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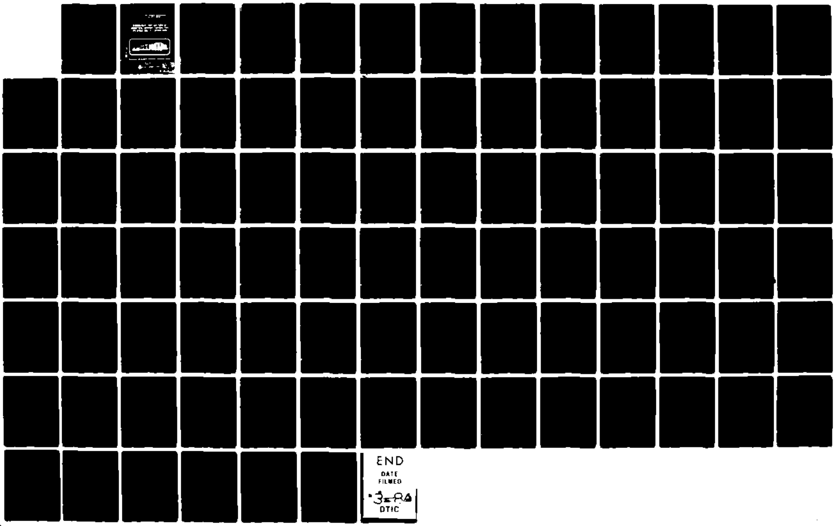

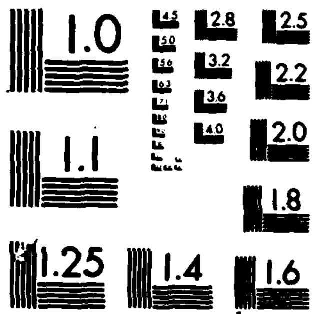

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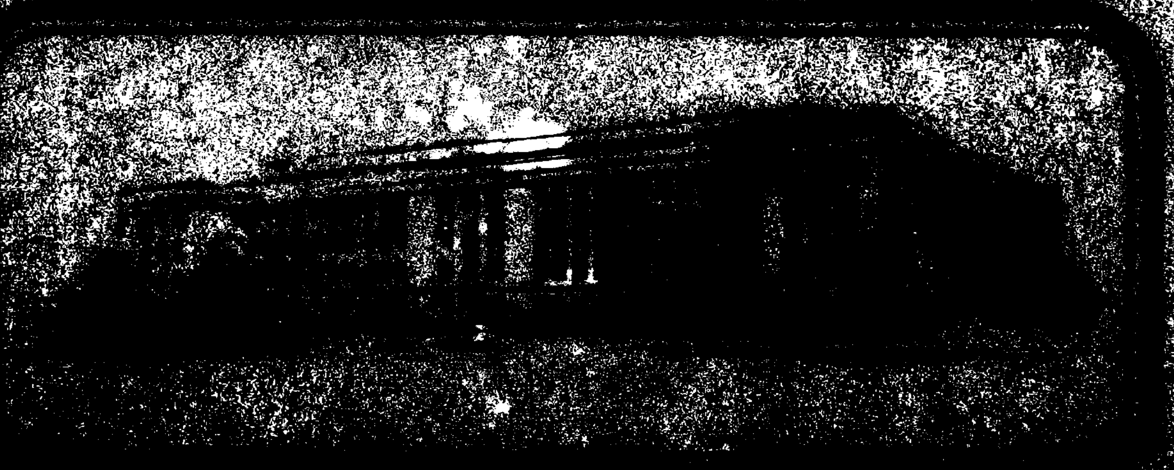
MANAGEMENT IMPLICATIONS OF INDUSTRIAL SUPPORT CAPABILITIES FOR SPACE SHUTTLE OPERATIONS



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This study examines implications of Space Shuttle logistics support concepts and policies, which have been planned to rely heavily on contractor or vendor support through a substantial portion of the system's operational life, especially in the areas of spares and maintenance. The analysis focuses on the effects of open production lines and the impact on logistics support if production is completed or terminated, with ensuing shutdown of those lines. Unique characteristics of Space Shuttle support in terms of equipment, organizational roles, and funding and cost are identifies, and risks associated with both operational support and funding

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INDUSTRIAL COLLEGE OF THE ARMED FORCES
NATIONAL DEFENSE UNIVERSITY

INDEPENDENT RESEARCH PROGRAM REPORT

MANAGEMENT IMPLICATIONS OF INDUSTRIAL SUPPORT CAPABILITIES FOR SPACE SHUTTLE OPERATIONS

by

JON F. REYNOLDS, COL., USAF
JAMES L. GRAHAM, JR., LT. COL., USAF

A RESEARCH REPORT SUBMITTED TO THE FACULTY
IN
FULFILLMENT OF THE RESEARCH
REQUIREMENT

RESEARCH SUPERVISOR: COL. WALTER J. RABE

INDUSTRIAL COLLEGE OF THE ARMED FORCES

MAY 1983

TABLE OF CONTENTS

DISCLAIMER-ABSTAINER

ABSTRACT OF STUDENT RESEARCH REPORT

INDUSTRIAL COLLEGE OF THE ARMED FORCES

NAME OF RESEARCHER(S)	TITLE OF REPORT
Jon F. Reynolds, COL, USAF James L. Graham, Jr., LT COL, USAF	Management Implications of Industrial Support Capabilities for Space Shuttle Orbiter Operations

SECURITY CLASSIFICATION OF REPORT	REPORT NUMBER
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ABSTRACT

This study examines implications of Space Shuttle logistics support concepts and policies, which have been planned to rely heavily on contractor or vendor support through a substantial portion of the system's operational life, especially in the areas of spares and maintenance. The analysis focuses on the effects of open production lines and the impact on logistics support if production is completed or terminated, with ensuing shutdown of those lines. Unique characteristics of Space Shuttle support in terms of equipment, organizational roles, and funding and cost are identified; and risks associated with both operational support and funding are addressed.

Problem Statement. To achieve the stated STS Program goal of maintaining operational launch schedules, there must be improved allocation of resources and timeliness of support decisions during FY 83 to FY 86 in postproduction Space Shuttle operations support.

Conclusions. Specific support problems being faced by the Space Shuttle program and the Orbiter project follow:

1. The end of production is approaching, with an accompanying loss of logistics support resources.

2. Support contracts are expiring, threatening a serious loss of skills and other support capabilities.

3. Excessive charges by contractors are being experienced.

4. Delays in funding and procurement have caused a possible period of nonsupport.

5. Repair times for failed hardware are greater than anticipated.

Recommendations. Fifteen recommendations encompassing three broad strategies are proposed, covering:

1. Maintenance and other support efforts.

2. Hardware acquisition, especially spares.

3. Support management systems and procedures.

EXECUTIVE SUMMARY

The Space Shuttle is intended to be the nation's primary space launch vehicle --- the principal means to space --- for both civilian and military payloads.

This study examines the implications of the Space Shuttle logistics support, of the concepts and policies, which have been planned to rely heavily on contractors or vendors through a substantial portion of the system's operational life, especially in the areas of spares and maintenance. The analysis focuses in particular upon the effects of open production lines and the impact on logistics support if production is completed or terminated, with the ensuing shutdown of those lines. Risks associated with both operational support and funding are addressed.

The Space Shuttle Orbiter is used as a case study and example of a system for which development test and operations have depended heavily upon vendor production lines for logistics support. The study centers on the key management decisions needed in logistics support of the Shuttle as an operational system.

The central hypothesis is that, to achieve the stated Space Transportation System (STS) Program goal of maintaining operational launch schedules, there must be improved allocation of resources and timeliness of support decisions during the period FY 83 to FY 86 in postproduction Space Shuttle Orbiter operations support. A conceptual basis is developed for the review involving budgetary and funding decisions addressing the questions of how much, where, and when. The answers to these questions form the basis of executive decisions in support of a given program or project, and they form the constraints or boundaries within which lower organizational levels carry out program objectives and tasks.

The paper proposes some key steps that seem essential to establish and preserve a viable logistics support base for the Shuttle, particularly the Orbiter. Proposed strategies involve:

* Maintenance and other support efforts.

* Hardware acquisition, especially spares.

* Support management systems and procedures.

A survey and economic analysis of support sources is an essential first step to avoid a major logistics support crisis. A comprehensive economic trade study would be useful in developing a long-range support base structure and strategy.

The DOD depots operated by the military services have been largely ignored to date as sources of maintenance and repair for Shuttle items. NASA should begin now to identify selected Shuttle items, both ground support equipment and flight hardware, that can be more economically supported by DOD depots, and should establish an organized set of pilot repair programs at these depots.

Another way to reduce risk to Shuttle support is to contract with selected manufacturers or vendors for an in-place, standby maintenance capability.

Further actions are needed to build up the intermediate-level repair capability both at launch sites and perhaps at the test facilities.

Completion of the Intermediate and Depot Maintenance Manuals (IDMM's) is another relatively straightforward action that would vastly improve flexibility of Shuttle repair and also would seem to reduce support risk.

Based upon the high support risks caused by suppliers leaving or intending to leave the Shuttle program, economic analyses should be conducted on the desirability of procuring the total life cycle spares needs for selected critical items.

All needed shop replaceable units (SRUs) and repair parts should be identified and procured from current vendors before production ends.

Remaining technical data required should be obtained as soon as possible.

NASA should consider consolidating most, if not all, off-line support under a single support contractor (SSC).

NASA should increase its emphasis, priority, and funding on establishing integrated support data bases and information management systems across the entire Shuttle system.

NASA should also establish a critical item management system, in order to provide close management control of high-value, small-population items and other pieces of equipment that may have unusual characteristics.

NASA should move aggressively to develop an improved spares requirements model, especially for recoverable (i.e. reparable) items.

In addition to an improved spares requirements model, NASA should develop a closely related model to provide a quantitative assessment of logistics capability and posture.

NASA should begin now to develop the necessary framework for buying support and test equipment, technical documentation, engineering and configuration data, and other support items, and for smoothly transferring this capability into an organic support activity.

CHAPTER I

INTRODUCTION

OVERVIEW

Purpose

The Space Shuttle is intended to be the nation's primary space launch vehicle --- the principal means to space --- for both civilian and military payloads. The U.S. capability to take advantage of the space environment will depend greatly on the degree to which space-related systems like the Shuttle are supportable in a practical sense. Space Shuttle support so far has been characterized by a significant reliance on vendor production lines and use of assets already in the system for other reasons. This approach, if continued, presents risks in being able to process and launch on schedule. The current political and managerial environment is one of resource shortfalls and detailed scrutiny of budgets, priorities, and mission requirements. Development of support strategies and risk assessments, therefore, is of paramount importance in management decisions for a system so vital to our national interests and defense. This paper attempts to assess support planning and philosophy, with the objective of affecting resource allocations.

Scope/Content

This study examines the implications of the logistics support concepts and policies that rely heavily on contractors or vendors through a substantial portion of a system's operational life, especially in the areas of spares and maintenance. The analysis focuses in particular on the effects of open production lines and the impact on logistics support if production is completed or terminated, with the ensuing shutdown of those lines. Risks associated with both operational support and funding are addressed.

Methodology

To provide a framework for analysis and discussion, the Space Shuttle Orbiter is used as a case study and example of a system for which development test and operations have depended heavily upon vendor production lines as a source of logistics support resources and services. The study centers on the key executive and management decisions needed in logistics support of the Shuttle as an operational system.

Hypothesis/Problem Statement

To achieve the stated STS Program goal of maintaining operational launch schedules, there must be improved allocation of resources and timeliness of support decisions during the period FY 83 - FY 86 in postproduction Space Shuttle Orbiter operations support.

BACKGROUND

General

A large number of new systems, especially space systems, are characterized by their very advanced technology, small populations, and high unit costs. Rather than invest heavily in the expensive support systems needed for an organic support capability, an attractive alternative has been to develop and retain the required support through a contractor who has built up a large portion of this capability by developing and producing the system or its components. Moreover, as long as the production lines remain open, they serve as a contingency source of supply. This situation reduces the apparent number of separate spares and component parts otherwise needed if the production lines were no longer in operation, and consequently reduces "up-front" costs of support planning and implementation. In effect, the open production lines serve as a "warm industrial base" for the support of on-going or even expanded system operations.

Serious risks to system operations and mission requirements are inherent in this type of support concept, however, particularly near the end of production. If production is completed or terminated before the end of the operational life of the system, a full complement of required spares must be acquired to offset the prior dependence on the open production line. Furthermore, if the vendor has also been using part of a production line or related test facilities for maintenance or repair of failed items previously delivered, a new source of repair will have to be established, with attendant costs of capital investment, support equipment, acquisition of technical data, training, and recertification of quality control. Acute management and financial problems can arise when a vendor ceases activity in a program without adequate anticipation and without proper funding of alternative means of support by the vendor.

Vendors may wish to discontinue their involvement in programs for many reasons. Follow-on production quantities or repair activity may not appear profitable. Firms may wish to devote their efforts to newer technologies and new programs. Companies may simply go out of business. Because of the severe impact that an unplanned departure of a vendor can produce in system operations, it is essential that management decisionmakers understand the full implications of production line and vendor support, both pro and con, as a basis for minimizing risks to their programs.

STS/SPACE SHUTTLE PROGRAM

System Description. The Space Shuttle is a part of the national Space Transportation System, or STS. The Shuttle flight vehicle itself has several major elements, with the Orbiter as the major reusable Shuttle component. The Space Shuttle Main Engines (SSMEs), although physically installed in the Orbiter, are a separate Shuttle element, as are the Solid Rocket Boosters (SRBs) and the External Tank (the ET is the only non-reuseable element of the Shuttle system). Although the Shuttle is the major STS element, also key in the STS are the European-developed Spacelab, the Inertial Upper State (IUS developed by the USAF), other upper stages, flight crew and ground support equipment, and the east coast and west coast launch sites at Kennedy Space Center (KSC) and Vandenberg AFB (VAFBO respectively.

Development and Test. Shuttle design, development, test, and evaluation (DDT&E) began in the mid-1970s and included production of the initial test Orbiter, OV101, "Enterprise." This vehicle was used primarily for the Approach and Landing Tests conducted during 1977, in which the Orbiter was released in flight from its carrier aircraft and was flown to a dead-stick landing. Between 1978 and 1980, the SSMEs, ETs, and SRBs continued to be tested and qualified for flight; Orbiter OV102 "Columbia" was delivered; and ground launch facilities at Kennedy Space Center were essentially completed. With the first STS mission in March 1981, the Orbital Flight Test Phase of DDT&E began; and it continued through the completion of the fourth flight in July 1982. This sustained development activity led to the beginning of the STS Operations phase with the fifth STS mission in November 1982.

Operations and the STS Mission Model. The STS will continue to be launched, flown on missions of various types, recovered, and processed for re-launch, all at a greatly increasing rate. By 1988 it is planned that flights will be occurring 24 times per year, 18 each year at KSC and 6 per year at Vandenberg AFB, using a fleet of four Orbiters. DOD plans to utilize the Space Shuttle extensively, even in a mixed fleet environment consisting of both the Titan 34D and the Space Shuttle.

In terms of dollars required, recent budgetary estimates for Orbiter logistics requirements alone have approached $1.75 billion. This is comprised of approximately $400 million for investment spares, more than $800 million for sustaining spares, and nearly $500 million for overhaul and repair of equipment, and even these estimates may be low.

NASA and the DOD are partners in the STS program, with the Air Force being the executive agent for the DOD. NASA has been directed to develop and produce the STS flight vehicle as described above and the Kennedy Space Center (KSC) launch site. The Air Force is responsible for the VAFB launch site and the Inertial Upper Stage (IUS).

Both NASA and the DOD have had contractors engaged in primary design, developme nt, test, and production of their respective equipment and facilities. Rockwell International is NASA's prime contractor for Space Shuttle integration as well as Orbiter development and production. The External Tank was developed and is being produced by the Martin Marietta Co., at the Michoud Assembly Facility, Louisiana. The Space Shuttle Main Engines are built by the Rocketdyne Division of Rockwell International, located in Canoga Park, California. The Solid Rocket Boosters consist of solid motor assemblies developed and produced by Thiokol Corporation, Wasatch, Utah, with system components produced by various aerospace firms, all assembled and checked out by USBI (United Space Boosters, Inc).

NASA employs numerous contractors at its KSC launch site to process Shuttle components and end items in preparation for each launch. This launch site contractual arrangement is evolving quickly as operations progress It is planned that in the near future essentially all launch site processing for STS launches will be performed by one of three primary contractors, yet to be selected: the SPC (Shuttle Processing Contractor), the CPC (Cargo Processing Contractor), or the BOC (Base Operations Contractor). This change is being made by NASA to save the cost of the government integrating the dozens of individual contractors previously involved separately. It also takes advantage of anticipated economies of scale possible when a single contractor can be responsible for essentially all phases of a major part of a project. The Air Force has agreed to participate with NASA in utilizing the SPC for launch processing at VAFB as well as at KSC and has made major contributions to preparations for that contact.

CHAPTER II

GENERALIZED ANALYSIS

Before analyzing the details of Space Shuttle support capabilities, a conceptual basis will be developed for the review that follows in Sections III and IV.

EXECUTIVE LEVEL DECISIONS

At the executive management levels, decisions basically deal with one resource: money. In particular, budgetary and funding decisions address the following three questions:

* How much?
* Where?
* When?

The answers to these questions form the basis of executive decisions in support of a given program or project, and they form the constraints or boundaries within which lower organizational levels carry out program objectives and tasks. Normally, decisions in each of these three categories are based upon extensive justifications and arguments described in terms of how the money will be spent and results will be achieved. But the questions themselves are directed toward fundamentally differernt (although related) issues in terms of their concepts, analysis, and implementation.

Requirements Decisions

The first question, "How much?", relates to the requirement for resources (and in the immediate context here, funding) in the aggregate. Requirements will depend heavily upon how the money will be allocated to different portions of the whole program as well as upon when the money will be spent. The challenge for lower management levels is to conceive and identify the most efficient allocations and schedules to minimize the total requirement.

Cost estimating relationships, forecasting techniques, and other analytic tools used for estimating total requirements are often more simplistic than those for allocation decisions. On the other hand, to the extent that allocations and schedules can be reflected in quantitative models, predictions of total requirements should be inherently more accurate.

Allocation Decisions

The second decision category, "Where?", is concerned with allocation. Allocation decisions determine how resources (or funds) are to be distributed among the various components and subdivisions of a project and its input variables. These decisions both affect and are affected by program requirements, because different levels of available funding can constrain the allocation process to produce different decisions; conversely, different allocation schemes can yield varying resource requirements. Typically, resource allocation problems are solved iteratively from both directions to arrive at the preferred solution.

Analytic tools such as mathematical programming can sometimes be effective aids in attacking allocation problems, at least insofar as the decision variables and the system objectives are subject to quantification. At the highest decision levels, however, judgment and subjective analysis will still play dominant roles.

Timing Decisions

The third question "When?", relates to the timing or scheduling of resource allocations. Variable lead time and activity times to accomplish different project tasks, synchronization and sequencing constraints on project activities, and the time value of money (as well as inflation) all influence timing decisions. In addition, fiscal constraints and budgetary realities, as well as priorities of competing programs or projects, can also have dramatic effects on resource timing decisions, often with significant consequences for total resource requirements.

Quantitative methods in capital investment, equipment replacement, and engineering economy can frequently be employed to assist in resource timing decisions. Often, though, heuristic and opportunistic approaches are necessary and may be nearly as effective as rigorous quantitative tools in scheduling resource allocations.

LOGISTICS SUPPORT BASE

The logistics support base for an operational system possesses numerous attributes. For discussion purposes here, however, it will be useful to focus on three aspects of the support base:

1. Capabilities of the logistics support base in terms of its productive output and ability to support the operational mission and activity level.

2. Locations, including physical or geographical positioning as well as organizational and functional characteristics.

3. Development and evolution of the support base.

Although the second of the items above, Locations, could conceivably be wrapped into the broader topic of Capabilities, its implications are sufficiently significant by themselves to warrant separate treatment. Also, as will be seen, there is a rough parallelism between these aspects of the logistics support base and the three resource categories of requirements, allocation, and timing.

Capabilities

From a very general, conceptual perspective, the capabilities of the logistics support base can be described in terms of two attributes:

1. Services or functions that the support base provides or performs.

2. Capacity of the support base services and functions to fulfill the needs of various levels of operational activity.

The principal purpose of the support base is to make the operational system ready and available and to sustain this readiness through the planned mission activity levels or operational schedule. As a part of this objective, the support base also monitors the operational system performance and generates engineering changes or modifications to insure that the system can accomplish its intended mission or function.

Primarily, the logistics support base focuses on availability and, in particular, supportability. Here, the objective is to attain timely turnaround from one operational mission to the next. The restoration of the system involves three basic activities:

1. Servicing, including preventive maintenance, routine checkout and system tests, and replenishment of consumable items.

2. Replacement of faulty items or those of limited or questionable mission capability.

3. Repair of items to restore them to serviceable condition.

These activities are not mutually exclusive, and any given item or piece of equipment could be subject to all three processes. Figure 1 summarizes the conceptual relationships between these activities and the objective of the logistics support base.

It should be emphasized that there are important economic tradeoffs among these three restoration activities. The support resources needed for each of these activities, although possessing a number of elements in common, differ substantially in capability, responsiveness to mission schedules, and, especially, cost to acquire and maintain. Whereas the overall capability of the logistics support base is directly related to the issue of total resource requirements addressed previously, the efficient distribution of resources across the restoration activities and among the assorted services and functions of the support base is an allocation decision problem. A typical example would be the question of investing in more spares or in additional repair capability to increase the velocity of existing spares through the logistics pipeline. The resolution of this issue and others similar to it entails consideration of a host of implications for many of the other services, functions, and resources in the support base, such as transportation, facilities, technical data, support and test equipment, manpower and skill mixes, training, software or other computer resources support, and management information and control systems. These major components of the logistics support base are depicted in Figure 2.

A fundamental difficulty in solving these resource allocation problems and in performing the economic tradeoffs is to quantitatively model the interrelationships among the different resource inputs. In addition to the uncertainty in the relationships and the probabilistic nature of the demand for spares and other support services, there is considerable uncertainty in the estimates of associated costs. The complexity of allocation problems is compounded even further by lead times, activity times, and other timing or scheduling issues, along with their own inherent uncertainties. Allocation decisions pose some of the most challenging management problems in achieving and preserving an effective logistics support base. Many quantitative tools and models are available to assist in this decision process, but they must be tailored to the specific logistics support base and system operational concepts if their outputs or results are to be reliable as a basis for decisions. When these tools and models fall short in their ability to represent the problem or to capture all the relevant variables, decisionmakers must necessarily rely more heavily on subjective judgment and common sense.

Locations

The word "locations" as used here is meant to imply a broad concept of the overall relational structure of suport sources, including physical, organizational, and functional attributes. Within the scope of this subject lies an almost infinite set of combinations of support sources, geographical locations, interrelationships, and services and functions provided by the support services. As a brief illustration, maintenance, overhaul, and repair of items may be performed at each of several hundred manufacturers or vendors; or they may be consolidated at a single or small number of contractor facilities, or at an on-site central facility (i.e. at the location of system operations). Spares may be positioned on-site and dedicated to the turnaround of the system or may be viewed as the total population of existing assets, including those installed in other systems or already committed to other production installations. Engineering and other technical data may be comprehensive and complete, thereby allowing easier transfer of support services from one source to the other; or they may be sketchy and vague with strong reliance on experienced personnel to accomplish critical tasks. Maintenance and test equipment may be general purpose and usable on a variety of items or it may be specialized and unique. Transportation modes may provide low-cost, commercial carrier handling; or they may routinely furnish expensive,expedited shipping of parts as a means of meeting operational schedules because too few spare assets are in the logistics pipeline. Vendors and subcontractors may continue as the primary sources of various support services, such as sustaining engineering, configuration management, and maintenance and support planning; or these activities may be centralized at either a major contractor or government location or organization.

Again, the specific structure and interrelations to be selected present an allocation decision problem. Moreover, because of the greater ambiguities in this type of problem, which is implicitly one of organizational design and synthesis, it is inherently less tractable by quantitative methods and techniques. Heuristics and rules of dominance (i.e. common sense) emerge as more useful, if not essential, approaches for dealing with these problems, at least at the aggregate level.

Development and Evolution

The form, structure, functions, capacity, locations, capability, and other characteristics of the logistics support base are the results of managerial decisions and actions. These decisions may be directed toward some overall objective support system; or, as is all too often the unfortunate case, they may comprise a series of piecemeal, patchwork responses to shifts in priority and to budget constraints. The design of an effective, economical logistics support base, tailored to the support requirements of the primary system and considering exploitable features of any existing logistics support infrastructure, is an essential first step of acquisition logistics (along with designing supportability into the primary system). Having established a target logistics support base, which may, in fact, be a sequence of planned support structures and capacities synchronized to the projected growth and expansion of the usage of activity levels of the system supported, the next task is to effect a strategy of management actions leading to the desired support base.

In contrast to a well-conceived, disciplined approch to its development, the support base may merely evolve as a consequence of reactive decisions made in a "firefighting" mode to stave off some crisis. Not only can this procedure be detrimental to the basic system mission by adding to uncertainties in mission performance, but it also can be very inefficient and costly. A typical situation that can lead to nonoptimal decisionmaking is one in which support funds are diverted to solve near-term technical difficulties in the primary system. In other attempts to get by within available budgets, engineering and technical data may not be bought, frequently resulting in being locked-in to an increasingly expensive sole-source contractor. Numerous other examples can be cited of ways in which efforts to build a support base rationally are often thwarted.

It is also true that basic changes in program scope and activity can properly drive prudent adjustments to the support base design. If mission activity expands (such as through a planned step-up in launch rate or sortie rate or an increase in the number of primary mission systems), modifications to the support base development strategy may be appropriate. Ideally, a sound logistics support base development strategy should accommodate program changes, including overall funding.

One of the greatest management challenges in designing and developing a logistics support base is to measure support capability. The ability of the support base to satisfy operational mission requirements over a range of activity levels is difficult to estimate and especially resistant to quantification. Nevertheless, at least a rough, subjective assessment of logistics support capability is implicit in almost every support resource allocation and requirements decision. What is needed are more reliable figures of merit and quantitative measures of support capability as a basis for better and more timely decisions.

This latter decision characteristic, timeliness, is perhaps most curcial to the orderly development of the logistics support base; and it is at the same time most seriously impaired by a lack of support capability measurement. If the impact of, say, trying to get along with fewer spares cannot be translated into a quantitative degradation of mission performance or increased life cycle costs, management may not be sufficiently motivated to take corrective action. The consequence may be to simply make-do, focus on the front-end "cash flows," and limp along with an inefficient support base. Through the management visibility into mission performance, logistics support capability measurement (both for prediction and historical assessment) may well be the key to aggressive and early requirements and resource allocation decisions leading to the rational development of an appropriate and economical logistics support base.

CHAPTER III

SPACE SHUTTLE SUPPORT ANALYSIS

The executive decisions affecting Space Shuttle support have necessarily varied as the program has evolved. Although these decisions generally fit the categories under "General Analysis," they will be examined in this chapter with regard to conceptual, equipment, organizational, and funding related issues.

CONCEPTS AND STRATEGIES

DDT&E

The logistics support for development was of a different nature than that necessary for full-scale operations. Logistics support in development relied heavily on the fact that the system was still in its infancy, launch rates were low, some design work was yet to be done, development contractors were still involved in system test and operation, and configurations were expected to continue changing through the successful completion of development. Inasmuch as production was just beginning on the remaining operational vehicles, NASA management was able to plan to use production components to meet logistics requirements. In some cases, production components were already on hand, as well as test units for many subsystems. This seeming wealth of hardware, coupled with the relative immaturity of the program, led to postponing expenditure of the large amounts of money that were agreed to be eventually needed for Shuttle operational logistics support.

As a result, during DDT&E, there was justifiable confidence that there would be sources of hardware and ways to perform the required priority maintenance. Substantial sums were in fact spent for spares for the DDT&E phase. During this time, baseline methodology was set up in almost all the logistics disciplines, and the limited support needed for development was there when it was needed. The decisions made with respect to delaying preparations for long-term logistics support were justified on the basis of the higher priority demands of development and production schedules. Even more important for the long run, efforts were begun during DDT&E to define and start acquiring the hardware, data, maintenance and transportation capabilities, and support systems that would be needed for operations.

Operations

The strategy for supporting the Shuttle in its operational phase has been to continue as long as feasible in the "piggyback" or deferred procurement mode originated during DDT&E. The rationale has been that the longer such costs can be deferred, the better for the development and production aspects of the program. Engineering managers tend to feel that support expenditures detract from the amounts needed to continue developmental improvements or even procure end items (additional Orbiters, for example). Consequently, these support expenditures were intentionally decreased in budgets that supported the early operational period.

Maintenance work to support spare hardware turnaround has been planned for (and accomplished to date) at the original vendors' plants in most cases. This has allowed for continuity of skills, general availability of repair parts, and timeliness of repair, because there has been on-going production for later vehicles occurring simultaneously.

A major issue in the Shuttle program (and the major issue in this paper) is whether such a support strategy can be continued further into the Shuttle operational phase. By delaying expenditures on support for vehicles and mission rates already planned or in being, a considerable risk is assumed, perhaps without a full appreciation of the probability of it occurring. The risk can be highlighted in the following scenario:

It is July 1983. Orbiter OV103, "Discovery," is expected to be delivered on time within three months. Final major assembly and initial checkout of Orbiter OV104, "Atlantis," is proceeding on schedule for an expected delivery in December 1984. As of this date, essentially all component parts and major line replaceable units for 104 (and unquestionably all for 103) have been completed by subcontractors. A substantial quantity of spare parts have been ordered, primarily LRUs (line replaceable units) and major SRUs (shop replaceable units); and assembly work on those items is continuing at selected vendors. OV105 continues as a possibility, although it is not in the approved budget.

Many subtier vendors who have not yet received orders for follow-on spares purchases have already decided to move on to other product lines, to DOD contracts, or to otherwise make themselves unavailable as a source of parts or repair for their non-finished part of the Shuttle program.

In some cases, equipment used in the production program for checkout of newly produced items (and repair of returned units), has been transferred to another program, moved to make room for current manufacturing or development activities, or has reached its practical life limit.

Repair parts are still available in small numbers within subcontractors' facilities, but there is not a broad range of parts nor sufficient depth to do frequent repairs, should this be necessary. The possibility of obtaining repair parts from their own subvendor is fading rapidly, because the stage at which they are now was reached many months earlier by bit-and-piece suppliers.

The funding available so far to procure initial spares has been used primarily for long-lead line replaceable units in relatively small quantities to meet on-line turnaround requirements. No dedicated funding has yet been made available to set aside or guarantee that a complete range of repair capabilities is in place in case of a requirement.

The launch rate should soon approach one a month. Although Shuttle component failures have been seen at a lower than expected frequency, the increasing launch rate continues to generate a steady flow of reparable components, the repair of which will depend upon an expected vendor repair capability that is becoming unavailable.

EQUIPMENT CONSIDERATIONS

Space Shuttle equipment varies widely in complexity, characteristics, and physical attributes. These variables can each have singular or interactive effects on how the system must be supported.

Item Population

The item population for most Orbiter hardware is relatively small, inasmuch as plans are now to launch only four Orbiters from two sites. This includes an installed quantity, based on the number in each vehicle times the number of Orbiters in operation. Planned spares are another component of item population, and for the Orbiter this quantity is still generally small. The repair cycle can account for a significant portion of total system assets, depending on several other variables to be covered later: repair turnaround time (TAT), and failure rate or maintenance demand rate. In the past a number of assets have typically been in the "to-be-installed" category, available after their own production is complete but prior to the need date for their incorporation into an end assembly or Orbiter. Items located in test facilities and laboratories such as the Shuttle Avionics Integration Laboratory (SAIL) may also comprise a significant portion of total system assets (and demands for spares as well), although these test assets may sometimes not be qualified or qualifiable as flight units.

Reliability

Reliability of Orbiter hardware has been excellent in most cases. The irony of high reliability in the low-volume Shuttle environment is that the relatively slow rate of reparable generations tends to make the establishment and maintenance of dedicated repair facilities uneconomical. In cases where reliability is not up to specification, modification programs have been initiated even during late development to upgrade the item (e.g. landing gear, leading edge structural subsystem). This has the effect of decreasing the maintenance demand rate and, correspondingly, the flow through a repair facility.

Cost

Unit cost varies considerably, from small seals, rings, and connectors to the multimillion dollar cost of major subsystems such as the OMS (Orbital Maneuvering Subsystem) engine or KU Band radar system. Cost variability in an item's life depends on the number of units procured, lead time, availability of critical materials and processes, and accuracy of earlier cost data accumulated or estimated during DDT&E. Apparent cost increases of an order of magnitude resulted during the early operations planning period when several of these factors compounded each other. These increases could have been real or only apparent, but in any case they were cause for alarm and reassessment of the estimating process. Unexplainable cost variances can have a major impact on timely processing of spares provisioning orders and their resulting contracts.

Design Stability

Some Orbiter items are expected to have design changes in the foreseeable future. The Auxiliary (or hydraulic) Power Unit (APU) is one such example. In these cases there is understandable reluctance to buy many spares of a configuration likely to be superseded. If it can be determined, however, that the modification can be retrofitted to earlier procured spares as well, this reluctance can be minimized and continuing support can be maintained.

Reparable or Consumable

The administrative handling of, and indeed the planning for, item support are both greatly affected by whether an item is a reparable or consumable type. Reparable items tend to be the major (and costly) systems and subsystems, as well as many of their internal replaceable components. Another cross-reference is that most Orbiter LRUs and many SRUs (shop replaceable units) are reparable, whereas piece parts are generally not reparable. Conversely, some LRUs are not reparable (such as throw-away filters), and these items normally are considered as consumables. Reparable item use occurs both in the shop and on-line at the vehicle; use of a consumable sometimes occurs at the vehicle but more often is in the shop where an LRU has been disassembled for repair. Finally, after so many repairs, the item may no longer be reparable, and is condemned, requiring replacement.

Repair Level

The level at which repair is authorized affects the quantity required for support. If repair of a failed item is relatively easy and fits within the timelines of the remaining on-line work, it can be designated for on-line (or organizational level) repair. In this case, relatively few spare items need to be available, because there will be a demand only if repair cannot be accomplished in the expected manner. It is usually safer for the operational schedule, as well as more economical, to remove and replace at the assembly level so that the problem can be isolated and repaired independent of operating constraints (time, access, orientation, etc.). This item would thus be designated as an LRU (line replaceable unit). It is physically moved to a repair shop, either on-site or off-site. At the present time, and into the foreseeable future, most Orbiter flight hardware goes to off-site repair facilities. The expected failure rate as well as the time involved in the repair cycle determine the number of spare items needed for probable replacement use. This time starts with item removal and ends when it is returned to stock at the user's facility as a "good spare." An on-site repair facility (often called intermediate level) will reduce the number of such spares needed because of the shorter time involved in transportation and administration on both ends of the repair process. On the other hand, a high propensity to utilize depot or factory repair can significantly increase the spares needed to fill the repair cycle.

Time to Repair

Turnaround time has been already referred to as a pacing factor in the determination of the number of spares required. This can also be depicted in the term "meant time to repair," or MTTR. The Shuttle program uses either estimates or actual data in projecting needed spares. The major factor setting this program apart is that some repair times are expected to be extremely long. One reason is the inherent complexity of the items themselves. A second, less obvious reason is the extended engineering analysis times likely to be required to ascertain failure causes and modes. Such items as the Orbiter IMU (inertial measuring unit) will likely have a greater than six-month MTTR, which drives the program toward a heavy spares requirement. Further complications include the fact that the IMU may yet be modified or enhanced. This tends, at least for the present, to inhibit early spares procu-ement.

Technical Data

Technical data, called Operations and Maintenance Documentation (OMD) in NASA, can be a pacing factor in the freedom to decide levels and locations of repair. If adequate maintenance data were not procured with the item (and much of it was not within the Shuttle program), program management is substantially constrained to continue using the original manufacturer for maintenance and production of new spares. In the event the original manufacturer goes out of business or declines to bid, management's only reasonable alternative short of item redesign is an expensive and lengthy "reverse engineering" effort to build up technical data and support capability from available interface information and the hardware itself.

Service Life and Operating Time

Time of operation plays a big part in planning for support because some items, such as Orbiter pyrotechnics and life support consumables, need to be changed at specific time intervals. This requirement drives substantial funds and hardware needs on a repetitive basis. Some items, such as the Orbiter fuel cells, are not meeting their expected lifetimes. After a fuel cell modification that added an additional stack of cells to the assembly, the new projected lifetime was still below originally predicted or hoped for levels. As a result, support of this system will entail a greater input of replacement units (and upgraded components) than was forecast in earlier program projections.

Quality and Test Requirements

It has been widely accepted since early in the U.S. space program that NASA demands and gets quality of an exceptionally high level. This is certainly true of the Orbiter program as well, considering the "man-rated" nature of the hardware and the unacceptable consequences of catastrophic failure while in space. Test requirements are stringent, and traceability of components and sources is normally required at least for flight hardware systems. Flight hardware is normally returned to a practically "like-new" condition after maintenance by the factory, resulting in somewhat longer and more costly acceptance test procedures than might be utilized for more routine kinds of hardware. For the support of Shuttle flight hardware, it should be said that there is no such thing as "routine" in the handling and care given systems and components returned to an held by the manufacturer for maintenance and analysis. Turnaround/repair times are therefore likely to remain long.

Manpower

A critical issue facing the entire Shuttle program is retention of special skills and trained individuals who have provided the basis for the development and production to date. These people are important to maintaining a real capability into the future for support of maintenance, follow-on production, and an engineering and modification capability. This is especially so in cases where the quantity or quality of available data is less than desired. Funding reductions and production completion have made this problem increasingly difficult because these conditions prompt personnel moves to other programs, other in-company facilities, different companies, or even retirement.

Producibility, Maintainability, and Transferability

Producibility and maintainability are both important elements to Shuttle Operations. The former is needed to permit direct procurement and second sourcing of follow-on spares and support buys, and to reduce the cost of these procurements even if they are returned to the original source. Maintainability has a major impact on how much normal turnaround processing of the Orbiter vehicle will cost. Although the program is sufficiently far along that it is impossible to influence the basic design of either the flight or ground support systems, maintainability must be built into the modifications made to these systems. Further, these producibility and maintainability processes must be transferable as much as possible because of the turbulence likely in the industrial support base as a result of vendors withdrawing from activity with the Shuttle program.

Critical Materials

Critical materials have affected the Orbiter vehicle production and support much as they have other high technology aerospace programs in the past ten years. In addition to titanium, which will be covered under the lead time topic, columbium is an expensive critical material that is used in several key areas of the Orbiter. The sonic nozzle on the flash evaporator is machined from a solid piece of columbium, and columbium is also used as a material in the RCS (reaction control subsystem) nozzle liner. Special skills are needed in these processes, and in some cases one specific subvendor is the only source with the combination of capability, capacity, and willingness to produce low quantities of relatively high technology components.

Hardware Availability Commonality

Orbiter hardware is rarely standard commercial equipment available "off the shelf." In fact, there may be relatively few pieces of standard test equipment used for ground support, but essentially all the remainder do not have a commercial or even direct military corollary application in the model being used. Although the TACAN used in the Orbiter vehicle is very similar to military versions, form and fit are different, and parts at the assembly level are only coincidentally similar. Repair capability is somewhat more transferable, however, in terms of skills and test equipment, given that the different range of spare replaceable components is available to the maintenance technician.

Further, on the subject of source of hardware, many Orbiter subsystems and components are for all practical purposes available from only a single source. They were designed and developed by a particular company, often with substantial costs being incurred along the way for specialized skills and equipment. Additionally, the data associated with building up a support base were not normally procured by NASA in sufficient detail nor across the board for all items. As a result, the item technology may not be directly transferrable to another source without a large reinvestment in several elements of support: data, manpower and skills, test and support equipment, unique facilities, and other items.

Lead Time

Lead times for Orbiter hardware range from several weeks for standard small components up to four years for major subsystem end items like the OMS engine. Landing gear assemblies also range up to 48 months lead time, largely because of the time to acquire the major forgings that are the heart of the gear. Availability of titanium has been a pacing factor for main propulsion system feed lines, ducts, and manifolds. Both titanium and inconel forgings are needed for primary and vernier RCS thrusters, driving their lead times to approximately 36 months. Although these lead times are admittedly extreme, average lead times are on the order of 6 to 10 months for minor components, 8 to 18 months for larger assemblies and complex SRUs, and anywhere from 15 to 48 months for the major subsystem end items and modules. The message is that with lead times of such magnitude, the logistics planner must work literally years in the future, and the budget process that supports this activity must be capable of accepting long-lead estimates and the changes that inevitably occur as they mature.

Production

The item's production status directly affects its supportability, especially when support has long been consciously "piggybacked" up to now on production capabilities, personnel, testing, and spare assets. When production ceases, many or most of these elements are no longer availble. Certain tooling and test equipment will have either reached its expected life limit or will have to be transferred to other programs upon which the contractor has more firm and sizeable contractual commitments.

Flight Certification

The question of flight certification plays a major role in determining just which assets in a total item population can be utilized as spares on the Orbiter flight vehicle. Nonflight items can in some cases be brought up to meet flight specifications if adequate historical data have been kept, if testing can be accomplished within required times, and if the item is otherwise serviceable and correct in form, fit, and function.

Special Requirements

Several categories of specialized requirements that affect Orbiter support include maintenance and test equipment needs; special facilities such as clean rooms; and packaging, handling, storage, and transportation requirements. Orbiter hardware vendors have developed numerous unique capabilities that address these needs; and whereas they may not be of such magnitude to prevent other sources from providing support, they certainly must be documented and considered in planning for and acquiring support capability.

ORGANIZATIONAL CONSIDERATIONS

Governmental Roles

The government role in Space Shuttle management is little different from other major aerospace programs. It provides for long-range planning of the entire program and its relationship with other programs. After considering relevant planning factors, the government prepares and publishes policy on program direction and the major issues facing the program. Implementing levels within the government build up specific sets of requirements and specifications to be followed in the development, production, operation, and support of the system hardware and software involved. The government must prepare budgetary estimates through orderly review and consultation within the various levels of program management. It provides for funding within available constraints based on the budget previously laid out, awards contracts to carry out the program policy, and insures their management at a level of detail consistent with lowest cost and within schedule and performance criteria established.

Industry Roles

The Shuttle manufacturers and their subvendors have a wide range of detailed resposibilities involving the basic production and manufacturing effort, and follow-on work as well. New components destined for use in the production vehicles are required, as well as spares, which are normally in the same configuration as those currently being produced. These contractors usually provide for maintenance and support planning to the extent needed for their own purposes, or as directed by the government in basic policy or requirements documents. Further, these vendors may in fact perform a level of analysis greater than that formally required in order to better understand and implement a correct and competitive company strategy and to establish themselves in a positive position for later support work. Such support planning includes maintenance engineering analyses or logistics support analyses, requirements computations (and iterations within this process), and provisioning and procurement activity to support the specific direction of the government.

Once all this planning and support work has established a workable base, the contractor is in a position to use its technical know-how and facilities to perform maintenance, overhaul, and repair of its own hardware, and even possibly that of other companies, within the range of hardware similarity.

The vendor is often on contract to provide some degree of sustaining engineering for the hardware it developed and produced. This requirement includes the capability and responsibility to devise and implement modifications that, once approved by the government, will allow the system hardware to meet a current or new specification. In addition, the vendor provides some "as-built" configuration support to insure that the hardware on which it works is maintained in a pure fashion consistent with pertinent drawings, specifications, and interface documents.

Finally, the contractor must maintain a fairly high level of performance and maintenance history data so that the essential experience can be fed back into maintenance and planning. That some data are already available is unquestionable. The usability of the contractor data has often seemed in question, however, even within contractor organizations. This is because of the questionable "pedigree" or the information, the circumstances in which it was collected, and the high variability among kinds of failures. There can be wide differences among ways one should treat development test failures, human-induced problems, and other failure modes distinctly different from operational failure modes likely to be experienced in the future. This situation makes the highly essential maintenance history data base subject to considerable skepticism until a significant number of maintenance actions have occurred.

The contractor is responsible to provide for configuration management of program hardware and software. In addition, the contractor provides the unique maintenance and test equipment, and the very necessary unique skills and special facilities. Finally, the contractor often provides a varying level of information management and control, involving, for example, inventory management data, the maintenance data previously mentioned, and work scheduling necessary to carry out other contracted functions.

FUNDING AND COST CONSIDERATIONS, AND THE INDUSTRIAL BASE

NASA has recently provided funding for support of the Shuttle at what would seem to be generous levels. There have been numerous other requirements for funds, however, that have reduced funding available for support. The amounts provided for logistics support in the operations preparatory stages were often less than the calculated requirement and were generally phased over a longer period of time.

The Process

The Shuttle support funding process in NASA operates approximately as follows: A "submit" comes from the working level at JSC, KSC, or MSFC, based on a set of guidelines issued by the headquarters. Items that respond directly to the guidelines are "above the line," whereas other new requirements are generally submitted "below the line," or for headquarters' consideration only. When received, the complete submit is considered along with all the other competing needs for funding; and it is either approved as requested or, more often, revised in some way. The dollar amount requested can be altered for numerous reasons. Sometimes it is increased because of a higher projected flight rate or some other new piece of information. More often it is decreased, based on various possibilities, such as the perceived availability of production hardware that had not previously been considered, or a belief that item or system reliability will improve significantly.

The amount so arrived at by headquarters then becomes the NASA "submit" to OMB (Office of Management and Budget), and much of the same process is repeated. The final "mark" then becomes the baseline against which annual funding availability and procurement are measured. The original requirement is by definition no longer the requirement, although the differential not funded is sometimes rolled into succeeding years.

The Requirement

What, then, is the real support requirement? The answer is that it is almost always a higher number than the budgetary process will allow to go forward or to be documented. An operational definition of "real requirement" in program management terminology could be that it is whatever amount the responsible manager can afford to give that part of the program. In that respect, calculated requirements and real (ultimately stated) requirements often differ, sometimes by substantial amounts. This situation can result in an increasing divergence between required and available funding.

Use of Production to Meet Requirements

A particular funding concern in the past has been how production spare assets have been handled. In the early stages of the program, during development and early production, the most pressing needs of the program were for specific hardware design fixes to permit meeting specifications and requirements levied in the basic program plan. During production itself, it was discerned that spares already provisioned for DDT&E could be used as a source of hardware for the Orbiters then in production, and at the same time those items would nominally be avaiable for use as "operational" spares, because they could be removed from the end item in case of a pressing need at the launch site. This "piggyback" procedure was adopted as a means of saving or delaying expenditure of production funds. This procedure reduced the quantity of "dedicated" spare assets in the system and introduced several new constraints to being able to support the operational program. Use of a production "spare" required that management answer several questions. What would be the impact on the production flow? When could the production line be paid back? What is the relative cost trade of removal time and effort on the production vehicle vs. wait time and impact on the operational processing flow? This procedure unquestionably "saved" money in that it allowed many given pieces of hardware to do double duty. It reinforced the desirability of having production line items available to meet operational needs, inasmuch as there was always the possibility that the operational vehicle might need an item that had never been provisioned and could be obtained only from a production source.

Although this policy was satisfactory for a time, it cannot be practiced indefinitely. As production comes to an end, many items are no longer available from stock awaiting assembly, because they have been long since assembled into their own particular system or end item. As the Shuttle moves into this period, the costs and risks of using production hardware rise precipitously. Further, long lead times force planners to provision and begin funding replacement hardware at least two to three years in advance of the need, a time when the urgency of need seems low, relative to current problems.

Follow-on Activity

No comprehensive study has yet been completed on the effect of lack on the industrial base supporting the Shuttle of lack of follow-on spares orders. Rockwell International carried out a Logistics Review Team (LRT) exercise in late 1981, into 1982, and subsequently into 1983 as well. This activity has attempted to assess what needs to be accomplished with respect to each of the numerous Rockwell vendors on spares provisioning, supporting analyses, maintenance capability, and other logistics support factors. To date the results of this activity are not available. In-process findings, however, are expected to greatly influence the Spring 1983 budget process. When completed, the LRT results are likely to be the closest so far to the comprehensive study needed.

A Credibility Issue

There has been a certain lack of credibility in contractor and project office cost estimates for many of the logistics support disciplines, especially as perceived by senior program management. This lack, in turn, has contributed to delays and funding reductions. The logistics community itself perceives the estimates to be accurate and credible. Even so, it has occasionally come to light that certain component failure rates included inappropriate data, or did not assume a sufficiently optimistic improvement (learning curve) in the program's ability to reduce demands in the later years.

Another difficulty that adversely affects logistics support is that the prime contractor has failed to meet the "cost" goals for spares procurement. These goals aim to ensure that the total spares funding available in a given year is actually spent in a timely way. If the contractor underspends, it brings into question whether the spares requirement is really accurate. Even though the procuring team (government and prime contractor) may fail to spend the authorized funds, the actual (or original) spares requirement usually remains valid and is likely to be even more pressing because of loss of valuable lead time. Failure to meet these goals has debilitated the front-end prospects of adequate, unencumbered, dedicated logistics support in the early - to mid-operations time period.

SUMMARY OF PROBLEMS

The support problems being faced by the Space Shuttle program and the Orbiter project include the following:

1. The end of production is approaching, and the "crutch" that has permited less than full funding of support elements is going away.

2. Support contracts are expiring along with the end of production, so the skills these contracts provide are disappearing.

3. Along with the increasing lack of flexibility in sources of hardware, it has been perceived that excessive (or certainly higher than expected) costs are being charged by contractors because it is a seller's market.

4. Delays in initiating funding and procurement of needed spare hardware and the lead times associated with their production have caused a possible period of nonsupport in the early - to mid-operations period.

5. Turnaround times for failed hardware are no longer than they shou ld be, resulting in relatively high demands for spare assets.

6. Finally, many contractors upon which the Shuttle Program has depended for years need to have meaningful follow-on business from this program, or they will probably leave the business. There are not enough other contractors presently in the field to provide satisfactory replacements. Some capability must be arranged to ensure continuous program support.

CHAPTER IV

(RECOMMENDED) MANAGEMENT STRATEGIES AND ACTIONS

The analysis in the preceding chapter identified the critical logistics support problems that currently threaten the readiness and sustainability of the Shuttle program. Although numerous management actions can and should be taken to reduce the support risk, this chapter will present only the key steps that seem essential to establish and preserve a viable logistics support base for the Shuttle, particularly the Orbiter.

STRATEGIES

For purposes of discussion and analysis, management efforts to systematically resolve current support issues and rationally develop a steady-state logistics support base can be grouped into three general strategies. The strategies may be described in abbreviated form as those actions dealing with:

* Maintenance and other support effort

* Hardware acquisition, especially spares

* Support management systems and procedures

Two actions relate to contract structure and technical data that overlap both of the first two strategies. To some degree, all three strategies are interrelated and mutually supporting.

Fundamentally, the objective is to develop a logistics support base that permits the Shuttle to fulfill its intended purpose and mission. The support base not only should provide for prompt turnaround, launch availability, and readiness, but also should possess the capacity and flexibility to accommodate growth as well as fluctuations in Shuttle launch rates. In addition to ensuring effective support of the Shuttle, the support base also should be efficient and economical to operate. Finally, the development and acquisition of the support base should proceed as economically as possible within the constraints of fiscal realities. These constraints, however, should not be allowed to be arbitrary or irrationally restrictive without being subjected to intense management challenge or readjustment of priorities.

These more or less "ideal" qualities of the logistics support base serve to guide the synthesis of the strategies for attaining them. These three strategies will be examined in greater detail. In each case, the specific actions comprising the strategy will be described, along with the rationale of how they lead to improvements in the support base and resolve critical support problems and issues. Where feasible, the management responsibilities, timing of decisions and actions, estimated resource requirements, and impacts of nonaccomplishment will also be presented.

MAINTENANCE AND OTHER SUPPORT EFFORTS

This strategy is aimed at the basic services, functions, and processes of the logistics support base, aspects that are more aptly characterized as "effort" in contrast to "hardware" or physical products. Chief among these efforts is maintenance or repair of the Shuttle and its component equipment as well as of the multitude of ground support systems associated with ground processing and launch and flight operations. Other important services and processes include transportation, training, configuration management, engineering, computer software support, inventory management, and information management.

Studies of Support Sources

A survey and economic analysis of support sources is an essential first step to avoid a major logistics support crisis. This is necessary to address the problems noted in Chapter III --- the expiring support contracts and the shrinking industrial base of firms interested in or willing to pursue the relatively low-volume work of Shuttle maintenance, repair, overhaul, and other support. As the industrial base continues to decline and become more costly, an important alternative is to begin now to establish the capability to perform portions of this work. Some contractor operated facilities already exist at both the Kennedy Space Center and Vandenberg Air Force Base launch sites, and it may be economically desirable to expand these capabilities for selected Shuttle items. In addition, there is also capability in the form of facilities, support equipment, and skilled personnel at Air Force Air Logistics Centers and other DOD depots that could be further utilized for Shuttle support.

There are a number of difficulties to be dealt with in bringing such work "in house" (all the more reason for examining this alternative in the near term). Office of Management and Budget (OMB) Circular A-76 contains some specific restrictions that must be addressed, particularly in the area of government-provided services that are otherwise commercially available. In addition, front-end costs in data, support equipment, and training are likely to be incurred to accomplish the transfer from any source to another, not to mention lead times to set up new sources and to certify quality assurance procedures.

A comprehensive economic trade study should be of significant use in developing a long-range support-base structure and strategy. The study should identify promising sources, support in both government and industry, along with estimated costs of operation and nonrecurring set-up costs. In addition, the study should attempt to forecast lead times and construct funding profiles. The study could be spnsored by NASA Headquarters, or by the Johnson or Kennedy Space Centers. It is difficult to estimate a price for such an effort if performed by a contractor, but the payoff in a more efficient support structure and reduced risk should be immense. The study should form a principal basis for management allocation decisions involving support resources and could be a valuable source of data for developing budget estimates for total support resource requirements.

Although it might be convenient for the prime contractor for Orbiter to perform this study and analysis, an independent assessment would be more desirable. The prime contractor should be and is carrying out its own study along these lines. Not only is the prime contractor in a competitively advantageous position, but a parallel study would provide a check on the validity of the prime contractor's analysis.

It would be most helpful to begin the trade study as soon as possible in FY83 and conclude in FY84. Inasmuch as the study would probably require twelve to eighteen months to complete in the quality and detail needed, effort needs to get underway immediately for the results to be available for the FY85 budget and beyond. Without such a study, NASA must continue to base funding decisions on recommendations of the prime contractor and on largely fragmented data and analyses.

DOD Repair Sources

Important alternative sources of maintenance and repair for Shuttle items that have been largely ignored to date are the DOD depots operated by the military services. Although at least one pilot repair effort on ground support equipment has been initiated with one of these depots (the Air Force's Sacramento Air Logistics Center at McClellan Air Force Base, California), no policy or procedure has yet been established by NASA for obtaining this kind of support more routinely. Not only do the DOD depots offer a "fallback" source of support as the Shuttle program matures, but they could already be the most cost-effective source for repair of some Shuttle items. The current NASA contractual relationship with the Shuttle prime contractor for all levels of support somewhat complicates the problem by creating a sort of artificial barrier; it is unlikely that the prime contractor would ever on his own initiative "contract" with a government agency directly for vendor services.

NASA should begin now to identify selected Shuttle items, both ground support e quipment and flight hardware, that can be more economically supported by DOD depots, and should establish pilot repair programs at these depots. NASA should also direct its prime contractor to include the DOD depots as alternatives in economic trade studies of sources of repair, and should formalize working relationships with the military services to facilitate a flow of cost and production data from the depots to the prime contractor. Further, NASA Headquarters should develop and publish formal policy on the use of DOD repair sources; and Johnson Space Center, with the assistance of

Kennedy Space Center, should negotiate and fund specific repair arrangements with the military depots.

The chief advantages of developing DOD organic repair sources at this time are that the depots will become familiar with NASA repair processes, documentation, and quality assurance requirements; they will get used to NASA and Shuttle administrative procedures; and they will identify and work out operating problems that could later present obstacles to smooth support. The "reverse-engineering: capability of these depots is well-known, and could be a major means to help offset inadequate technical data. Use of DOD depots as repair sources for selected Shuttle items should cost no more (and maybe significantly less) than commercial sources. It would provide a valuable hedge against the total loss of commercial sources. Most of all, these capable and qualified DOD organic repair sources reduce the risk of insurmountable future support problems in the Shuttle program and serve as a competitive environment to help hold down support costs.

Standby Vendor Maintenance Capability

Another step that could greatly reduce risk to Shuttle support is to contract with selected manufacturers or vendors for an in-place, standby maintenance capability. This action tends to be most attractive for critical items that require highly specialized skills or equipment and whose volume of repair activity is too low to economically justify an open repair line. Having this capability available for emergencies could be an excellent insurance against low probability but crucial malfunctions. An economic trade study should identify these items and the funding requirements for the standby repair source.

Repair Capability At Launch Sites

Further actions to build up the intermediate level repair capability at both launch sites and perhaps at the test facilities also would seem productive. Again, economic trade studies and level of repair analyses should be performed to support specific management decisions in this area. Some of this build-up has already taken place at the Kennedy Space Center in the form of enhanced test and checkout equipment for flight hardware components. At Vandenberg AFB, the use of existing contractor-operated facilities that currently support other programs is being evaluated for Shuttle support, in this case, primarily for ground support equipment.

What seems to be lacking is a standard procedure or policy for more actively considering adding capability to the launch site in order to eliminate the need for factory repair that is no longer available. Such a policy should contain "look ahead" features that will alert management to potential losses of vendor repair soon enough to allow funding and expansion of launch site capabilities before vendor support is terminated and Shuttle readiness is threatened.

Development of these policies and procedures should be initiated immediately by NASA Headquarters. Necessarily, the full participation of Kennedy, Johnson, and Marshall Space Centers and the Air Force will also be required. Kennedy Space Center needs to assist especially in the location and capacity decisions in as much as the added repair capability would be largely at that launch site. In addition, the Shuttle Processing Contractor (SPC) would play a major role in managing intermediate level maintenance at the launch site. Johnson Space Center's part is particularly important because much of the needed data for the trade studies would come from the prime contractor for Orbiter. In turn, direction on new sources of repair must go back to the prime contractor through the NASA Program and Project Offices.

Development of policies and procedures for relocating more repair capability to the launch sites would itself require little extra funding and could be accomplished by the NASA Headquarters and Center staffs. But as long as policy is ambiguous or no policy exists, little active movement will take place to exploit what seems to be an economical alternative, especially when vendors quit the Shuttle business.

IDMMs

One relatively straigfhtforward action that would vastly improve Shuttle repair flexibility and would also seem to reduce support risk is to complete the Intermediate and Depot Maintenance Manuals (IDMMs). Although effort has been underway on this documentation for some time, it has been at a low level of activity, priority, and funding. Top-level management emphasis and funding are needed as soon as possible to successfully conclude this task. The TDMM's are essential technical data and maintenance procedural documentation, and they would greatly facilitate the transfer of maintenance and repair from one source (say, a vendor who goes out of business, or who raises prices inordinately) to another, more appropriate source.

Without completed TDMM's, Shuttle support remains largely captive to original equipment manufacturers and vendors to provide the needed skills and services for maintenance and repair. The risks inherent in this situation have already been noted. Prompt resolution is needed.

HARDWARE ACQUISITION AND SPARES

The second major strategy deals with what might be termed "deliverables" of hardware. Strong interest in sources of installed equipment will continue, particularly as long as the question of a fifth Orbiter (or more) remains open. The following discussion, however, will focus primarily on spares and repair parts. The specific concern presented in Chapter III is to sustain a continuing, adequate, responsive source of spares and repair parts over the life cycle of the Shuttle. The actions suggested in this section are directed toward achieving acceptable spares support for the Shuttle program.

"Life Of Type" Procurements

Based upon the high risks to support caused by suppliers leaving or intending to leave the Shuttle program, economic analyses should be conducted on the desirability of procuring the total life cycle spares requirement for selected items, especially critical ones. Although it may be possible to acquire and qualify a new source later in the program, the cost to do so in some cases could well exceed that of a "buy-out." This possibility is especially likely inasmuch as the quantities are relatively low (compared to, for example, those that might be required for a fleet of airplanes).

Identification and evaluation of candidate items should be initiated as quickly as possible because of the increasing departures of suppliers as production draws to a close. Items have been identified in the past such as cables, cable connectors, and related hardware, but funding has been inadequate to buy the entire quantity needed. The Orbiter prime contractor could be directed to perform an appropriate analysis; but the work should be carefully scrutinized by NASA management and, equally important, funding made available where warranted. Further delays in pursuing this action could elminiate it as an option and result in a significant lost opportunity and an increase in Shuttle support risk.

Acquisition of SRUs and Repair Parts

All needed shop replaceable units (SRUs) and repair parts should be identified and procured from current vendors before production ends. Enough funding should be provided to acquire sufficient spares not only to satisfy all estimated support requirements through the end of Orbiter production, but also to fill the projected maintenance and repair lines. These steps would reduce substantially the present uncertainty concerning the total range and depth of SRUs and repair parts needed to support the program. They would also fill the logistics pipeline and significantly reduce Shuttle support risk.

NASA Headquarters should move these efforts forward by providing policy, direction, and funding. Johnson Space Center would have to accomplish most of the detailed tasks through the prime contractor, and could also draw to some extent on the funds already allocated for this purpose. These actions would improve support posture, which improvement would enable the transfer of hardware sources, if necessary, without the threat of disrupting Shuttle launches; and they would also keep the current production lines open longer. Failure to take these actions now or in the near future risks serious delays in supply support of the Shuttle, particularly as launch activity increases during the next year or so. Such failure would also compound the previously identified problems of smoothly transferring to new sources as vendors leave the Shuttle program.

Standby Supply of SRUs and Repair Parts

This recommendation is directly related to the recommendation to establish standby maintenance contracts, except that this action deals with the supply aspect. Contractors should be assigned this responsibility through a standard provision in the standing maintenance contract. Such an agreement would provide an economical means to ensure that vendors performing maintenance and repair work have enough replacement and repair materials to meet specified turnaround requirements. It also would permit more credibility to be built up in turnaround data maintained by program sources. Johnson Space Center, as the item manager for Orbiter equipment, should be responsible for including this provision in their vendor contracts.

SPARES, MAINTENANCE, AND OTHER SUPPORT

Two recommendations do not fit cleanly into either of the preceding strategies but are related to both. They will be described as a separate group.

Technical Data to Permit Second Sourcing

Obtaining adequate technical data is perhaps the single greatest difficulty in transferring from one source to another, for either hardware or maintenance.

The new source absolutely needs these data both for pricing the effort and for getting the work underway promptly. Although completing all IDMMs would alleviate part of the problem for new sources of maintenance and repair, it is also essential to have available adequate drawings, test parameters, configuration management data, and other engineering data or special processes.

Unfortunately, technical data can be expensive, particularly if procured in a sole-source environment or if government rights in data have not been previously acquired. Nevertheless, these costs may be justified, even in extreme cases, if no other sources are available for the needed hardware or other support services. Although it may be possible or even necessary for a new source to "reverse-engineer" the equipment and generate the needed data, this process, too, is costly and time-consuming.

Johnson Space Center should initiate action to acquire the remaining technical data as soon as possible. Many of the tasks will likely need to be accomplished through the Orbiter prime contractor. Priorities in funding and in management effort should be allocated to items for which production or maintenance contracts are ending or are growing excessively costly. In spite of the expense of the data, they may be, upon analysis, a bargin compared to the cost of potential support for the Shuttle without them.

Consolidation of Off-Line Support

Another option that needs to be considered now by NASA Headquarters and by Kennedy and Johnson Space Centers is consolidation of most, if not all, off-line support under a single support contractor (SSC). This contract would include responsibility for all support activities for items once they are removed from, or before they are installed on, the Shuttle. A similar concept is already being implemented at Kennedy Space Center as covered earlier, with three single contractors being planned for Shuttle Processing, Base Operations, and Cargo (Payload) Processing. The rationale for this approach is a significant projected saving in duplicative overhead costs and in government management and technical manpower. Logic indicates that comparable economies might be achievable for logistics support as well.

The scope of an SSC contract might involve the entire spectrum of operational logistics services, functions, and processes for the Shuttle, ranging from maintenance, supply, transportation, and production of support hardware to training, configuration management, and engineering. The major advantage of an SSC lies in the potential for significant economies of scale through the aggregation of numerous low-volume, small-population support activities into a more efficient operation. It has already been emphasized that the low-volume, high-technology character of Shuttle contracts is a key driver of high costs and vendor departures. An SSC might be a feasible and desirable solution to these problems.

SUPPORT MANAGEMENT SYSTEMS AND PROCEDURES

The final strategy involves management systems and procedures for logistics support of the Shuttle during "steady state," mature operations. These actions are focused on the development of information systems, analytical models, and policies to be employed on a continuing or recurring basis throughout the operational life of the Shuttle. They embrace a broad array of support management services, functions, and processes.

Data Bases and Information Management Systems

As the situation now stands, each of the numerous contractors, subcontractors, and vendors in the Shuttle program has its own unique support data bases and information management systems. Although in most cases these systems are adequate for the individual companies, they cannot "talk to each other," or transfer data automatically, thereby seriously impeding efficient management and integration of the total Shuttle logistics support program. The result is a proliferation of company-generated systems for inventory management and control, configuration management, maintenance control, technical documentation control, and other information systems.

To overcome these inefficiencies and to provide a cohesive framework for managing the logistics support of the Shuttle, NASA should increase its emphasis, priority, and funding on establishing integrated support data bases and information management systems across the entire Shuttle system. The Shuttle Inventory Management System (SIMS), now under development at the Kennedy Space Center, is an excellent initial step twoard the unified data and information management systems that are urgently needed. Much work remains, however, to obtain similar systems for other important functions such as configuration management, maintenance control, and operations and maintenance documentation (OMD).

With integrated data bases and information systems, NASA not only would have far greater visibility into its total support posture for the Shuttle, but would also be in a much stronger position to bring in new sources of support hardware, services, and functions more conveniently and less expensively. In addition, these systems should facilitate much better coordination and communication among the various contractors, subcontractors, and vendors. As the new Shuttle Orbiters are delivered and the launch rate increases, integrated data bases and information systems become even more essential to enable management actions to achieve launch schedules. Because of lead times, development of the full complement of required integrated systems needs to get underway as rapidly as possible.

One key point that cannot be overemphasized is that the standardized inputs and use of the integrated data bases must be mandatory for all Shuttle contractors and vendors. This requirement may necessitate some additional front-end funding for initial conversions of company-unique formats and data elements, introductory training and orientation, and perhaps some software modifications and telecommunications hardware. Contract provisions should be modified to insure compliance; but unless these systems are made mandatory, it is unlikely that a truly integrated and unified support information system will ever come about. Contractors will simply pay lip service to the standard systems but will continue to use their company-unique ones, perhaps even hoping to help lock in contractual dependency or a sole-source relationship.

Another aspect of integrated data bases that deserves noting is the crucial importance of currency. It is axiomatic that a data base full of obsolete data is virtually useless and contributes to its being ignored while other means are found to fulfill data requirements. Such a situation is highly counterproductive to the aim of reducing proliferation of data bases and achieving integrated data bases and systems. Consequently, strong emphasis and management discipline must be placed on insuring the integrity of the unified data base. Accordingly, data update efforts should be adequately funded on contracts, and verification and quality assurance procedures should be implemented.

Critical Item Management System

In addition to recommended integrated systems, NASA should also establish a critical item management system. This system should provide close management control of high-value, small-population items and other pieces of equipment having unusual characteristics, such as abnormally long lead times for procurement or repair. Critical item management systems are commonly used to manage large, heterogeneous inventories, characteristics that clearly apply to the Shuttle and especially to the Orbiter.

Because of the allocation of Shuttle item management responsibilities, the development of this critical item management system must be carefully coordinated between Johnson and Kennedy Space Centers. NASA Headquarters should furnish policy guidance to these centers on this project along with the necessary funding.

This system should be particularly helpful in reducing Shuttle support risk through improved visibility into the status of critical assets. As production draws to a close while launch rates rise, more concentrated management attention on the critical items will be required. Moreover, this system should assist in controlling support costs and repair turnaround time. Without such a system, the critical items may become obscured in the total population of items and lose their inherently higher management priority.

Spares Requirements Model

Although some preliminary efforts are underway at Kennedy Space Center, NASA should move aggressively to develop an improved spares requirements model, especially for recoverable (i.e. reparable) items. Present NASA spares estimation techniques tend to be based only upon failure rates, which, moreover, are often represented by obsolete reliability estimates and data. Furthermore, the techniques now used are often simplistic in their underlying assumptions and fail to consider such relevant factors as multiple launch sites and stockage locations; the indentured relationship between SRUs and LRUs; the implicit priority due to time remaining to a scheduled launch; and, perhaps most important, the item costs.

Studies have shown that the latter attribute, cost of the item, can have a particularly significant effect on the reduction of support costs and risks. More specifically, the incorporation of item cost into a marginal analysis approach to determining spares requirements can often dramatically improve supply support within a given spares budget constraint; or, conversely, marginal analysis can achieve equivalent supply performance at a much lower cost of spares.

Some tentative steps were taken at one time by Johnson Space Center through the Orbiter prime contractor to reintroduce marginal analysis into the spares requirements determination process. Also, Kennedy Space Center has contracted with the RAND Corporation for a study that includes examination of spares demand and requirements issues. In addition, the Shuttle Inventory Management System (SIMS) contains provisions for accommodating a new spares requirements determination method. What is now needed is strong follow-through and funding by NASA to complete development of an improved spares requirements model and to gather any necessary additional data. If developed quickly, a new spares model could be a powerful and valuable management tool to aid in support decisions, especially as production ends and launch rates increase.

Logistics Capability Model

In addition to an improved spares requirements model, a closely related model should be developed by NASA to provide a quantitative assessment of logistics capability and posture. The primary difficulty at present is that NASA program management has little analytical basis or cohesive data for support system strategic decisions. No broad analytic framework exists to tie together the various components and capabilities of the logistics support base, along with projected launch rates and mission activity, to guide resource requirements and allocation decisions. As a result, and handicapped further by the longer planning horizon for logistics capabilities, support investments and priorities typically suffer in comparison to nearer term system development and operational funding "requirements." The forecasts and estimates upon which so many support needs are based are, in effect, heavily discounted, leading to repeated deferrals of support funding often beyond what lead times will allow for responsive support.

These problems in timely support resource allocation decisions underscore the immediate need for some method of logistics capability measurement. Without such a technique, NASA will continue to incur increasing risks of inadequate Shuttle support, especially as production lines are shut down and launch rates climb. Eventually, the credibility of NASA launch schedules may be undermined, seriously jeopardizing the competitive market position of the Shuttle with its payload customers. By proceeding with the development of a logistics capability model, NASA may be able to avoid many of these difficulties and, at the same time, discover new insights into Shuttle support issues and tradeoffs that will allow a more structured, rational, and economical development of the logistics support base.

Prepare to Transfer Some Support "In-House"

The importance of performing economic trade studies of support sources has already been addressed. Correspondingly, it is also essential that policies and procedures be established for implementing the support alternatives. As the industrial base shrinks, for the reasons cited earlier in this paper, or perhaps for economic reasons, provisions must surely be found for accomplishing some support work "in house." In anticipation of this need, NASA should begin now to develop the necessary framework for buying support and test equipment, technical documentation, engineering and configuration data, and other support items, and for smoothly transferring this capability into an organic support activity. Taking these planning actions now can drastically reduce the administrative lead time, thereby cutting down on the potential support risk. An added feature of being better prepared to perform the support work organically is that it may also provide competitive environment to help hold down contractor costs. NASA Headquarters, with the full assistance of Marshall, Kennedy, and Johnson Space Centers, should get underway quickly to develop such a framework.

CHAPTER V

SUMMARY AND CONCLUSIONS

A recurring theme in this paper has been that, throughout the limited history of the Shuttle program, heavy reliance has been placed on vendor support. This practice has been the de facto logistics support concept without necessarily being a purposefully designed plan for steady state, mature operations. Because of funding priorities and other assorted reasons, the Shuttle has not laid the groundwork to shift easily from what has now become a strong dependency on this vendor support and the "industrial base," such as it is, for the production of spares, the availability and use of production line assets as logistics spares, and production lines of other vendor contracts as the source of maintenance and repair.

Now the Shuttle program has to face the reality of production lines shutting down. In many important cases this means the loss of a spares source and of a maintenance and repair capability. Although it is possible and desirable to retain some vendors for continuing support work, others, owing to the low profitability and volume and various reasons previously cited, simply desire to leave the Shuttle business. Still another group of vendors may be willing to stay on, but their prices have risen well beyond what was originally expected by NASA. Moreover, even though the prices may be high, moving to new sources, with the associated costs of qualification and support delays, may not be less expensive.

Consequently, NASA can no longer continue to defer, as it has in the past, the needed investments in spares, maintenance facilities, and other support services, functions, and processes. Instead, it must come to grips with the problem now, before the existing industrial base deteriorates further or even vanishes altogether in some areas. Innovative methods must be found either to sustain the current industrial base of Shuttle support or to restructure it with new commercial sources or organic capabilities. And all this restructuring must be accomplished within tight budget constraints, close public and industry scrutiny, and growing launch schedule commitments and promises to increasingly skeptical customers.

This paper has attempted to trace the thread of the problem, beginning with a review of the background of the Shuttle program. The conceptual structure and nature of management decisions related to development of the logistics support base were then described. Following this discussion, more specific details of Shuttle support concepts and strategies, equipment characteristics, organizational roles and responsibilities, and funding and cost considerations were presented and analyzed. This led heuristically to a set of recommendations designed to deal collectively with the principal issues.

The solutions proposed are (even to the authors) far less than totally satisfying. Some recommendations probably seem to treat symptoms rather than problems. Others may seem to beg the question or to avoid issues by recommending further studies or analyses. Although it may be appealing to a decisionmaker, for example, to read a recommendation to "buy more spares," such simple, straightforward conclusions cannot be derived incontrovertibly from available data --- even though the authors believe that the procurement of more spares is in most cases essential for adequate Shuttle support. Lacking sufficiently solid evidence to cite the need for additional spares, what was deemed to be the next best thing --- an improved spares requirements model --- was recommended. By developing this model and using it to compare current and on-order assets with computed requirements in the context of increasing launch rates, any spares deficiencies should become readily apparent.

This illustration of seeking further information and performing additional analyses points to what may be a far more serious and insidious problem. It is analogous to the situation of not wanting to ask a question for fear of the answer. In the case of Shuttle logistics support, this fear translates into not wanting to do the analysis because of concern over what the conclusions may show. As long as future support capability remains ambiguous and unpredictable, "wise men can have honest disgreements" about the impact of support resource allocation decisions or "nondecisions," thereby maintaining an environment conducive to the continued deferral of support system investments. The recommendation in Chapter IV to develop a logistics capability model is specifically directed toward this problem.

The development of a logistics support base can take several years to complete and is commonly subjected to numerous changes and alterations. It also involves resource allocation decisions whose consequences may not be measurable until well into the future. Unfortunately, there is an almost natural human tendency to delay, defer, or otherwise avoid commitment of current resources (in particular, funds) to these downstream support requirements, and this procrastination is frequently fostered by ill-defined requirements and uncertain estimates. The present economic and budget conditions surely would lead decisionmakers to believe that the timing of these support decisions is poor. In fact, the timing never seems to be good. It would be nice if the choices were easier. They rarely are. Perhaps the most important conclusion that can be reached from this study, therefore, is that the solution to the predicted Shuttle support difficulties lies, as it so often does, in management discipline and leadership, and in making the system provide the kinds of data needed for balanced decisons that look as much to the future as they do to the present.

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Figure 1

OBJECTIVES OF THE LOGISTICS SUPPORT BASE-
READINESS AND SUSTAINABILITY

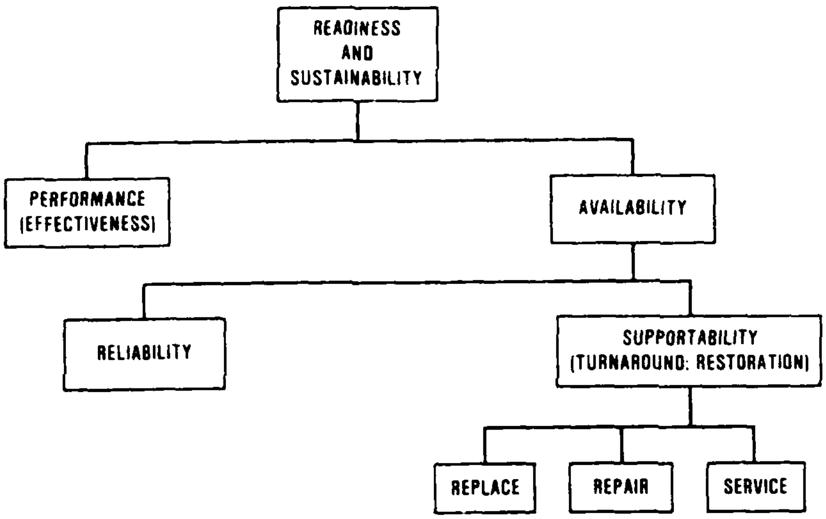
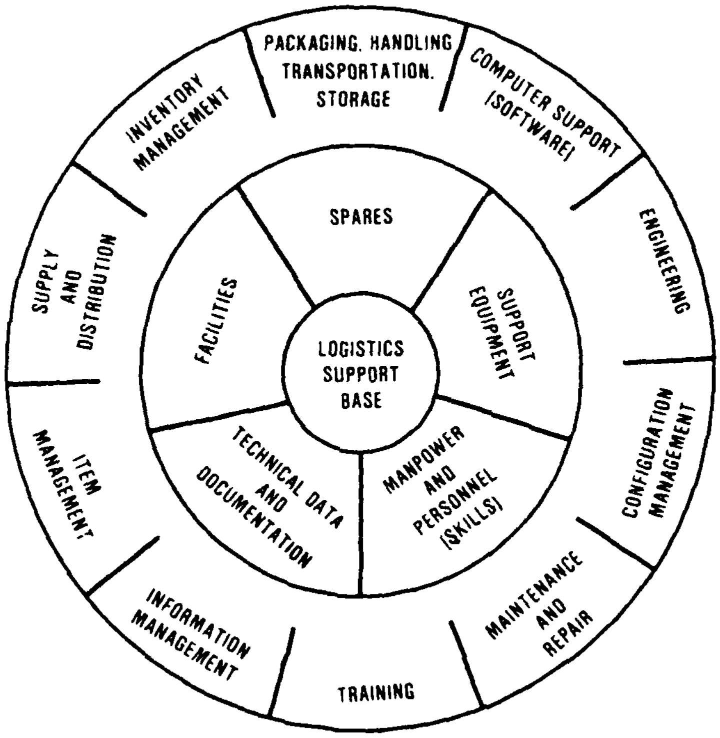


Figure 2

COMPONENTS OF THE LOGISTICS SUPPORT BASE



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