays required to acquire the system, including the dollar costs associated with manpower and its acquisition and supporting facilities.
			$C_{as}$	Acquisition Supporting Facilities Costs - the penalty cost to other systems through use of support facilities by the system during acquisition of the system.
Cost of Ownership	$C_o = f(C_{om}, C_{of}, C_{os})$	(B-10)	$C_{om}$	Ownership Manpower Costs - the manpower and skill levels required to operate and maintain the system
			$C_{of}$	Ownership Financial Costs (Dollar) - the dollar outlays required to operate and maintain the system, including the dollar costs associated with manpower and its acquisition and supporting facilities.
			$C_{os}$	Ownership Supporting Forces and Facilities Costs - the penalty costs to other systems through requirement for and use of supporting facilities and forces in the operation and maintenance of the system.

or number of passengers delivered, emitters located and identified. Two important conditions apply: (1) the measurement standard used must be applicable to the parameter used to determine the performance level and (2) the answer derived from exercising the expression must be used with caution because, with other than extremely simple systems, the achieved performance capability is almost always less than the theoretical performance capability. This circumstance occurs because the design-optimization process requires that some trade offs be made to achieve optimization of the overall system. As a result, even for the relatively simple, single-mission system, (F) is expressed as an index representing the ratio of the achieved performance level to the theoretical desired level. In essence, it is a figure of merit even under the assumption of absolute availability and absolute utilization.

In the case of the multi-mission system, consideration must also be given to the interaction of two judgments. The first comprises the assignment of weighting (importance) factors to the several mission modes of the system in such a way that their sum is 1.0. The second comprises the determination of the fraction of the system's total mission time that will be devoted to each of the several mission modes.

It is in the multi-mission system that the compelling reason for using indexes becomes most apparent. Many such systems have completely disparate standards for measuring the performance of their various mission modes. A comparison or aggregation of performance indexes that use different measurement standards can not be attempted validly. For example, tons of cargo delivered, area destroyed, personnel transported, and enemy radar sites located and identified cannot logically be compared or aggregated.

The second term, availability (A), is more complex than the first. Overall availability is relatively easy to measure, but separating the overall value into factors of reliability, maintainability, operability, and supportability remains a difficult task--particularly in regard to prediction of the effect of uptime or downtime. Figure 2-1\* indicates the factors that contribute to availability according to the Navy's definition of the term. The factors associated with the man-module(s) in the system are not now quantifiable; they must be quantized (provided numeric representations of judgment values) and indexes or figures of merit must be used to synthesize availability.

The third systems performance effectiveness term, Utilization (U), accounts for factors that are introduced by the tactical, functional, logistical, and environmental utilization of the system; all four are a function of the operational doctrine of the system.

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\* Chapter 2, page 6, in main text.

Utilization factors represent the degradation in system performance caused by mission conditions. The following are some examples:

- Loss of accuracy of an optical gun sight due to haze
- Increase in part failure rate due to high ambient temperature
- Reduction in repair-part availability due to remoteness of location from supply depot
- Infrequent use of search radar for security reasons

The utilization factors, except for analytic exercise of the model, are relatively constant. However, the assigned values will change whenever operational goals and criteria are modified in the process of achieving consonance between them and technical goals and criteria.

The real significance of the utilization factors lies in their ability to be varied in both sensitivity and trade-off analyses for optimizing the entire system and its use. The systems performance effectiveness model thus becomes a tool for bringing operational and technical goals and criteria into agreement with each other.

If the goals and criteria are not in agreement, technical managers can use the models to demonstrate to their operational counterparts the desirability of changing the operational goals and criteria. In such a demonstration the utilization factors are varied to show the impact of the variances on the index of the system's performance effectiveness. If this exercise does not demonstrate the desirability of changing the operational goals and criteria, the technical manager can readily understand why he must revise his goals and criteria to coincide with those of the operational manager. In most cases it will become clear to both that revisions are necessary on both sides to achieve an optimum system.

As with the performance and availability indexes, the variances in utilization indexes must be evaluated in terms of cost considerations and military-worth considerations. Each variance of a factor affects the other factors and is in turn affected by variances in the other factors. At the same time, each variance of a factor has an associated cost that must be considered. Only when all factors have been considered in terms of mission accomplishment will true performance effectiveness be achieved for the system.

#### 4.2 The Air Force (WSEIAC) Model

This section summarizes the generalized mission-oriented system-effectiveness model that was developed by Task Group II of WSEIAC\*. In the simple case in which the system can only be in either a working state or a failed state, the

\*Weapons System Effectiveness Industry Advisory Committee (WSEIAC). Final Report of Task Group II, Prediction Measurement, System-Effectiveness Division, Air Force Systems Command, AFSC-TR-65-2, AD-458454, 48455 and 45356, January 1965.

measures of availability, dependability, and capability concern the following fundamental questions:

- (1) Is the system working at the start of the mission?
- (2) If the system is working at the start of the mission will it continue to work throughout the mission?
- (3) If the system worked throughout the mission, will it achieve mission success?

Although these questions represent the fundamental approach to be used in evaluating effectiveness on a mission-oriented basis, they are too simplified for purposes of model construction. Moreover, as the systems considered become more complex--e.g., there are more than two possible system states--such elements as degraded modes of operation, multimission requirements, enemy countermeasures, and natural environment must also be quantified in the model.

The basic effectiveness model can be divided into two major elements: the probability that the system will be in a particular state at mission-performance time, and the effectiveness of the system when it is in that state. Thus if effectiveness is quantified by a probability that the system will successfully meet the mission objectives, each term in the product  $\underline{A} \cdot \underline{D}$  represents the probability that the system will be in a particular state, and the corresponding term in the  $\underline{C}$  vector is the effectiveness of the system, given that state.

For example,

$$E = \underline{A} \cdot \underline{D} \cdot \underline{C}$$
$$= \sum_{i=1}^n \{P[\text{system is in state } i] \cdot P[\text{mission objectives are met, given state } i]\}$$

For some types of systems and missions, it may be more desirable to quantify effectiveness by some performance parameter other than a probability. For example, the expected miss distance for a missile might be a more meaningful performance parameter than the probability of its hitting within a specified area. For a reconnaissance system, the average amount of usable information might be appropriate. Figures of merit for these forms are readily usable by the appropriate quantification of the  $\underline{C}$  vector.

The mission model proposed by the WSEIAC Task Group II is, in essence, more a model framework for effectiveness evaluation than a directly applicable set of equations. This generality is necessary since the range of possible systems, missions, and depth of analysis precludes the specification of any single model.

The model framework, based on the availability, dependability, and capability factors, allows for flexibility in application by an appropriate combination of the associated elements. In Volume 3 of the Task Group II report, detailed examples are presented for an airborne avionics system, an intercontinental missile system, a radar surveillance system, and a spacecraft system.

The level of detail at which an analysis is performed will depend on the information and data available and on the purpose of the evaluation. For one study, a mean repair time may be sufficient input for the availability evaluation, while for another study such factors as queuing theory, spare parts availability, maintenance efficiency, and periodic-checkout procedures may have to be incorporated.

There are still many different areas that will require further research. One major problem is to develop improved techniques to convert available data into the appropriate vector and matrix elements of A, D, and C. Better analytic and computational techniques are required to incorporate state changes and those associated capabilities which can occur over a continuous interval. Such factors as state occupancy times and steady-state behavior may be involved in such analyses. Study also is recommended on a means to obtain some measure of "confidence" in the results of the effectiveness evaluation, both in the probabilistic combination of estimates and in guiding the decision process associated with the evaluation. Computerized analytic and simulation methods are needed for complex systems that generate a very large number of system states.

The WSEIAC model framework, or similar approach, has been applied to several systems, and has generally been found to be a reasonable method for evaluating effectiveness on a mission-oriented basis. Because of the impetus provided by WSEIAC, a great deal of research is being sponsored by the military and private agencies in order to improve this first effort.

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13. ABSTRACT

The effective performance of Navy systems in Fleet use is essential to successful Navy operations. With the increasing complexity of Naval systems, the achievement of an acceptable level of performance effectiveness has become increasingly difficult. During the past three years, useful techniques have evolved from a continuing extensive effort to develop the ways and means to improve performance effectiveness of Fleet systems.

The purpose of this manual is to describe the techniques developed under the System Performance Effectiveness (SPE) program. Navy program managers, project managers and project engineers are urged to use the manual as appropriate in the development of systems to assure the maximum feasible effectiveness.

It is intended that this manual will be periodically revised and updated by the Chief of Naval Material to meet the varied needs of groups within the Naval Material Command.