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Matrix Management for Aerospace 2000

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16. Abstract
The matrix management approach to program management is an organized approach to attaining program objectives by defining and structuring all elements so as to form a single system whose parts are united by interaction. The objective of the systems approach is uncompromisingly complete coverage of the program management endeavor. Starting with an analysis of the functions necessary to carry out a given program, a model must be defined; a matrix of responsibility assignment must be prepared; and each operational process must be examined to establish how it is to be carried out and how it relates to all other processes.

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Prepared for the
International Meeting and Technical Display: Global Technology 2000
sponsored by the American Institute of Aeronautics and Astronautics
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MATRIX MANAGEMENT
for
AEROSPACE 2000

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INTRODUCTION

Beginning with the U.S. weapon system development programs of the 1950's, there has been a trend in our increasingly complicated technological society to undertake fewer but much larger and more comprehensive programs. The National Aeronautics and Space Administration's Apollo Program and, more recently, the Space Shuttle, are examples of this growth in program magnitude and complexity.

Although the Apollo Program goal was clear, to reach it required the use of rapidly developing technology that was based on rapidly increasing scientific knowledge. It required the organization to be highly flexible, and it was changed when unexpected developments made it necessary. As a measure of the magnitude of the Apollo Program, staffing at its peak grew to 390 000 workers in industry, 33 000 in NASA Centers and 10 000 in

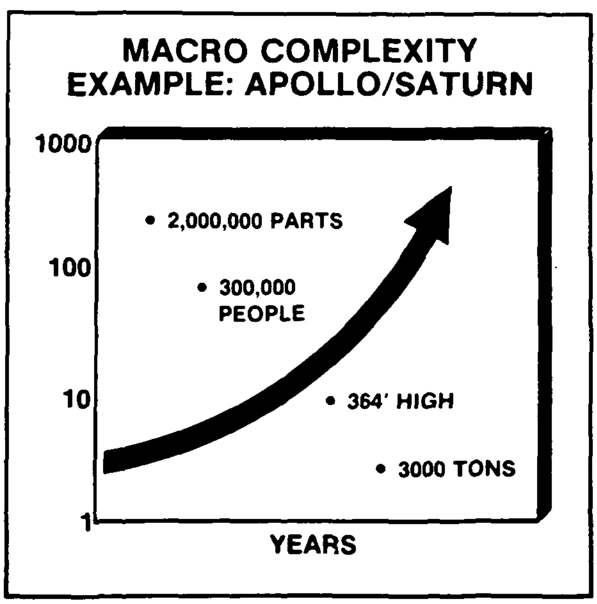


Figure 1

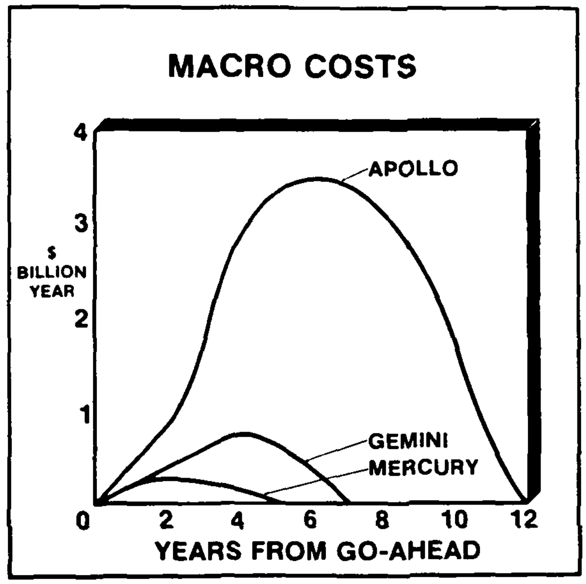


Figure 2

universities. By 1969, the year of the first lunar landing, total staffing had been reduced by 190 000. By 1974, it was down to 126 000 (ref. 1).

Enormous as the Apollo effort was and as the Space Shuttle Program is, such programs may be viewed as only forerunners of future national programs that will be even larger and more complex. Examples of the macrotrends that confront the future programs are shown in figures 1 to 5. Although these trends depict aerospace industry products, they are generally applicable to large programs other high technology industries.

The complexity of the systems have almost gone beyond the point of human grasp (fig. 1). In fact, today, the computer is taking control of many of the traditional management functions relating to the flow of the millions of parts that must converge into the final system. And scheduling the work of thousands of people has become a computer function in many areas.

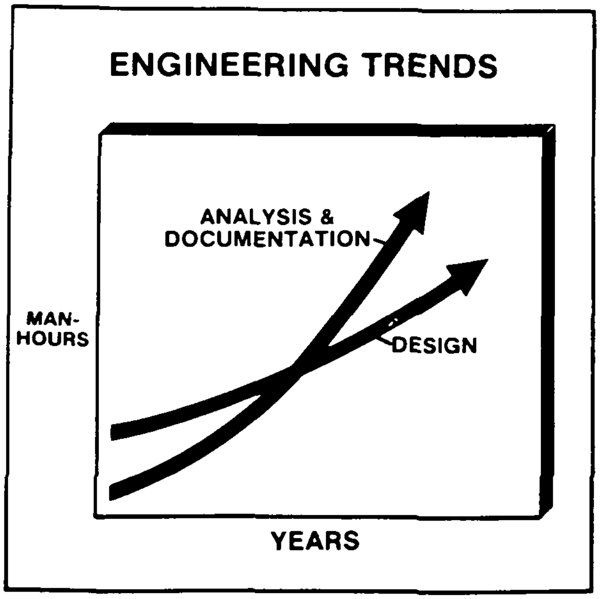


Figure 3

Macrocosts in billions of dollars vs. years from go-ahead for three NASA programs are shown in figure 2. The curves dramatize the exponential cost increases and extended periods of time required as the programs become more complex and broader in scope. The total cost estimate for the Space Shuttle design, development, test, and evaluation (DDT & E) program is now 6.18 billion (1971 dollars).

The increasing engineering manpower as a function of time required for analysis and documentation and for design is shown in figure 3. Although both curves are shown exponentially increasing, the analysis and documentation investment increases at a greater rate than the design functions. This trend can be attributed to program objectives involving greater risk, investment cost, and scope. The greater risk in turn drives the decision-making process into the generation and evaluation of a much greater number of alternative solutions as the decision tree is worked.

Figure 4 shows the accelerating trend of engineering development costs that result from increasing program complexity. The decreasing production costs result from increased experience and more detailed analysis, design, and development.

In the aerospace business the number of test articles (fig. 5) available for flight testing has continually decreased because of the enormous cost and sophistication of each succeeding generation. For example, at present, only four Space Shuttle craft are budgeted.

These macrotrends are not all-inclusive but generally give a taste of the harsh flavors that can be expected. The increasingly complex decision matrix is unfortunately worked in an exponentially decreasing time frame.

AN APPROACH TO MANAGING LARGE, COMPLEX PROGRAMS

The work of management can be defined as making decisions in terms of the activities of planning, organizing, staffing, controlling, and directing the allocation of scarce resources to achieve the organizational goals, usually with poor management information. A proliferation of theories exists as to how these management activities should be carried out, and tons of literature exist on concepts such as authority, responsibility, span of control, and single reporting (refs. 2 and 3). Most of these principles are related to so-called vertical management, that is, management characterized by organization along

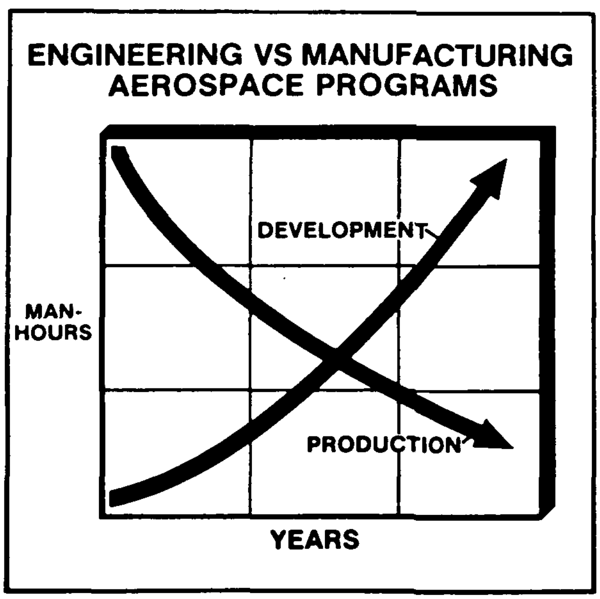


Figure 4

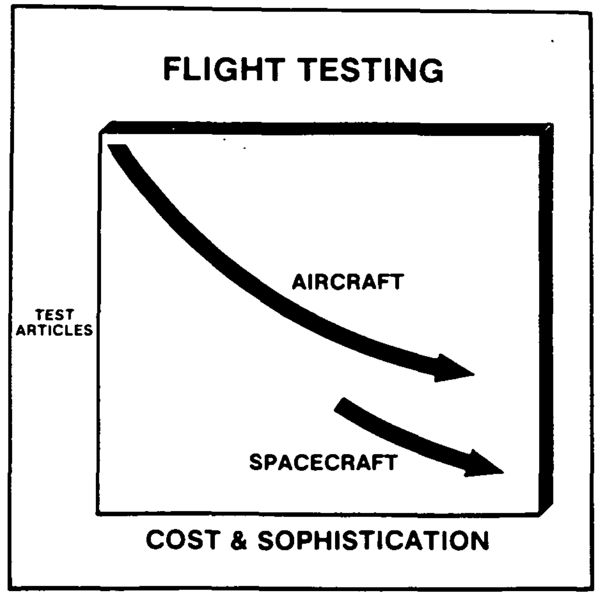


Figure 5

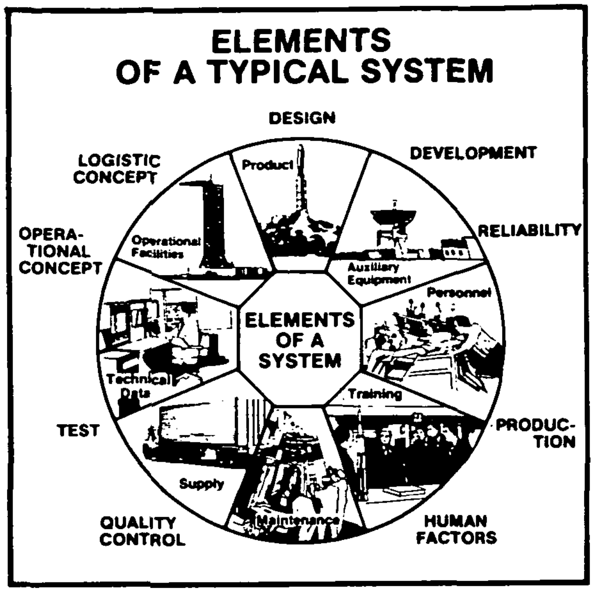


Figure 6

the traditional pattern of the hierarchical chart in which authority and responsibility flow downward and information and glory upward.

Critics of vertical management point out that the work to be performed flows horizontally across the organization chart and that the hierarchical structure, by fostering parochialism, creates barriers to communications and can actually impede the progress of a program. To overcome these problems, some mechanism for lateral management is needed. The most common attempt at a solution is to superimpose a horizontal program management activity over the vertical framework to draw upon and coordinate selected skills and services present in the hierarchy (refs. 4 and 5).

In the 1960's people began to seriously apply the systems approach to the management of large, complex programs. The objective was uncompromisingly complete coverage of the program management endeavor. Starting with an analysis of the functions necessary to carry out a given program, a model was defined, a matrix of responsibility assignments was prepared, and each operational process was examined in detail to establish how it was to be carried out and how it was related to all other processes. Planning for implementation of this management tool was started in 1967 (ref. 6).

As applied to program management, the systems concept may be viewed as an organized approach to attaining program objectives by defining and structuring all elements involved in such a way as to form a single system whose constituent parts are united by some form of interaction (fig. 6). The systems management approach is a method of *objectively* considering flows through an organization, with an information feedback system supplying quantitative information about the flows, so that decisions can be made to manage the flows to attain the greatest payoff relative to organizational goals. And this activity takes place in an active environment, not a vacuum. The word *objectively* is a key to the usefulness of the approach. Nowhere is this more evident than in functional analysis, a process fundamental to the concept.

MANAGEMENT PHASES

Because of the immense complexity and large costs of today's macrosystems, they typically must last for many years. Also, before the huge investments that are required are committed, many studies are made and much debate takes place. All levels of society may become involved in the sorting out process, including national and local. The government is highly involved, except in very isolated cases. Typical of a macrosystem currently in the gestation stage is the MX program. The Department of Defense (DOD) has studied survival basing modes and missile configurations for many years. A national debate at all levels of government is now underway.

Both the DOD and NASA have found it desirable to formalize the life cycle of typical macrosystems. The details differ between DOD and NASA, but the general concepts are identical. Figure 7 shows the life cycle of a typical macrosystem. During the conceptual phase, the mission is defined, requirements are established, alternative approaches are evaluated, and advanced development takes place, usually for the pacing high technologies.

In the definition phase a design baseline is established, performance specifications are drafted, and detailed development plans are formulated. The go-ahead for development is preceded by formal

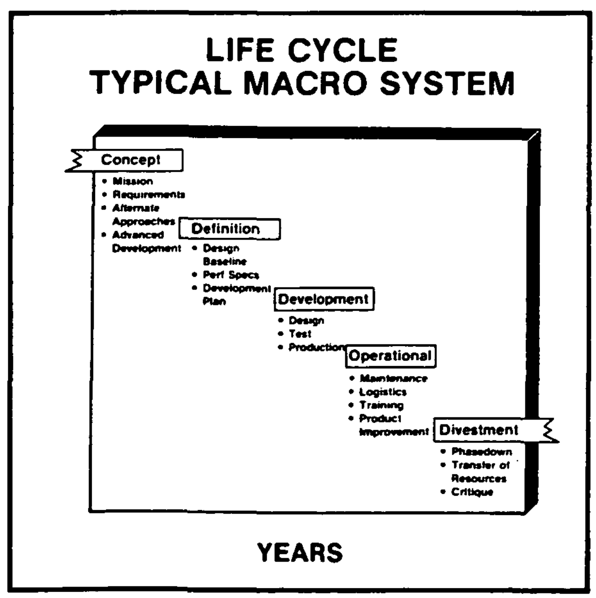


Figure 7

high-level government reviews, which are endorsed by the Administration and Congress. These formal reviews are required because large expenditures are committed when full-scale development is approved. The development phase consists of design, test, and production prototypes of the full-scale macrosystem.

In the operational phase full-scale production and operational employment are underway. Maintenance concepts are implemented; logistics, including spares and support, are activated; training takes place at all levels of the operation; and product improvements based on operational experience are evaluated and implemented when desirable. Needless to say, once in the operational phase, a macrosystem can consume huge resources. Any mistakes not uncovered in previous phases can be very costly indeed—not only in terms of money and manpower, but also in terms of operational capability.

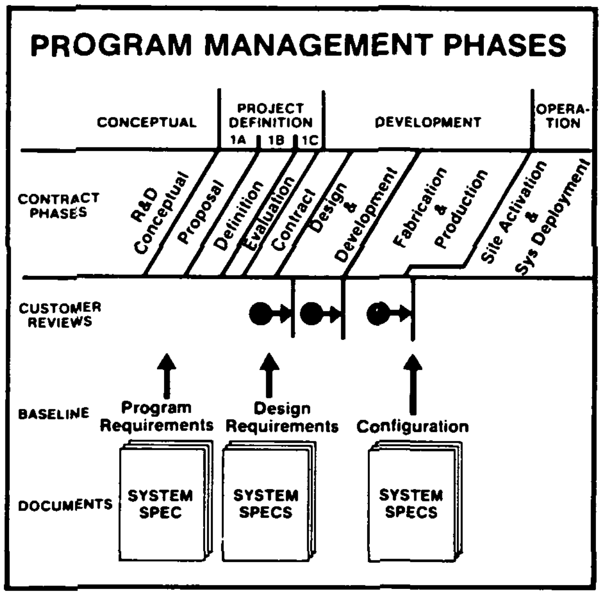


Figure 8

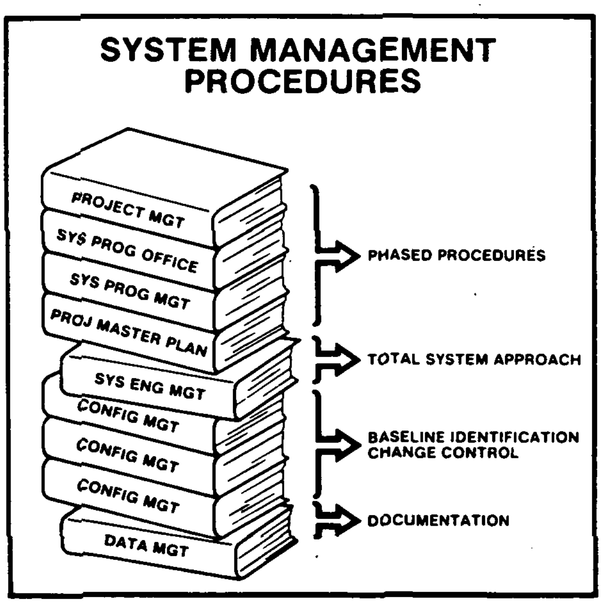


Figure 9

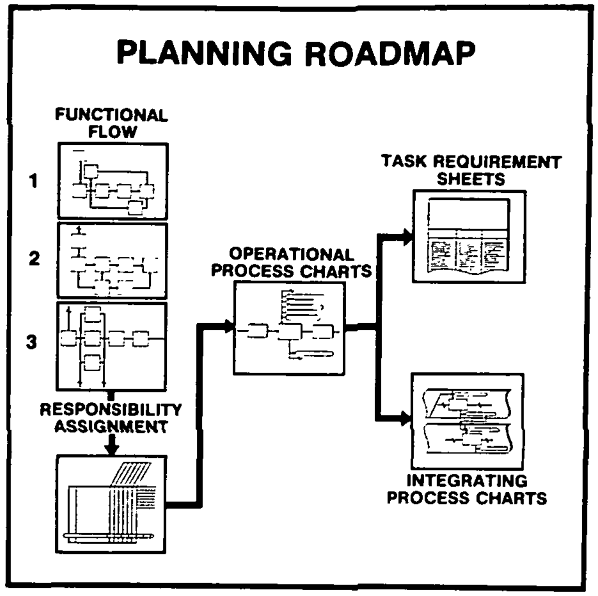


Figure 10

The divestment phase is less precise, since many systems seem to live on forever, at least portions of them. The DOD can phase a weapon system out of the Force Structure, but the same system may be utilized by the National Guard, or by foreign allies, long afterwards. Therefore, the items associated with divestment shown in figure 7 often do not take place completely. Ideally, there would be a phase-down, a transfer of resources, and a formal critique.

Over the years, formal management phases have been developed for both DOD and NASA, although again, the two agencies differ in detail. Figure 8 shows typical program management phases, which include contract phases, and some formal customer reviews. Formal baselines are established at certain points in the management phases, and these are documented by formal systems specifications to provide a basis for contractual negotiations, change control, and formal reviews.

In order to formalize the management process, system management procedures have been generated over the years. These are constantly changing as more experience is accumulated. Some typical procedures are shown in figure 9, along with associated objectives. These procedures have multiplied over the years so that today large organizations exist just to cope with the formal requirements of major systems. The paperwork associated with compliance can be astounding!

PLANNING ROADMAP

An overall rationale for planning a complex, high-technology program is illustrated in figure 10. The

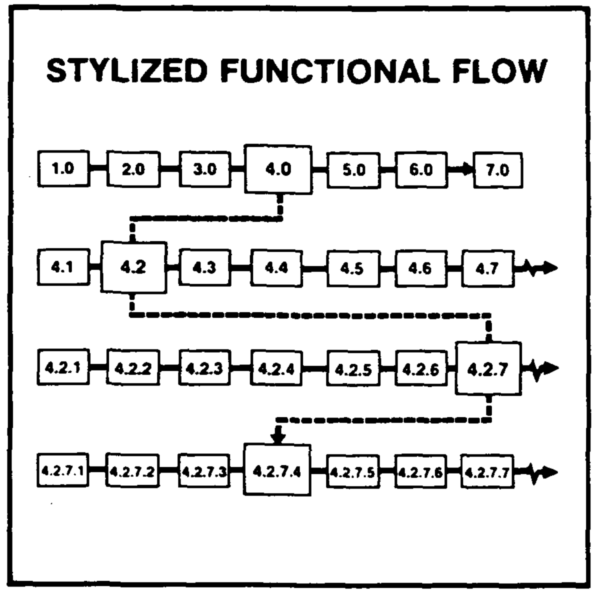


Figure 11

scheme can be generalized so that it is applicable to any program with deliverable end items. Considerable effort was devoted to structuring the process by North American Aviation, Inc., (now Rockwell International Corporation) during the development of Apollo (refs. 1 and 6). Because of the immense complexity of the Apollo Program, systematic planning was essential for success.

It should be emphasized that the procedure outlined in figure 10 is *not* another new management scheme—there are indeed too many of these buried in the literature. Rather, it is an orderly mechanism for planning a complex program out of which will fall the traditional products which must be generated before project initiation such as a Work Breakdown Structure, Program Plan, Reliability Plan, Master Program Schedule, Material Review Procedures, etc.

As discussed previously, there are essentially four management phases in most large aerospace programs, *viz.*, *conceptual, definition, development,* and operational. The planning roadmap of figure 10 must be generated for each of these phases, especially for large programs. Good planning is most critical for the development and operational phases where most of the resources are expended. Illustrative examples given in this paper are associated with the development phase.

As shown in figure 10, the initial planning process starts with the generation of functional flows. These define the work to be done, either in series or in parallel, to fulfill the program requirement. The work is defined to a level low enough that first-line supervision can assume meaningful tasks. This planning process is analogous to the generating of the Work Breakdown Structure, although by proper formalization other planning products will emerge and the opportunity for good program and functional management will present itself. Also, generation of functional flows can be generalized so that a planning baseline can be established which is applicable to any program. Generalized functional flows have been produced (ref. 6). They are extremely useful tools in attacking the planning of new programs—a difficult, very creative endeavor.

Once generalized functional flows have been generated, each activity is assigned to an organization element. At this point, generality can be preserved, as is the case in this paper, or organizational peculiarities can be introduced to fit a given program or organization. In any case, the rationale is applicable whether or not universality is retained.

After responsibility has been assigned to all tasks, operational process charts can be produced. These are generated for the functional organization, independent of program organizational structure. The need for matrix management now becomes evident since programs are end-item oriented, and the functional organization used to accomplish interim tasks is of little consequence to the program manager.

After the generation of the program tasks and assignment to organizational elements, task requirement sheets can be produced. Because the functional flows were generated in enough detail for first-line supervision, these sheets can be given to each organizational unit for planning purposes. They constitute the baseline definition of the work to be performed and schedules to be met, and specify interfaces with other organizational elements.

At this point, the end-item-oriented program manager comes into play. He can generate integrating process charts for each end item or interim product of interest. The final planning product will be the definition of each activity, organizational responsibility, interfaces, and products leading to

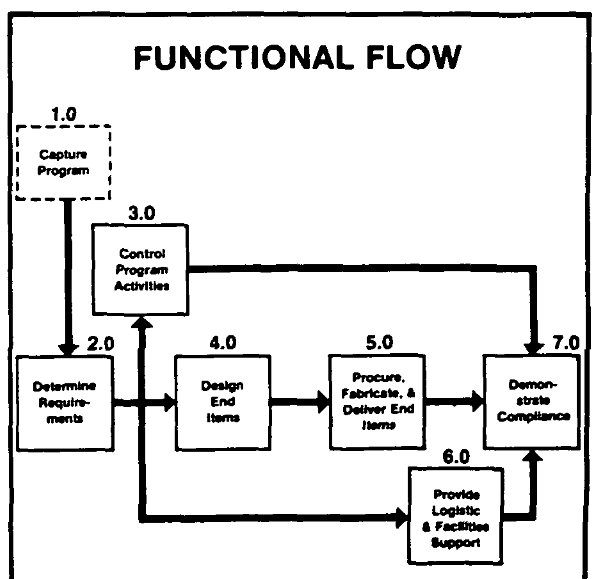


Figure 12

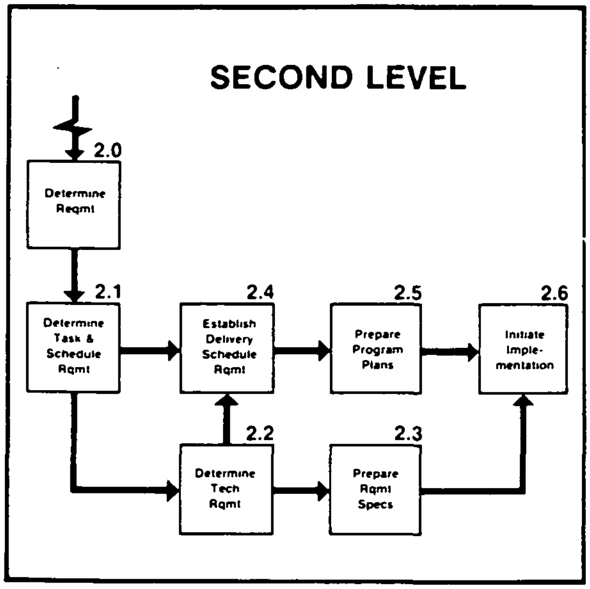


Figure 13

the end item. Integrating process charts are invaluable tools for project engineers who must track and forecast cost, schedule, and performance bogies.

FUNCTIONAL FLOW

Functional analysis is predicated on the precept that, before a decision is made as to *how* to do something, a careful look should be taken at *what* is to be done. An innocent-appearing proposition—until examination reveals that we habitually confuse *what* with *how* and that the consequences of this confusion can be disastrous. The systems approach seeks to develop a way of thinking, a viewpoint, a conceptual framework, together with a methodology for implementation.

The rationale for generating functional flow is shown in figure 11. Major functions necessary to fulfill a program requirement are defined. Seven major functions are sufficient for the development phase of most aerospace programs or contracts. Each major function is then broken down into increasingly finer structure until meaningful tasks are defined at the level of first-line supervision. Three levels are generally sufficient to meet this criterion. In some cases it is necessary to go to the fourth level. It is convenient to formalize the numbering process as shown in figure 11. The desirability of this formalization will become evident as we progress.

In executing the development phase of a program, it is assumed that the Advanced Systems people have captured the program. Therefore, the task before us is one of execution—whether it is building a little red wheelbarrow or delivering a Space Shuttle Orbiter. Therefore, in figure 12 the task of "Capturing the Program" is dotted. The remaining six functions are arranged in series or in parallel, depending on whether the output from preceding functions is necessary for execution. The arrangement of figure 12 has been applicable to most major aerospace programs. The ultimate objective, of course, is to demonstrate program or contract compliance.

The first-level function, "Determine Requirements," is further broken down in figure 13, and the second-level function, "Prepare Program Plans," is cascaded to a third level, as shown in figure 14. As mentioned above, it is the author's experience that detail at the third level, and occasionally at the fourth level, is sufficient to define the work for first-line supervision.

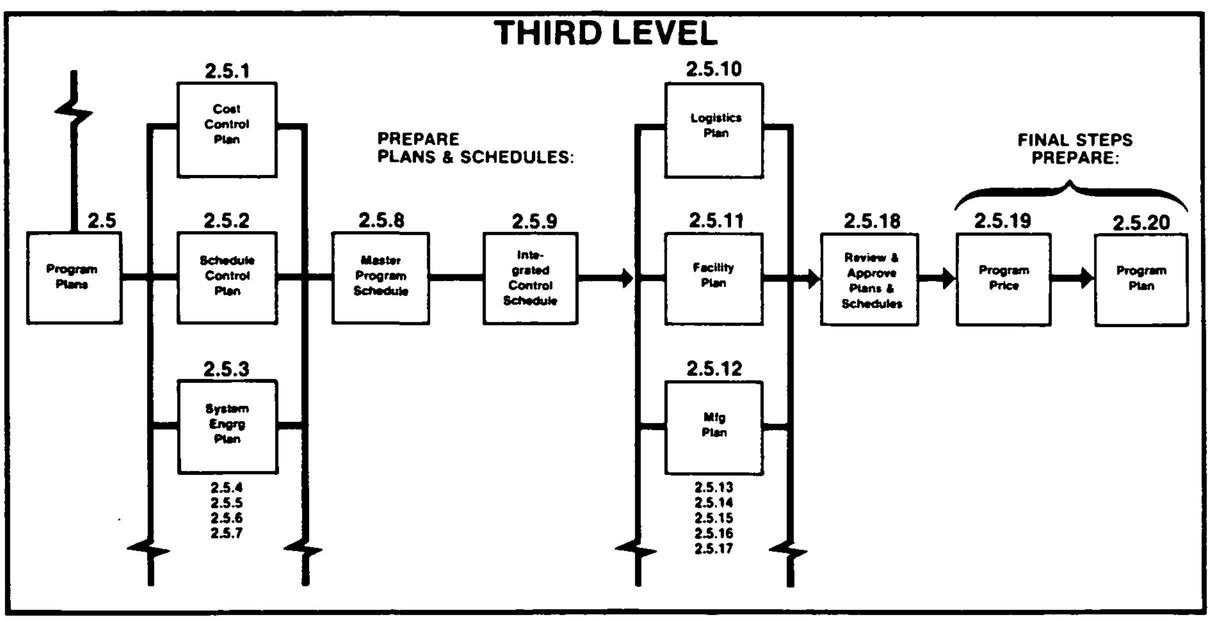


Figure 14

RESPONSIBILITY ASSIGNMENT MATRIX

Each function at the third or fourth level, must now be assigned to an organizational element for execution. In aerospace, 12 entities can accomplish a complex program, viz.:

Plans & Programs (P)
Configuration Management (C)
System Engineering (S)
Test Operations (T)
Design Engineering (E)
Logistics (L)
Procurement (M)
Facilities (X)
Manufacturing (F)
Data Management (B)
Quality Assurance (Q)
Contract Administration (A)

(To formalize the planning process, it is convenient

RESPONSIBILITY ASSIGNMENT MATRIX

Third Level Functions		Plans & Programs	System Engineering	Design Engineering	Procurement	Manufacturing	Others*
2.5.1	Prepare Cost Control Plan	P					
2.5.2	Prepare Schedule Control Plan	P					
2.5.3	Prepare System Engineering Plan		P				
2.5.4	Prepare Config Manage and Plan						
2.5.5	Prepare Quality Control Plan						
2.5.6	Prepare Reliability Plan		P				
2.5.7	Prepare Data and Documentation						
2.5.8	Prepare Master Program Schedule	P					
2.5.9	Prepare Integrated Control Sched Equip Schedule & Allocation	P					
2.5.10	Prepare Logistics Plan						
2.5.11	Prepare Facilities Plan						
2.5.12	Prepare Major Item Procure				P		
2.5.13	Procure Manufacturing Plan					P	
2.5.14	Prepare Test Program Plan		P				
2.5.15	Prepare Engrg Development Plan		P				
Review Plans & Revise Schedule		P	S		S	S	S
2.5.16	Prepare Site Activation Plan	P					

*Qual Assur, Config Mangmt, Test Ops, Logistics, Facilities, Data Mangmt, Contract Adm

Figure 15

to assign letters to each of these organizational entities as indicated.)

For a given organization, these entities may be grouped or contained within organizational elements. It is generally advantageous to proceed with the planning process in a generalized fashion, independent of organizational peculiarities which, in most cases, are transient. The tasks which emanate from the planning process can then be given to existing functional organizational elements, or alternatively, organizational deficiencies will become evident.

Each third or fourth-level function is now assigned as a primary task to one of the 12 organizational entities listed above. It should be emphasized that only one organizational entity has prime responsibility for each task, although support may be required from other organizational entities. The procedure for

DEFINITIONS

- **ACTIVITY — Transitive Verb**
- **FUNCTION — Activity + Object**
- **F'INCTIONAL FLOW — Structured Functions**
- **PROCESS — Functional Flow + Input-Output**

Figure 16

responsibility assignment is shown in figure 15. The letter P denotes prime responsibility and the letter S, support. For example, the third-level function, "Review Plans & Revise Schedule" is the prime responsibility of the organizational entity, Plans & Programs, with support from System Engineering, Procurement, Manufacturing, etc.

OPERATIONAL PROCESS CHARTS

At this point it is necessary to formalize certain definitions peculiar to the planning process as shown in figure 16. Since all programs are end-item oriented, each function must be end-item oriented. Thus, it is not sufficient to define a design function,

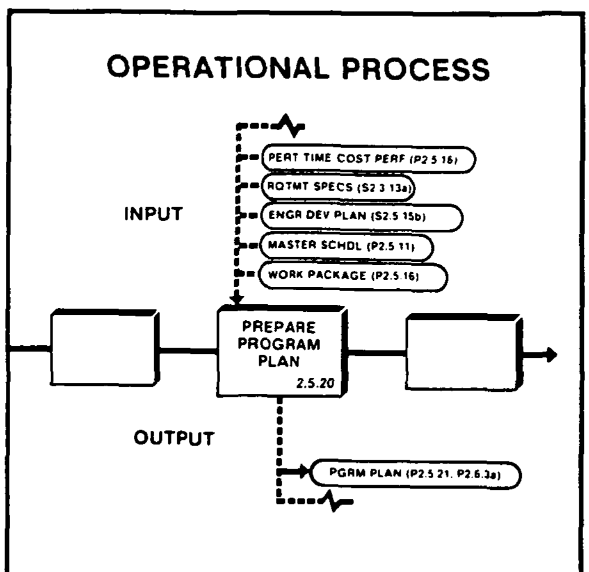


Figure 17

OPERATIONAL PROCESS CHARTS

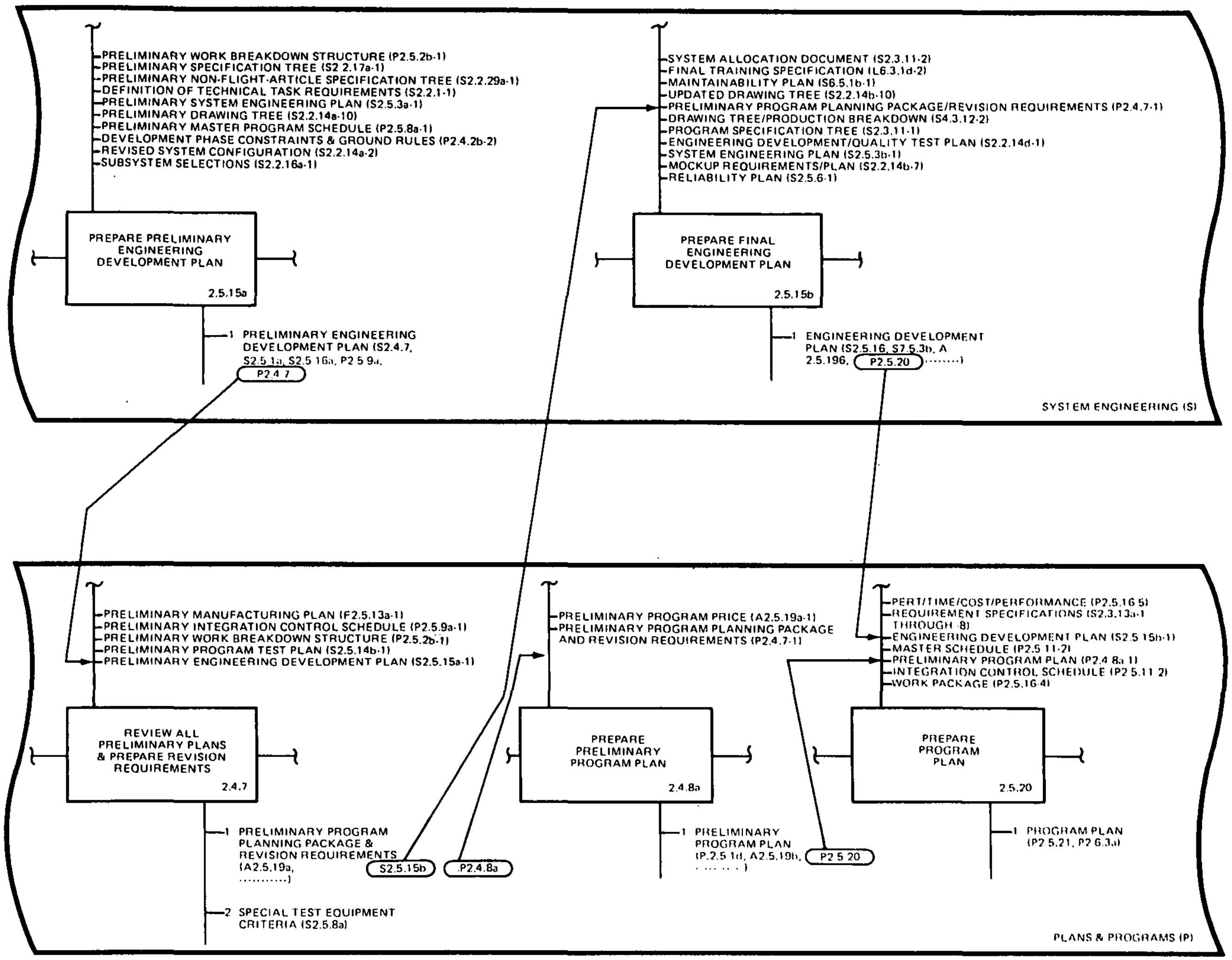


Figure 18

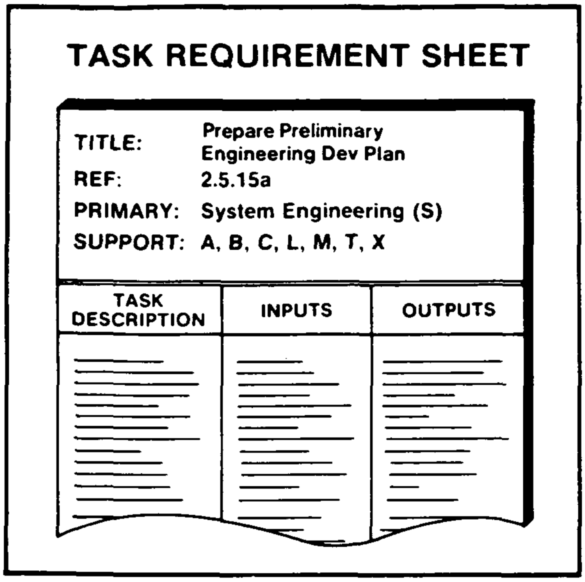


Figure 19

which is functionally oriented, but to define, in addition, the object to be designed. This difference between program management and functional management constitutes the basis for matrix management. Thus, an *activity* (project) is a transient verb requiring an object. A *function* is the activity plus the object. We will now discuss *functional flows* which are structured functions, and *processes* which are functional flows plus inputs and outputs.

In order for the first-line supervision to perform a given task, it is necessary that he or she obtain inputs from other organizations. These inputs must be documented. For example, it is not sufficient that a test be performed; the documented results of the test must be available for others to accomplish their tasks. In formalized program or project planning, inputs, or formalized documentation can be identified as requirements for the accomplishment of each function. The source of these inputs can be identified, both from an organizational and task viewpoint. In figure 17, for example, the first-line supervisor who has the responsibility for the function, "Prepare Program Plan," needs inputs from organizational entities such as, Plans & Programs (P) and System Engineering (S). His outputs, again, documented results of his efforts, go to other organizational elements as inputs to functions. Finally, an operational process is generated which is composed of structured functions along with their associated inputs and outputs. Typical operational process charts are shown in figure 18. Note the crossflow of inputs and outputs. Generalized operational processes for the 12 organizational entities listed previously have been structured for the Definition and Development phases of program management (ref. 6). These have proven to be invaluable in planning complex programs.

TASK REQUIREMENT SHEETS

Once the functions have been defined and inputs/outputs identified, it is now relatively simple to produce Task Requirement Sheets. These sheets can be given to first-line supervision as planning guides and as tools for managing project responsibilities. Figure 19 is an outline of a Task Requirement Sheet. The fourth-level function, 2.5.15a "Prepare Preliminary Engineering Development Plan," is assigned to the organizational element, System Engineering (S), as prime. Support is required from Contract Administration (A), Data Management (B), Configuration Management (C), Logistics (L), Procurement (M), Test Operations (T), and Facilities (X). The task description is a detailed outline of the function, "Prepare Engineering Development Plan." Inputs are the documented results of the tasks performed by other organizations; they constitute the outputs from other functions. In turn, the outputs from this function, that is, the documented results of this task, will constitute inputs to other functions.

INTEGRATING PROCESS CHARTS

Until now, we have dealt with planning a complex program, defining tasks, and assigning them to elements of a traditional functional organization. Over the years, project engineers and program managers have emerged in the aerospace industry because of the complexity of programs. Project engineers have traditionally been hard-nosed people who chased end-items through the complex maze of large, cumbersome, bureaucratic organizations. Often, they have no line authority, but use friend-

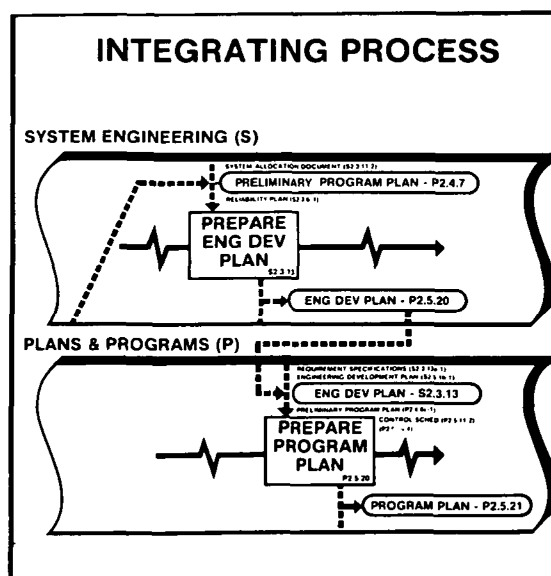


Figure 20

PORTION OF INTEGRATING PROCES

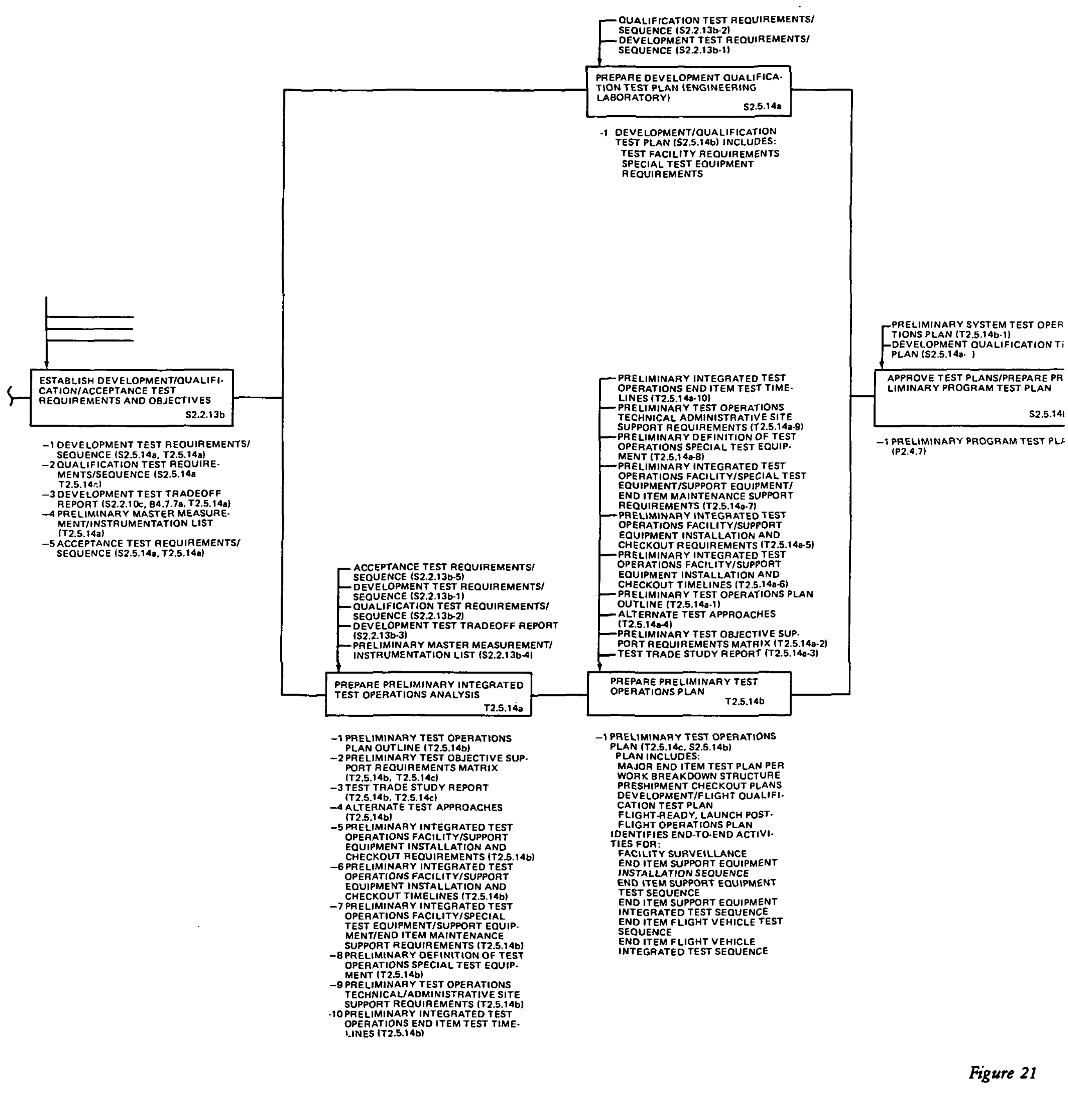
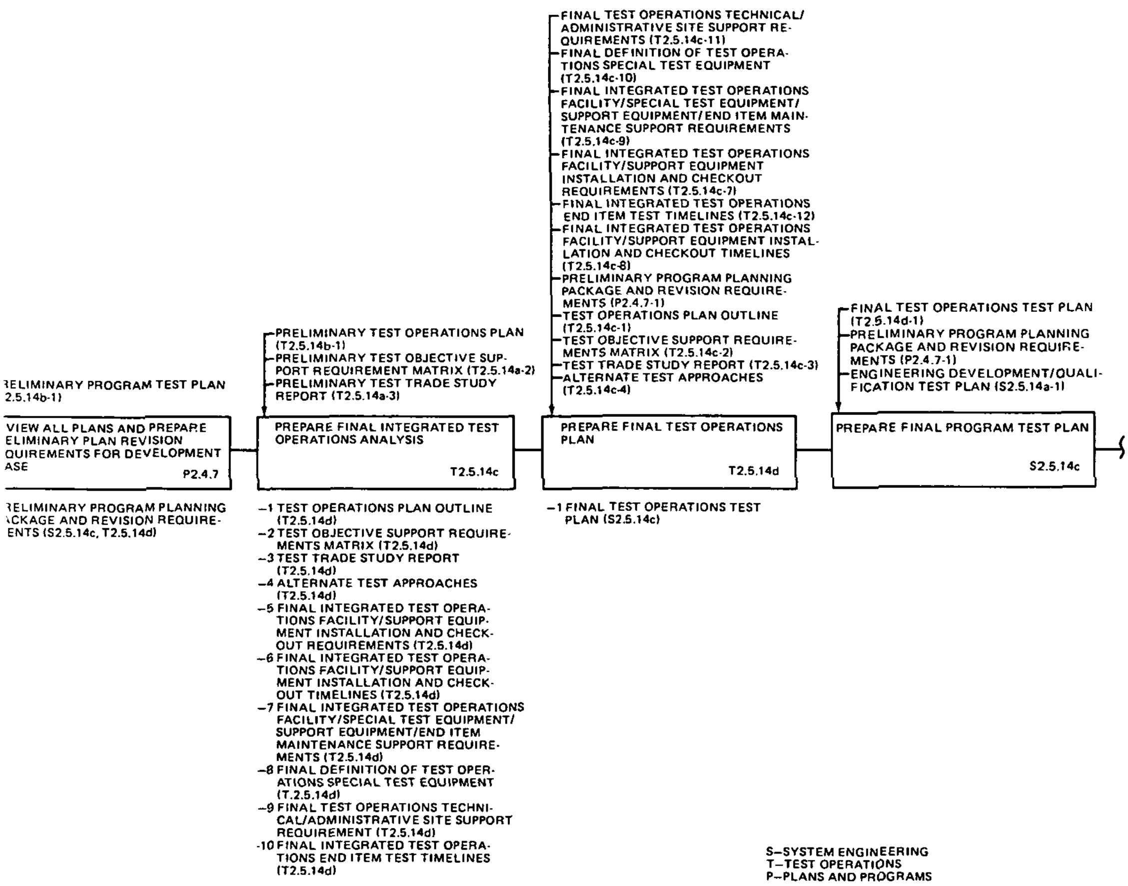


Figure 21

)R PROGRAM TEST PLAN



ship, persuasion, threats, embarrassment, or whatever tactics are necessary to push their end-items through the system. The best project engineer has usually been the toughest, loudest, and most obnoxious of the lot.

With the advent of macrosystems, the ad hoc project engineer has been replaced by matrix management. This concept is manifested in many forms, including powerful project organizations reporting to the program manager or a single coordinator who collects the status of end-items based on inputs from functional managers. The tools for effective management of end-items can be easily developed from the concepts outlined above.

Since the planning process is end-item oriented, one only needs to identify the end-item of interest and trace its path through the operational process charts already generated. In figure 20, for example, the identified end-item, "Program Plan," is an output from the third-level function, "Prepare Program Plan," which is performed in the organizational entity, Plans & Programs (P). To prepare the program plan, inputs, such as Engineering Development Plan, are required. The Engineering Development Plan is generated from the function, "Prepare Engineering Development Plan," which is performed in System Engineering (S). In order to prepare the Engineering Development Plan, a Preliminary Program Plan is required as an input.

Integrating Process Charts can be prepared for each end-item of interest. The inputs and outputs needed to generate the end-items can be identified, organizational interfaces defined, and schedules laid out for the project engineer. Generalized Integrating Process Charts can be made for end-items which are traditionally important to the program manager, such as the final Program Plan. However, for most

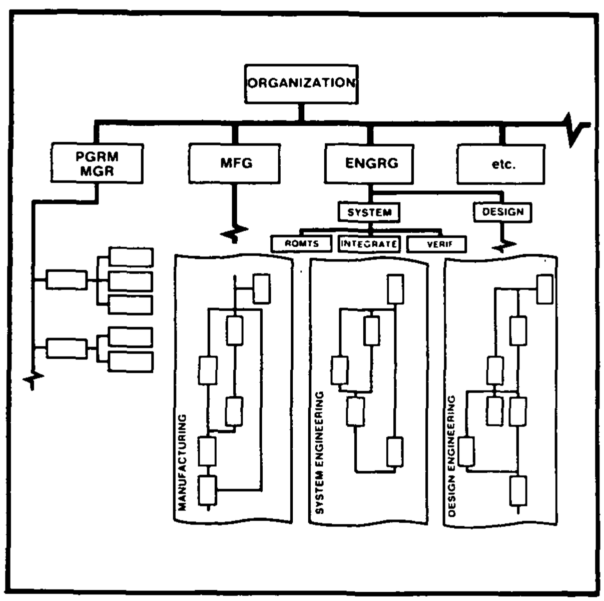


Figure 22

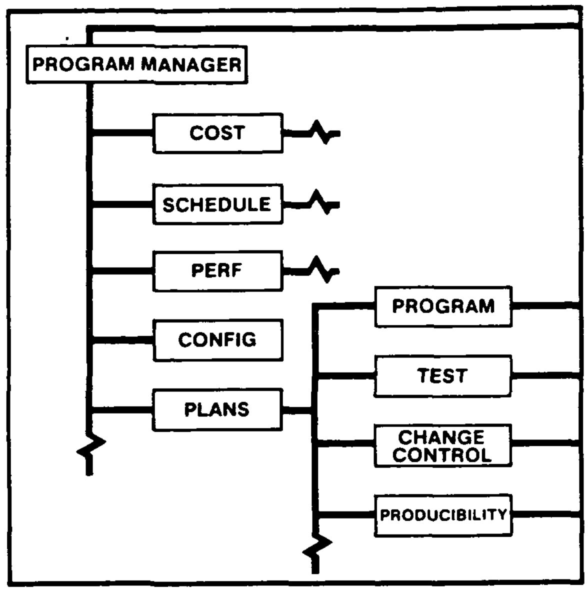


Figure 23

programs, it is necessary to make Integrating Process Charts which are peculiar to a particular program or project. An example of an Integrating Process Chart is shown in figure 21. The chart shows some of the activities of Systems Engineering (S), Test Operations (T) and Plans and Programs (P) along with inputs and outputs leading to the final program test plan.

In lieu of good project planning, the control room was born to track the status of end-items of interest to upper management. Some of these control rooms have indeed been sights to behold with magnetic boards, brilliant colors, and even flashing lights. But when the planning behind these end-items is probed in depth, it often becomes evident that there is little or no substance. How many project hours could be saved with a little forward planning!

MATRIX MANAGEMENT

The planning roadmap of figure 10 has generated Operational Process Charts for the functional organization and Integrating Process Charts for the program management organizations. These planning tools are illustrated in figure 22. Only certain end-items are of interest to the program manager (such as those shown in fig. 23). In addition to project management responsibilities, the functional organizations must retain expertise in several disciplines, generate long-range plans to maintain the enterprise, operate facilities, prepare for future projects, etc. Thus, the functional organization must be responsible for long-range corporate health, while the program managers are concerned with their end-items to satisfy the immediate customers (fig. 23). Upper management must be sensitive to the motives of both functional and program management and

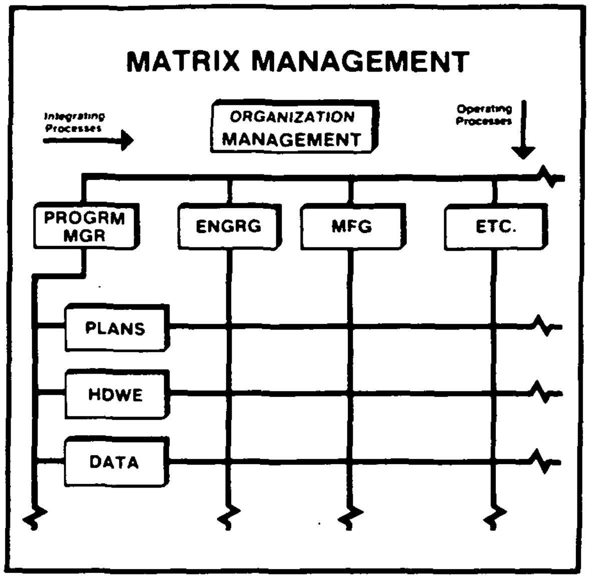


Figure 24

balance priorities accordingly. Even organizations such as NASA are concerned with these conflicting motivations. In NASA, for example, the Space Shuttle is an important program that requires the support of all the NASA centers. On the other hand, the long-range health of the Agency must be preserved for the post-Shuttle era.

A mixed program and functional or matrix organization (fig. 24) is generally the preferred structure for the aerospace industry with its large, complex programs and rigid cost, schedule, and performance standards. Both the program and functional groups benefit. The program is emphasized by designating one individual as a focal point for all matters pertaining to it. Manpower utilization is flexible and cost-effective because a reservoir of specialists is maintained in functional organizations and is employed by the program only when needed. Specialized knowledge is available to all programs, and the transfer of knowledge and experience among programs takes place through the functional organization. Project people have a functional home. Responsiveness to program needs and customer desires is generally faster than for purely functional or for purely project organizations. Management consistency among programs and projects can be maintained. A balance among cost, schedule, and performance can be obtained for upper management through built-in checks and balances.

The establishment of a matrix organization is no panacea (refs. 7 and 8), and conflicts will constantly arise between program or project and functional groups. The tendency of upper management is to support the program since the program needs affect this years profit, or this years budget, or this years customer. "Head Mothers" or functional managers need to be supported for the corporate good. The first step is insisting on good program baselines so that both functional and program management can accomplish adequate planning. An easy but painful alternative is to react to immediate problems, leaving both corporate and customer needs unsatisfied.

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16. Abstract

The matrix management approach to program management is an organized approach to attaining program objectives by defining and structuring all elements so as to form a single system whose parts are united by interaction. The objective of the systems approach is uncompromisingly complete coverage of the program management endeavor. Starting with an analysis of the functions necessary to carry out a given program, a model must be defined; a matrix of responsibility assignment must be prepared; and each operational process must be examined to establish how it is to be carried out and how it relates to all other processes.

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