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Integration Engineering for System Effectiveness		

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EFFECTIVENESS **Q**UANTIFICATION **B**ULLETIN

Integration Engineering for System Effectiveness



Engineering Department

ELECTRONIC INDUSTRIES ASSOCIATION

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Effectiveness Quantification Bulletin No. 2

EIA
INTEGRATION ENGINEERING
FOR
SYSTEM EFFECTIVENESS

"ZEITGEIST"

PREPARED BY:

EIA COMMITTEE G 47
EFFECTIVENESS QUANTIFICATION

ENGINEERING DEPARTMENT
ELECTRONICS INDUSTRIES ASSOCIATION

CONTENTS

	<u>Page</u>
INTRODUCTION	1
THE SETTING	2
PROFIT AS AN INTEGRATING PARAMETER	3
ENGINEERING OF PROGRAM INTEGRATION	6
COST	6
SCHEDULE	6
FUNCTIONAL PLANS	11
ALLOCATION OF FUNDS	18
DATA MANAGEMENT	22
INTEGRATION OF ENGINEERING	23
SCHEMATICS	23
TECHNICAL INTERFACE COMPATIBILITY	26
CHANGE MANAGEMENT	31
CONFIGURATION MANAGEMENT	31
"ABILITIES"	33
TECHNICAL PERFORMANCE ANALYSIS	33
LOGISTICS	42
COST EFFECTIVENESS	45
TRADE-OFFS	45
PROGRAM DECISION AIDS	45
CONCLUSION	49
REFERENCES	51

FOREWORD

Program Managers have considered the subject of effectiveness quantification from three diverse points of view. The first viewpoint, in conjunction with the system effectiveness analyst, is to quantify everything and to consider everything quantifiable into a figure of merit. The result is a numerical decision aid that usually has some undesirable attributes such as oversimplification, non-sensitivity to critical parameters, hidden calculations, and difficulty in exercise of the model. This technique is characterized by mathematical models, computer programs, and attempted optimizations. The second viewpoint, in conjunction with the controller, is to consider the effectiveness as specified and concentrate on cost reduction. This has a danger of formulating all technical problems in terms of cost or economic considerations. This technique is characterized by closely controlled work packages. The third viewpoint, in conjunction with program planning and control personnel, is a distrust of the "numbers game" of the system effectiveness analyst and places a stress on taking all of the management actions that have, in the past, yielded a cost effective product. The result may be a well-run project but could yield a product design that is less than satisfactory for mission success. This technique is characterized by an emphasis on understood and accepted policies, procedures, processes, organizational objectives, and functional plans.

This bulletin is the result of attempting to meld the three points of view. This is accomplished through the intermeshing of engineering efforts to ensure their full impact on the system design and the technical program and decision criteria that assure management decisions resulting in a product with high probability of mission accomplishment, a program with minimum risk, and product and program costs within acceptable values of resources expended.

This material was first presented by FREDERICK H. KRANZ, G-47 committee member, at a University of California at Los Angeles short course on system effectiveness. It was reviewed and critiqued by the EIA G-47 committee. The changes suggested by the committee were incorporated, resulting in this bulletin.

INTRODUCTION

Integration Engineering can best be described by the German word "Zeitgeist" meaning trend of the time. Like a trend, the key to application of the techniques of integration is "how much and when." The application requires a rhythm with the program and a sense of timing for maximum system effectiveness.

System effectiveness has been approached in three different ways by practitioners. The usual approach is to develop and exercise a mathematical model for mission accomplishment. With this, a figure of merit is the key to program control. The second approach is to set the design criteria and control the program for minimum cost. A third, not often recognized, approach is to control the development program by means of design, production, and management operational criteria that have been found to yield successful programs. This paper will meld the three approaches so as to yield a program that can be characterized as having satisficing integration. This has been called "satisficing" or reaching a solution that satisfies rather than striving for an optimum with the attendant penalties in cost and energy.

Integration Engineering may be defined as in MIL-STD-499 (1) as "timely and appropriate intermeshing of engineering efforts and disciplines to ensure their full influence on the system design and technical program." Webster's New World Dictionary states that "integrate" means "to make whole or complete by adding or bringing together parts." Too often in the past this has been the method of integration. Plans, specifications, and drawings would be stapled together with a cover sheet. This may have satisfied the definition of "integration," but it did not yield an integrated design or technical program. The concept of integration engineering is aimed at influencing the production of a coordinated and cohesive system and program to produce it. This requires clear definition of the constituent system and program elements and analysis of the interfaces between the elements in order to create a unified system and program. This paper will describe the author's approach to such an integration.

THE SETTING

In the last twenty-five years, weapon and utility systems have become more complex. This complexity has given rise to a requirement for an integration capability. These complex systems have been bought to solve problems, satisfy needs, and provide for mutual welfare. In recent times, many previously unsolvable problems have been shifted into the realm of solvability by the rapidly advancing technology. Complex systems have been developed, each new system building upon the systems of the past and becoming more complex. This growth in complexity has made the systems far more difficult to integrate in such a manner as to achieve the objective in a cost-effective manner. The fundamental problem has been that we have a tendency to overlay each increasingly complex system on its previous system rather than sorting out proper interfaces necessary to accomplish the fundamental objectives. This type of overlay is similar in both the aerospace industry and the Federal Government and results in not utilizing its time and talents effectively, but more importantly, utilizing more people and money, facilities, etc., than is necessary to accomplish the task. The difficulties in economically performing the integration lie not only in the complexity of the system but in the problem of decomposition of the system into parts that can be synthesized, and with entrancement with techniques, cults, and procedures. The complexity of the system has lead to integration systems that are themselves an element of complexity. That is why this paper will look more towards the understanding and capability required than a prescription of procedures.

Society, government agencies, and the DOD, as customers, have had a consistent objective in developing new systems. That objective is to have in-being, cost effective, properly integrated systems that meet their original system objectives and requirements. Industry's continuing objective has been to produce systems in such a manner as to satisfy the customers' needs and thereby establish a perpetuating profitable business. These two objectives have given rise to tools and cults for integration that are intersecting sets with unusual redundancies. Over the past quarter century, both industry and the governmental customer have been pulling together to work out a consistent technique or model for system development that would utilize these tools to the optimum, but not maximum. The most significant development was sponsored by the Air Force with the support of the Department of Defense and Industry. This resulted in the AFSCM 375 (2) series. The subjects include configuration management, program management, system engineering, development engineering, as well as lessons learned from the survey that initiated the effort and instructions for the program office.

The 375 series manuals specified rigid discipline through application of detailed methodological functional correlation techniques, rigid formats for the data resulting from these techniques, and formal reviews of the development process. These documents had the correct objective, but the approach was too rigid. Since then, the military services have realized this limitation and have revised their approach. The new approach has resulted in a set of military standards that aim at setting requirements rather than detailing procedures. These call for a more positive integration of hardware, technologies,

resources, and documentation to achieve a cost-effective program. In order to set the stage, it will be necessary to look at the contractor's objective in terms of the customer's objective.

PROFIT AS AN INTEGRATING PARAMETER

In contracting, the government uses four types of controls. Directive controls are typified by the Armed Services Procurement Regulation, Military Standards, Military Specifications, Manuals, and Handbooks. Direct controls are typified by financial audits, renegotiations, and technical direction. Contract redefinition is typified by specification change, incentive change, time requirement change, change of associate contractor, or directed change of subcontractors. The final control is that of the use of profit-sharing incentive. The trend in this area has been towards emphasis on fewer more critical parameters for incentivization. A discussion of profit as an integrating factor follows.

In order to perpetuate himself, the contractor must make a profit. The customers have recognized this and created incentive fee structures where the profit is a function of the cost effectiveness of the system, and perhaps such other items as investment. In this way, optimizing the design for the contractor's fee should also result in the optimum design from the government's viewpoint.

The concept of incentive contracting is based on the premise that a buyer can motivate a seller to execute a contract with improved efficiency and effectiveness by offering the seller an opportunity to earn increased fee (profit) as a function of increased efficiency and effectiveness. This concept has received significant attention in recent years by both the Department of Defense and the National Aeronautics and Space Administration as a basis for contracts with industry. The incentive concept is utilized in contract situations where complete and explicit delineation of mutually agreed contract requirements is neither possible nor desirable; this is in contrast to the fixed price type of contracting. The incentive contract is intended to serve as an instrument by which the buyer describes his value objectives for the contract concerned and thereby offers the seller an incentive fee (profit) based on the seller's effectiveness in meeting the buyer's value objectives. For example, the buyer may offer the seller additional fee (profit) for the attainment of reduced cost, increased performance, early delivery, or some combination thereof, through the incentive contract. In theory, then, the seller is motivated to maximize his incentive fee (profit) and, in so doing, to maximize the value objectives of the buyer.

The incentive principle, as a basis for contracts between buyers and sellers, has been defined by the Department of Defense as follows:

"The incentive principle holds, in brief, that a contractor should be motivated, in calculable terms (i) to turn out a product that meets significantly advanced performance goals, (ii) to improve the contract schedule up to and including final delivery, (iii) to substantially reduce the costs of the work, or (iv) to complete the project under a weighted combination of some or all of these objectives." (3)

This states that the fee may be expressed as:

$$1. \quad F = f_1(E_c) = f_2(E_s, C, T)$$

where E_c = cost effectiveness, E_s is the system effectiveness, C is the cost, and T is the time.

All of these variables are complex vectors. Cost is the total of research, engineering, development, test, procurement, operational logistics support, training, and facility costs. Time is more complex than contract schedule. It may be expressed in terms of development time, operational life, first operational date, first activation date, or force activation date. The advanced performance goals are expressed as system effectiveness. This may be expressed in a number of ways. The most common are:

$$2. \quad E_s = f_3(A, D, P)$$

$$3. \quad E_s = f_3(P, A, U)$$

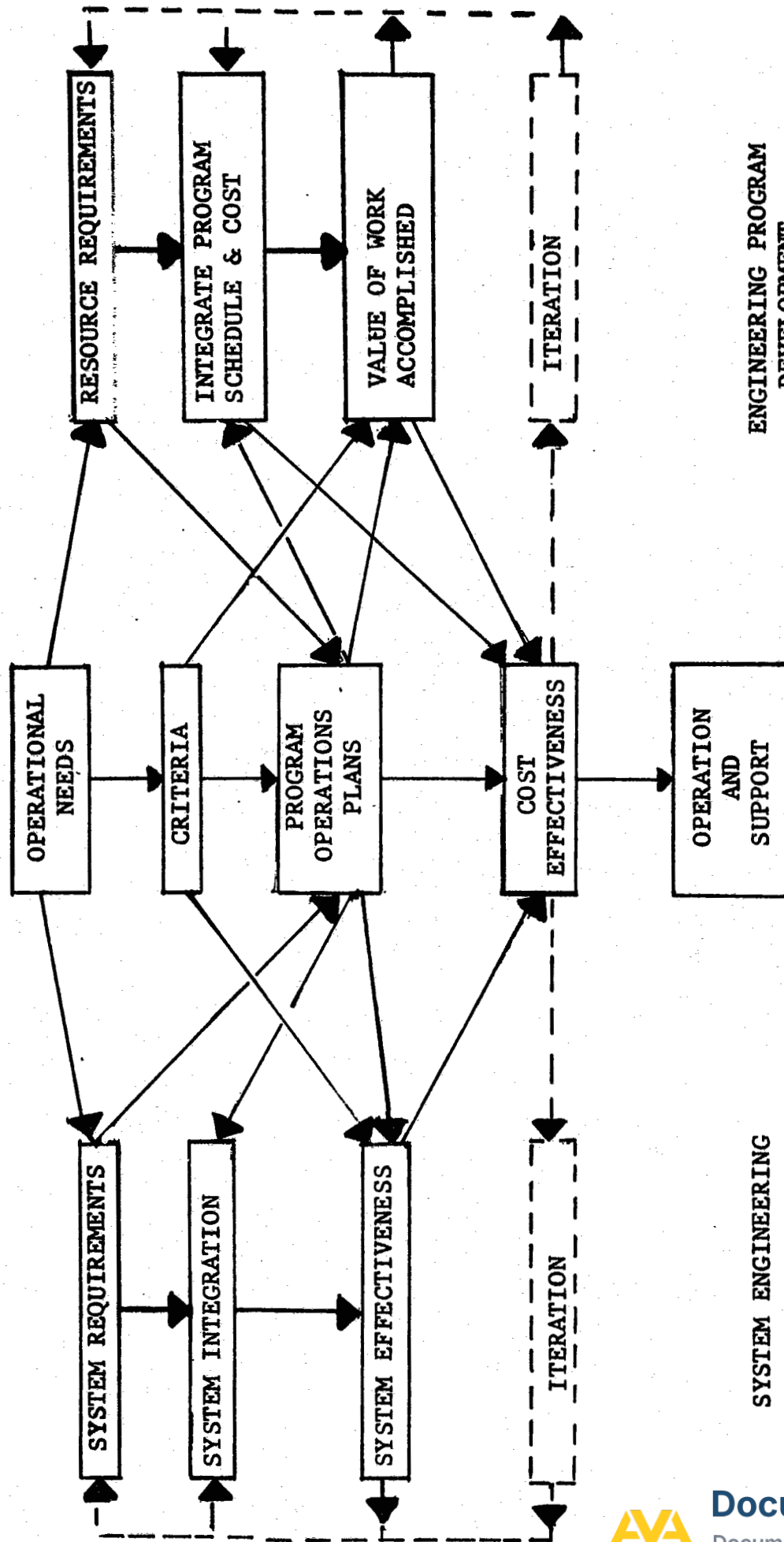
$$4. \quad E_s = f_3(U, D, P)$$

$$5. \quad E_s = f_3(W, A, D, P, U)$$

where A is the availability, D is the dependability or reliability, P is the performance or capability, W is the employment, and U is the utilization.

Incentives, then, are the integrating factors that pull together expenditures, schedule accomplishments, and system effectiveness into a cost effectiveness evaluation. This is shown in Figure 1. The right-hand side includes "integrate program schedule and cost," and the evaluation of this synthesis as "value of work accomplished." This will be discussed first. The left-hand side includes "system integration" and its evaluation "system effectiveness." This will be discussed next. Finally, the tying together of the integration by "cost effectiveness" will be touched upon. This is the outline and logic of this paper.

THE SETTING



ENGINEERING PROGRAM
DEVELOPMENT

SYSTEM ENGINEERING

FIGURE 1

ENGINEERING OF PROGRAM INTEGRATION

Integration contractors are frequently used in Defense contracting. These contractors serve to coordinate the multiple associated contractors. They direct only through the customer. This gives us a picture of the role of engineering in program planning, control and integration.

In setting up the program planning, control and integration, engineering provides an input and influences a program planning and control organization. This input is coordinated with other inputs into the master plan. These inputs are shown to influence the functions of Figure 2 by means of the right-hand side of Figure 1.

COST

Costs or expenditures are prime components of the incentive fee structure, and hence major integrating parameters. The project work breakdown structure (Figure 3) is the tool devised by the comptroller's office to gather expenditures and thereby integrate a program from a cost point of view. If the project work breakdown structure development and integration is not influenced by engineering consideration, it will not be compatible with the hardware tree, specification tree, performance breakdown structure (4), Hardware Utilization List, or the indentured parts list. This will show up when functional plans are developed and technologies are missing or major outputs skipped. Engineering should not try to supplant the normal program planning and control function, but should take the technical leadership and, along with manufacturing, material, and logistics, influence the development of the work breakdown structure. The key position of engineering in this process is primarily because, in the project formulative stages when the work breakdown structure is first made, most development processes take their base from engineering considerations and, secondarily, because engineering is a central user of the cost data in trade-off analyses.

SCHEDULE

This brings the discussion to the integrating tool devised by the program control organization. It is given various names, but the most common are Program Master Schedule, Program Management Network, and PERT subnets (Figure 4). These scheduling tools are event-oriented. That is, they represent the world by the interrelationship of outputs, milestones, and accomplishments. These events are derived primarily from the contract work breakdown structure and the outputs of the work packages. However, there are other sources of events. The contract statement of work, data requirements list, hardware utilization list, technical specification tree, technical allocation matrix, and functional plans/schedules/tasks all show potential events. If the WBS were engineering influenced and included all technologies, processes, and functions, then the integration of the WBS to PERT could be accomplished to evaluate the value of work (Figure 5) accomplished as compared to the planned value of work to be accomplished.

ENGINEERING OF PROGRAM INTEGRATION

INTEGRATION

WORK BREAKDOWN STRUCTURE

PROGRAM MANAGEMENT NETWORK (ALL SCHEDULES)

FUNCTIONAL PLANS & PLAN CHANGE CONTROL

FUNCTIONAL MODEL

RESOURCE ALLOCATION

TECHNICAL STUDY INTEGRATION

ASSOCIATE & SUBCONTRACTOR INTEGRATION

DATA MANAGEMENT

VALUE OF WORK ACCOMPLISHMENT

FIGURE 2

WORK BREAKDOWN STRUCTURE

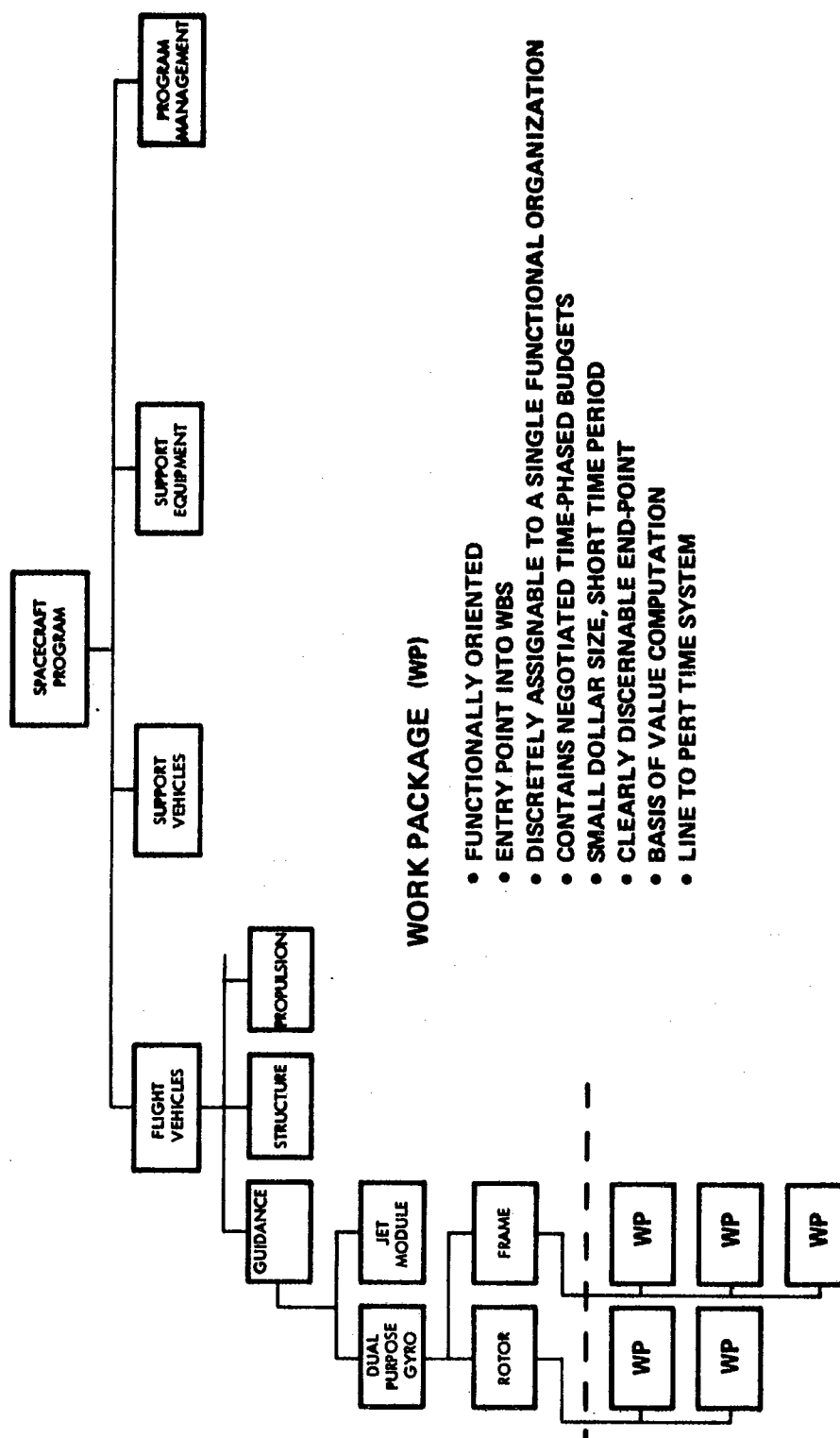


FIGURE 3

PROGRAM NETWORK/REPORT RELATIONSHIP

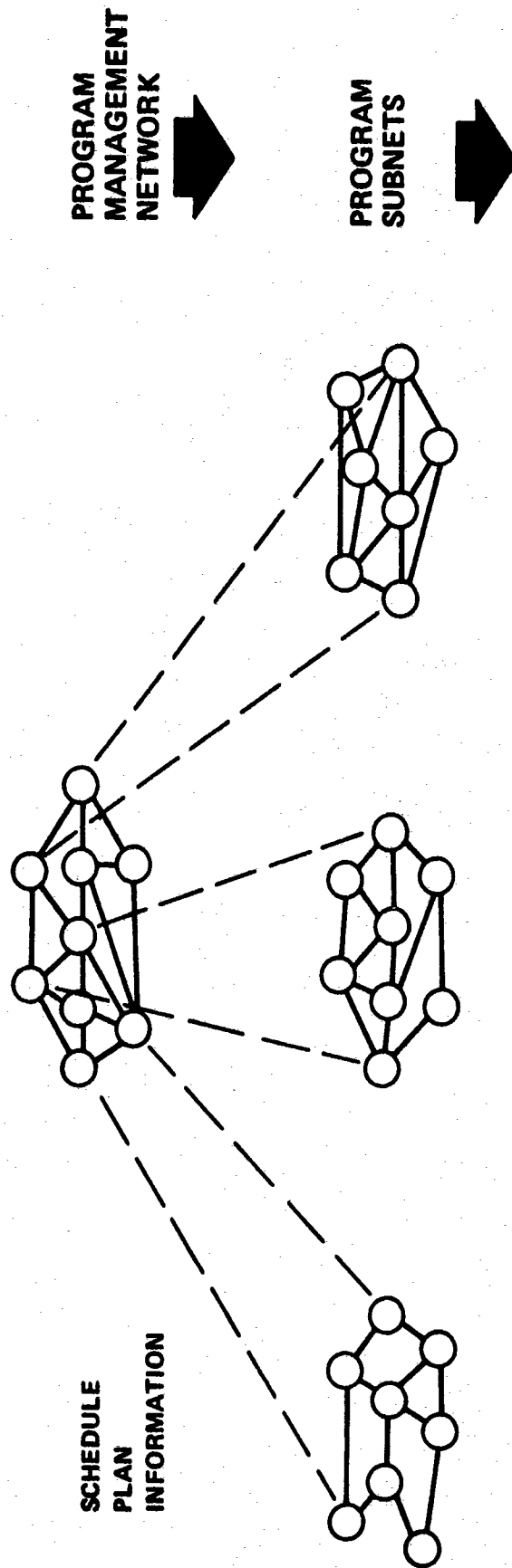


FIGURE 4

VALUE OF WORK

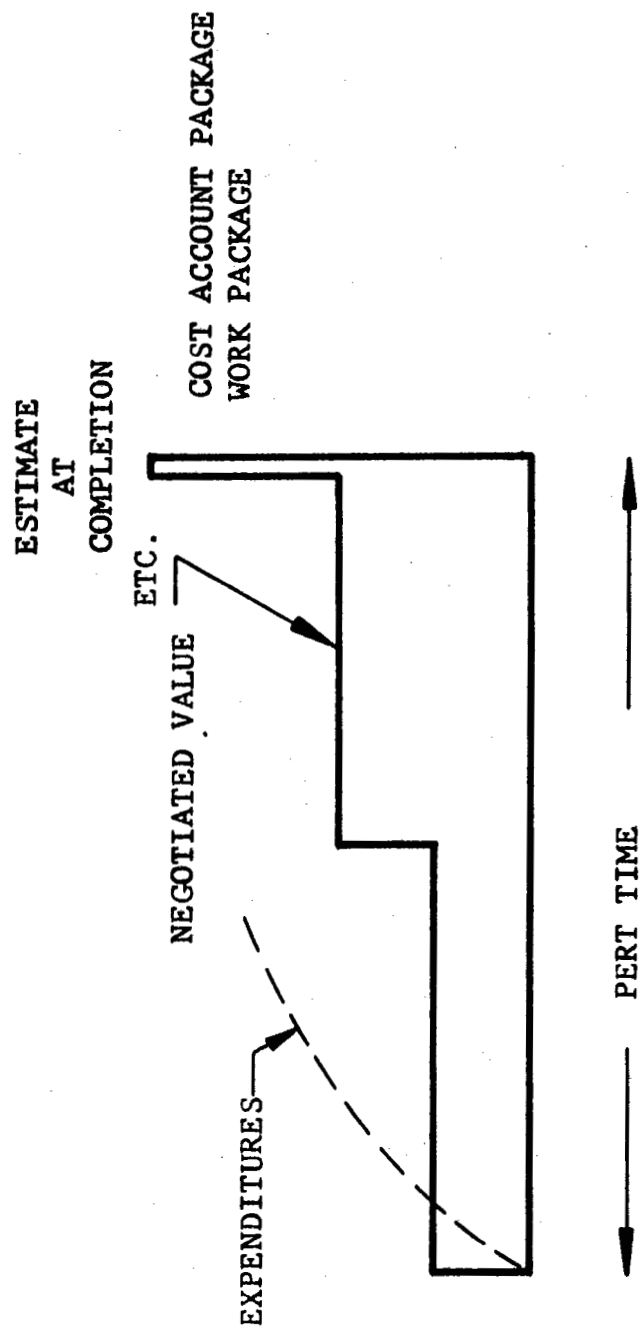


FIGURE 5

FUNCTIONAL PLANS

Functional plans are the plans developed by an organizational entity for the conduct of their part of a program. The plans specifically, factually, and numerically answer the what, why, when, how, where, and who for the organizations (Figure 6). Functional plans cover development processes, technologies, and resources, and cut across the work breakdown structure. They are the guiding documents for the conduct of a program for each functional area or organizational entity, such as fabrication or safety. All plans should be fully integrated with the work breakdown structure and PERT. However, not all plans are formal documents or contractually required. A plan tree (Figure 7) includes both functional plans and the integrating processes that tie together the functional plans. Figure 8 shows such a relationship. Tools for tying together the functional plans include not only the integrating processes, but the work breakdown structure assignment matrix, functional input/output analysis, and resource allocations.

The WBS assignment matrix is merely a matrix of cost account packages to organizational entities. This aids the integration when used in conjunction with a functional input/output model. A functional model of a program is similar to a functional analysis of a mission. It is the logic of the development cycle. The logic of a development cycle is essentially that of finding a strategy for the sequence and relationships of events that must take place in the course of developing a complex system. In order to be able to talk about development cycle strategies without ambiguity, and in order to promote the comparison of alternatives in the course of evolving good strategies, we need a special language; specifically, there is need for a language whose terms and concepts are public and precise and whose symbology is well-defined so that there can be an exchange of precise ideas among the specialists interested in the development process. Given such a language, there would be a good basis for communicating and improving development cycle models which exhibit useful strategies. The functional analysis provides such a language. The top level functions (5) look like what have been called processes (Figure 9). The next level shows both subsystems and technology as functions, which are sequenced throughout the program and oriented to the program. A fourth level functional analysis involves inputs and outputs and an addressing technique to show where each output goes (Figure 10). The inputs and outputs are the events of PERT. The functions are WBS elements. The functional flow for a technology is the functional plan. The totality of the flow charts articulates with the WBS, PERT, and functional plans. Figure 11 shows how an integration matrix is developed to show the relationship between work breakdown structure and the functional plans. It might be concluded that the language, if rich enough and precise enough, could enable evolution and elaboration of relatively complex models of the system development process. Such a complex model, if it obeys fixed rules in moving from state to state, could be the basis for a simple new calculus for development, planning integration (6).

PLANS

SPECIFICALLY AND FACTUALLY AND NUMERICALLY
MAKE AN ECONOMIC AND TECHNICAL COMMITMENT
OF KIPLING'S SIX SERVING MEN:

" I KEEP SIX HONEST SERVING MEN

(THEY TAUGHT ME ALL I KNEW);

THEIR NAMES ARE WHAT AND WHY AND

WHEN AND HOW AND WHERE AND WHO "

IN FORMAT THAT INCLUDES PURPOSE, SCOPE, TASK
DESCRIPTION, MANAGEMENT, OUTPUT (DATA, PRODUCTS
AND REPORTS), AND DIRECTIVE DOCUMENTS

FIGURE 6

PLAN TREE

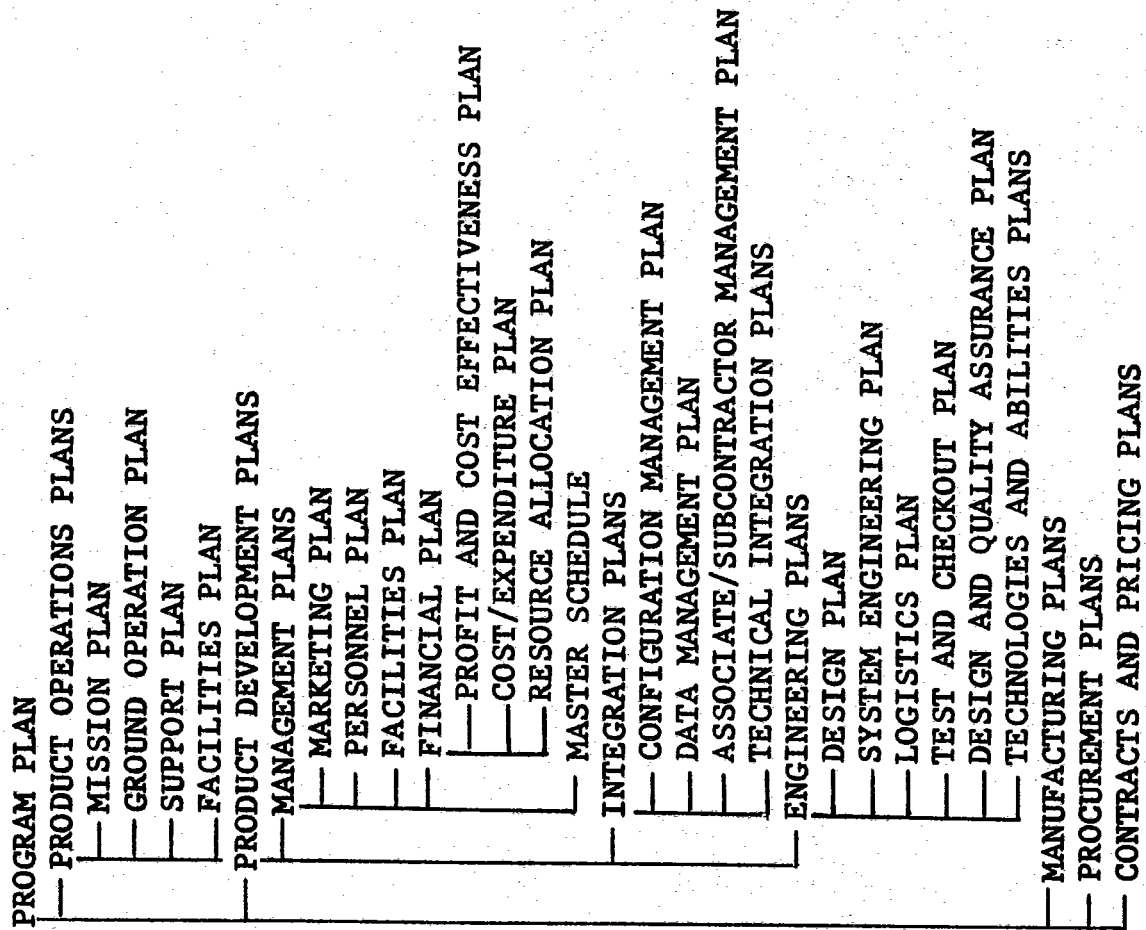


FIGURE 7