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STREAMLINING SHUTTLE GROUND OPERATIONS

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ABSTRACT

To meet NASA Space Transportation System goals the Shuttle Processing Contractors have to reduce Space Transportation System ground processing time and ground processing costs. These objectives must be met without compromising safety of flight or safety during assembly, test, and service operations. Ground processing requirements are analyzed to determine critical serial flow paths and costly labor-intensive tasks. Processing improvements are realized by improvements in processing methodology, by application of computer-aided technology, and by modernization of KSC facilities. Ongoing improvement efforts are outlined and progress-to-date is described.

INTRODUCTION

The Shuttle Processing Contractor (SPC) team comprises Lockheed Space Operations Company (LSOC), Grumman Technical Services, Inc., Morton Thiokol, Inc., and Pan American World Services, Inc. The SPC team has the responsibility of reducing Space Transportation System ground processing time and ground processing costs. Processing time and cost reductions must be achieved without compromising safety of flight and without compromising assembly, test and service requirements.

STS processing time objectives are shown in Figure 1. SPC processing time has evolved from a 53-day first full SPC flow in April of 1984, to a 44-day composite best-to-date flow. STS objectives require further evolution to a 35-day near term target and then to a 28-day goal. Cost per launch is proportional to processing flow time, thus reductions in processing time will add to other processing cost reductions achieved by streamlining methods and automation projects. Innovations in areas of processing methodology, computer-aided technology and modernization of KSC facilities are described in this paper. These improvements are ongoing, several more years are required to realize the full capability of these works-in-process.

ANALYSIS OF GROUND OPERATIONS

A generic 44-day schedule consisting of best-to-date turnaround times in the OPF, VAB and at the Pad has been established using as run data. The generic schedule serves as a baseline to generate actual schedules which take into account the types of cargo, mandatory modifications and periodic maintenance requirements detailed by the Operational Maintenance Requirements Specification (OMRS).

To streamline STS processing, ground operations are analyzed to determine critical paths. Figure 2 depicts how the Artemis system displays the critical path. The 4-day stay in the VAB for orbiter mate and integrated testing is considered optimum with present vehicle facility designs, no further reduction is envisioned. Some reduction in Pad stay is possible and is under study. The key to achieving substantial turnaround flow reduction is in OPF processing.

As shown in Figure 3, Critical Path Processing in the OPF contains 29 critical path elements which determine the orbiter OPF timeline and the 11 critical path elements which determine the payload bay processing timeline. These 40 elements represent 27 percent of the total flow elements with the remaining 110 elements being worked in parallel with the critical path. Accomplishing all 150 elements of a flow, as currently scheduled, requires orbiter electrical power to be on for 20 days of the 26-day OPF stay.

The six major critical path work operation categories and percentage of time required for each is shown in Figure 4. As can be seen, the propulsion operations represent one-third of the critical path effort. It is the single largest area for turnaround flow improvement. Several OPF requirements for increased propulsion work, and more recently, new requirements for extensive structural inspections have occurred since SPC transition -- adding to the challenge of decreasing OPF flow time.

In addition to planned work and scheduled maintenance, the processing team must be prepared to react efficiently to real time problems which result in unscheduled maintenance. Problems are documented into three categories. An Interim Problem Report (IPR) is used to describe a problem when troubleshooting is required to determine the cause of the problem. A Problem Report (PR) is used to describe a problem and remedial instructions when the cause of the problem has been determined. A Discrepancy Report (DR) is used to solve minor problems which can easily be returned to normal configuration. In a nominal flow, there are approximately 400 IPRs, PRs, and DRs written for STS vehicle processing.

The SPC team is attempting to reduce problems, which result in unscheduled maintenance, wherever possible. An example is in the area of connector and wiring repairs as shown in Figure 5. A number of measures have been adopted to minimize these occurrences. Training and technician awareness has been increased. The KSC Rockwell team has requested a design change to the orbiter to install permanent wiring protection shields.

PROCESSING METHODOLOGY IMPROVEMENTS

PROCESSING DOCUMENTATION

All work performed on Shuttle flight hardware, Shuttle facilities, and Shuttle ground support equipment must be documented for traceability. This results in a large amount of documentation which must be processed each flow. Figure 6 illustrates the key documents which support each shuttle turnaround. The time spent preparing documentation for each flow is being reduced by making use of more off-the-shelf work documents instead of documents written in real time.

Planned work for a Shuttle flow is defined by the Operational Maintenance Requirements Specifications (OMRS) and the mission manifest. OMRS requirements are broken down into subsystem Operating and Maintenance Instructions (OMIs) for stand-alone operations/testing and integrated OMIs for multi-system integrated actions, including launch. OMIs containing non-testing shop work are often broken down further into job cards similar to those used in commercial airline practice. Currently, the "Paperwork Projects" effort by Engineering, Shop, Quality Control, and Safety is focused on reviewing and amending OMIs to the most efficient form for processing -- with a careful eye to preserving safety and exact fulfillment of the OMRS.

To reduce paper preparation time for unscheduled maintenance, OMIs are being prepared for removal and replacement of Shuttle Line Replaceable Units (LRUs). These documents will be approved and on-the-shelf and will significantly reduce the amount of real time document preparation that engineers now do. Similarly, standard repair manuals are also being generated for repetitive types of repairs. These repair procedures are reviewed by NASA, SPC contractors and design agency contractors, and contain full material review board signatures. Standard practice manuals are also being prepared to define shop practices which will also minimize real time paper preparation.

BLOCK MODIFICATIONS PERIODS

Orbiter modifications are initiated by the design agency and are required to perform specific mission goals or to accommodate crew needs. These modifications are folded into the OPF processing flow and increase OPF processing time. Studies are underway to develop a "block mod" concept which has less impact on nominal processing. Figure 7 illustrates the concept in which a block of time for annual inspections and modifications is established during which the orbiter is taken out of service for thirty days each year. The block mod approach is more efficient because it concentrates mod activity and minimizes disturbances to routine processing throughout the year.

BLOCK TESTING CONCEPT

The Generic OPF Turnaround Flow, Figure 3, requires the orbiter to be electrically powered up for 20 days out of the 26-day flow. Recent studies have concluded that power-up test time can be reduced by 25 percent by grouping power-on test activities into one week periods at the beginning and end of the OPF period. This also requires rearranging power-up testing into compatible firing room formats. Figure 8 illustrates the block testing concept resulting from these studies. It requires the orbiter to be powered up for only 15 days of the 26-day flow. It allows manpower to be utilized more efficiently and reduces firing room manning which is required to support orbiter power-up periods. The 25 percent reduction in power-up time also extends component life. The block testing concept will be utilized in future orbiter flows.

LAUNCH TEAM SIMULATION TRAINING

Personnel training in the firing room and re-certification is an ongoing process and is the key to a successful launch team. On-the-job training (OJT) has traditionally been the primary means for engineering training. While effective in a development era when there are many day-to-day problems, it becomes time-consuming and inefficient when systems are in a normal operational mode. New techniques are now being introduced for training console engineers to handle abnormal or emergency problems. High fidelity math model programs exist which simulate orbiter onboard systems and are used to validate orbiter ground test and checkout software. These programs are being adapted for fault simulation training which will enable the launch team to develop the necessary fault detection, corrective action and reporting skills required to support servicing, testing and countdown. Figure 9 shows examples of problems that can be generated with fault simulation software.

TECHNOLOGY APPLICATIONS

WORK-IN-PROCESS SYSTEM

The purpose of the computerized work-in-process system (WIPS), Figure 10, is to enhance work planning and work control and, ultimately, reduce the length of time required for orbiter processing in the OPF. A computerized data base will be used for the scheduling of OMIs and related work authorization documents. The WIPS integrated manloaded schedules will allow for more efficient use of manpower. The WIPS system is based on a system used at the Lockheed California Company. It is hosted on an EPIC-TANDEM computer system. In its first use in late 1985, problems with WIPS were encountered in handling a dynamic schedule and with work place interfaces. It has, subsequently, been revised and will be re-evaluated during the next full orbiter flow. Implementing WIPS should result in a ten percent increase in productivity for orbiter processing in the OPF.

PROCESS ENGINEERING COMPUTER SYSTEM

The purpose of the Process Engineering Computer System (PECS), Figure 11, is to increase the productivity of the LSOC Process Engineering directorate by streamlining many management and engineering tasks. PECS will consist of a distributed computer network with both workstations and terminals connected to a central mini computer. The areas of efficiency improvement will be: management information, communications, documentation generation, workplace paperwork processing and data base accessing.

PECS will increase the productivity of individual engineers by decreasing the amount of time spent preparing paperwork manually. Experience has shown that many documents for maintenance can be stored in personal computers and reused with minor changes. Problem Reporting and Accountability System and Test Preparation Sheets can be written with keyboard entries on pre-prepared forms. The process of documentation transfer, review, coordination and approval will be streamlined. Finally, there will be an overall increase in efficiency in the workplace because of standardization of function, terminology and work practice.

At the time of writing, the PECS system is in the procurement cycle. In anticipation of its installation, engineers are already programming applications. An important example is the tile paper automation system. Methods, paperwork and a prototype software package are being developed. This is a first step in evolving to a paperless tile processing system, including electronic signature capability for the thousands of signoffs required each flow. Tile maintenance requires many repetitive repair/replacement procedures that are an ideal application for automation.

LPS SOFTWARE DEVELOPMENT NETWORK

Starting in 1983, the task of maintaining both application and system software for the Launch Processing System was investigated and the LPS Software Development Network (LSDN) concept was developed as the key method to reduce costs and enhance work flow. In contrast to the batch processing with overnight service now used for LPS software development, LSDN will make use of powerful distributed processor terminals for debugging and compiling programs. Programming productivity increases of an order of magnitude have been demonstrated.

LSDN has the ability to compile GOAL programs by implementing the syntax analysis phase of the current mainframe compiler. GOAL stands for Ground Operation Applications Language. It is the higher order language especially designed for engineers to program the algorithms used to control and sequence firing room operations. LSDN can also maintain (create/modify/display) the display skeletons used on firing room consoles.

The firing room consoles programs are hosted on ModComp computers. ModComp assembly language code can also be maintained on the LSDN. A ModComp cross-assembler is the first stage toward developing system software used in the firing room computers.

Software requirements can be cost-effectively managed on the LSDN by combining text and graphics in the same document, supporting on-line document access and on-line help capability. A new requirement affecting multiple departments can be assessed, approved, implemented, and closed by independent parallel actions carried out over the network.

LSDN has been under development since June of 1984 when a procurement was issued to Apollo Computer for the purchase of a twelve workstation network with disk storage, two X.25 lines for communication with Central Data System mainframe computers and various software packages. This equipment was installed in October, 1984. In December of 1985, another 40 terminals and related peripheral equipment were installed. Networking and system development are continuing even as the computers are being introduced into service for developing todays software. The system is shown diagrammatically in Figure 12.

SHUTTLE CONNECTOR ANALYSIS NETWORK

The Shuttle Connector Analysis Network (SCAN) is being developed utilizing artificial intelligence technology in conjunction with Apollo Computer engineering workstations to ensure the integrity of wiring before launch. The task of ensuring the flight readiness of the wiring within the Shuttle is expensive and time consuming. There are over 7,000 connectors containing more than 250,000 pins in each orbiter. An orbiter undergoes approximately 300 connector demates, mates and retest per launch due to scheduled and unscheduled maintenance, servicing and changing payloads. Each demate must be followed by a remate and retest of each copper path.

SCAN will provide real time status of systems wiring configuration. It will be used for troubleshooting electronic system problems, providing printouts at specific areas of orbiter wiring with exact status of configurations including demates, breakout boxes, missing LRUs, etc. Detailed wiring information for the orbiter, external tanks, and the solid rocket boosters are being entered into the SCAN artificial intelligence knowledge base.

Figure 13 illustrates the overall topology of SCAN. Each workstation on the network is able to access the up-to-the-minute status of any one of the shuttle vehicles being processed. Further, each station can independently perform "what-if" exercises to minimize impacts to work under consideration or to assist in troubleshooting vehicle testing problems. Also, as routine connector demates/mates, black box removal/replacement and modifications occur, they are entered into SCAN and are instantly available throughout the network.

Accuracy of the dynamically changing knowledge base is maintained by making regular comparisons between the SCAN knowledge base and wirelist tapes which contain the as-designed configurations for each orbiter.

FACILITY MODERNIZATION

KSC facilities are constantly being upgraded to meet the demands of the Shuttle Transportation System Program. Figure 14 categorizes 173 modifications completed to date and more are planned in the future. These mods are being performed to streamline ground operations and improve processing efficiency. Modifications are cataloged by facilities and characterized as:

- safety related
- flow-rate related
- cost effective

Safety-related modifications maintain or improve safety and are the highest priorities. Flow-rate related modifications reduce processing flow time. Cost effective modifications improve processing efficiency by reducing operating costs. Some of the modifications made to date are as follows:

- OPF bucket modifications for improved safety.
- Installation of TPS waterproofing vents in the OPF to provide for removal of trichloroethylene during waterproofing.
- Fully automated computer controlled hydrazine loading ground support equipment to reduce loading timelines.
- Redesign of hydraulic deaerators to consistently reduce the dissolved air content of hydraulic fluid to below 1 percent in 4 hours.
- Installation of flare stacks at Pad A and Pad B to replace the high maintenance hydrogen burn ponds.
- Installation of work control stations in OPF High Bay 1 and 2.

NEW LOGISTICS FACILITY

As the Space Transportation System moves from a research and development mode to the operational era, the Logistics support program assumes new dimensions. Responsiveness and cost become even more critical. The logistics facilities, systems and procedures used during the Apollo and early STS programs are no longer efficient nor economical. Lockheed has prepared a fully integrated logistics system to support the operational program at both Kennedy Space Center (KSC) and the Vandenberg Launch Site (VLS). The program for KSC included a new Logistics facility with automated material handling capabilities to permit consolidation of personnel and material support and to be responsive to existing and improved logistics data operations.

The new facility will provide a total integrated office-storage space of 301,740 square feet located close to the major shuttle processing facilities. In the design of the warehousing part of the facility, the emphasis has been on automation of the storage and retrieval function, utilizing state-of-the-art warehousing and inventory management technology. The automated storage system is designed to introduce materials handling automation and control of material from the time it is received at the facility until it is shipped out. Efficiencies will be achieved in the consolidation of inventories and locating all Logistics organizations under one roof. The automated storage and retrieval system, in itself, will permit a 30% increase in work volume without increase in manpower resources.

SUMMARY

Shuttle processing improvements have been made in three major areas: processing methodology, automation, and facilities improvements. Methodology changes reflected in such areas as paperwork and scheduling are a product of our experience with shuttle processing. The application of computer-aided technology, especially distributed processing systems, is well established. Advanced artificial intelligence techniques are starting to be used. Very positive reductions in daily effort of both hardware and software engineers is the payoff. Performance of many non-technical tasks by computers will reduce processing costs and promote a better work climate for the engineering staff. Similarly, automation of tile processing will reduce paperwork for technicians and work hours per launch will decrease. Facility modernization is an ongoing activity. Priority is on safety but improvements that increase rate and efficiency are also being incorporated. The new Logistics facility introduces a whole new concept of logistics technology to KSC.

Significant progress has been made on many fronts to streamline Shuttle ground operations and considerably more will be realized when all the planned methodology, technology and facility improvements are complete and operational. These improvements are part of a multi-year effort to evolve a safe and modern operation era processing infrustructure for the STS.

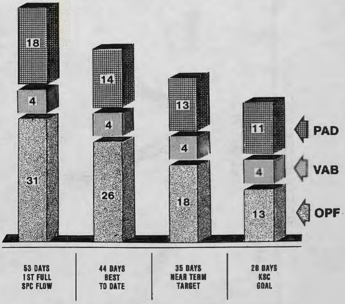

Figure 1 STS Processing Time Objectives

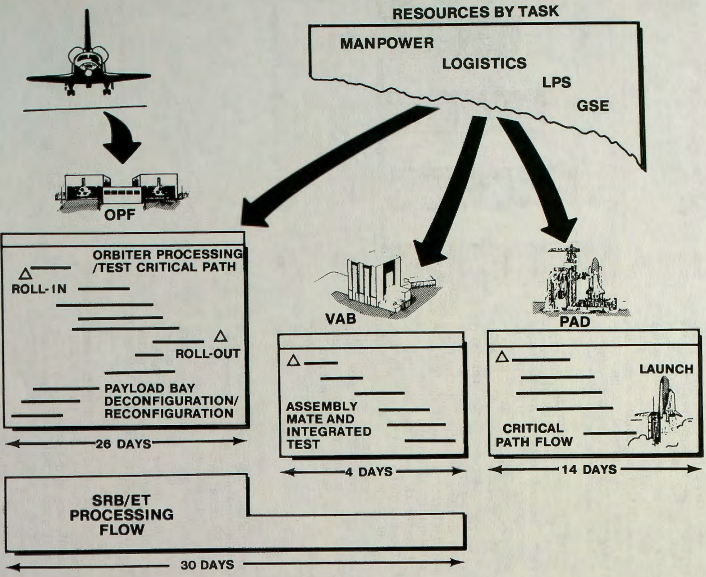

Figure 2 ARTEMIS Critical Path

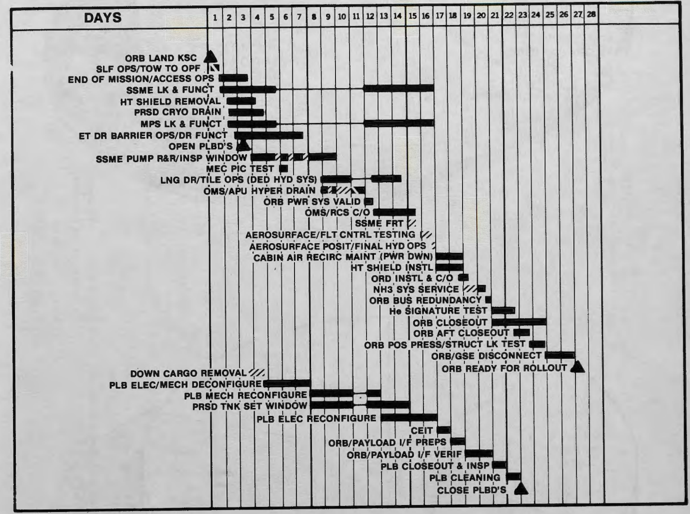

Figure 3 OPF Critical Path Processing

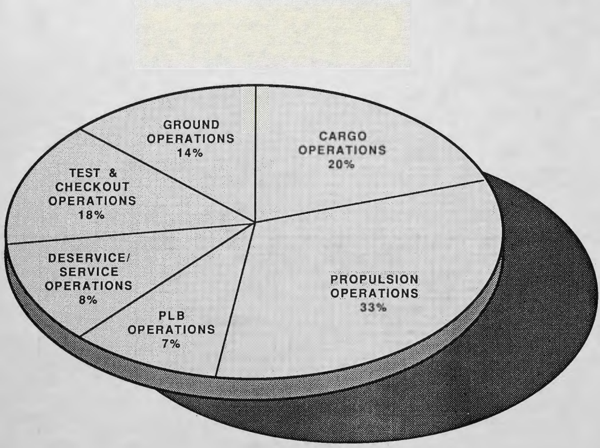

Figure 4 OPF Critical Path Time

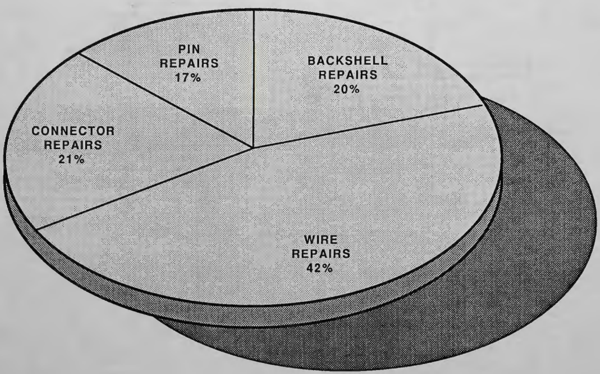

Figure 5 Connector/Wiring Repairs

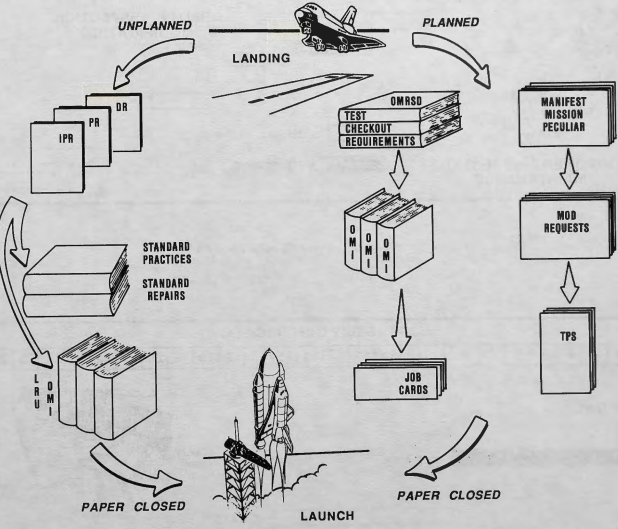

Figure 6 Processing Documentation

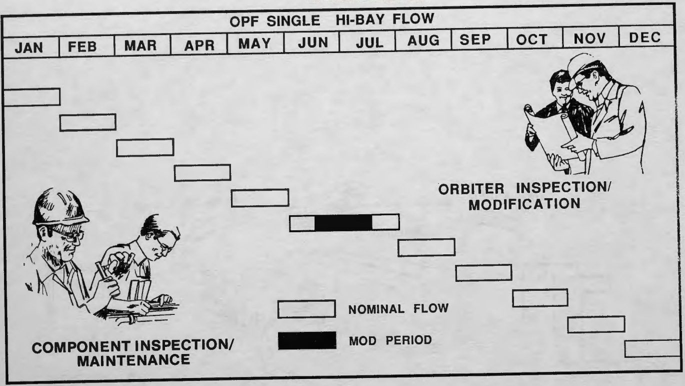

Figure 7 Block Inspection/Modification Period

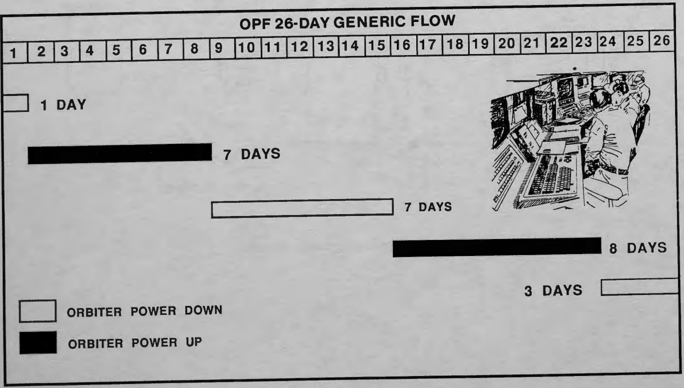

Figure 8 Block Testing Concept

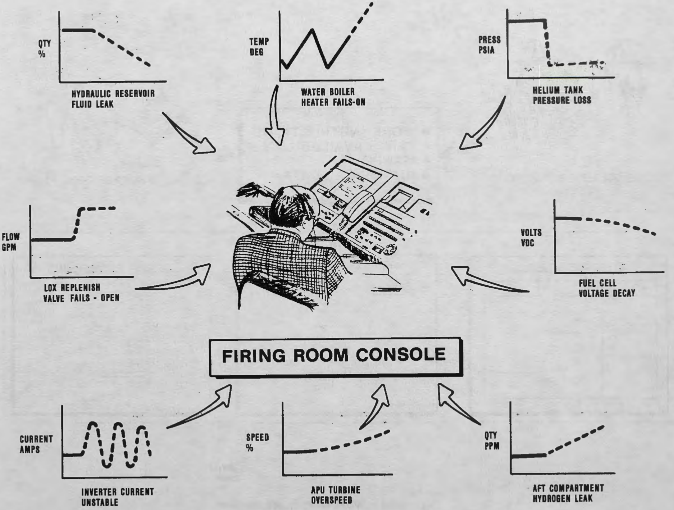

Figure 9 Fault Simulation Problems

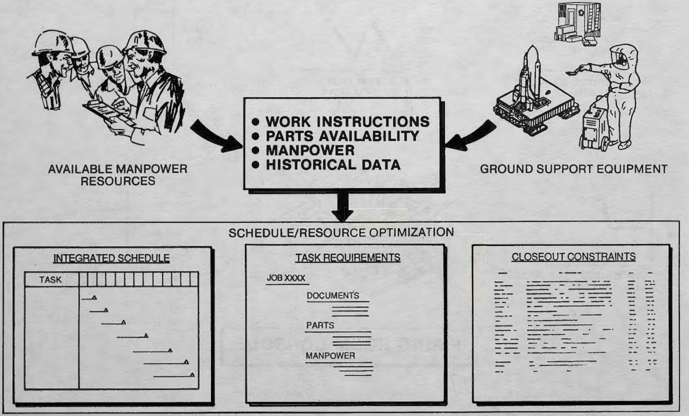

Figure 10 Work-In-Process System

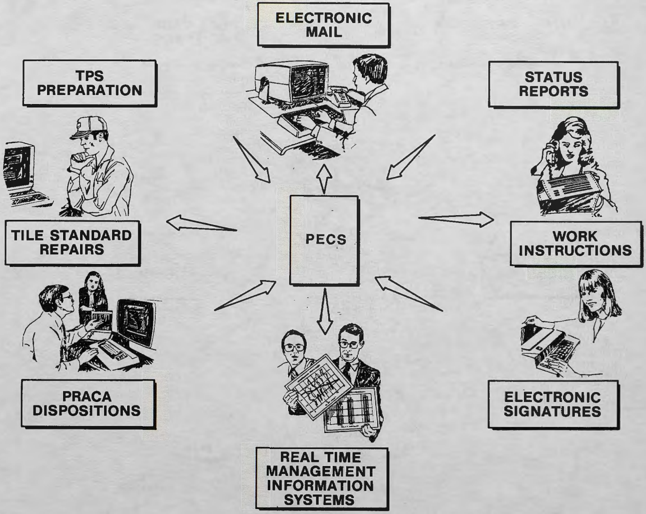

Figure 11 Process Engineering Computer System

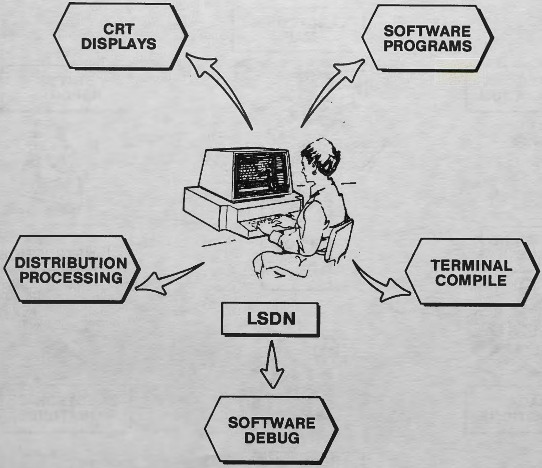

Figure 12 LPS Software Development Network

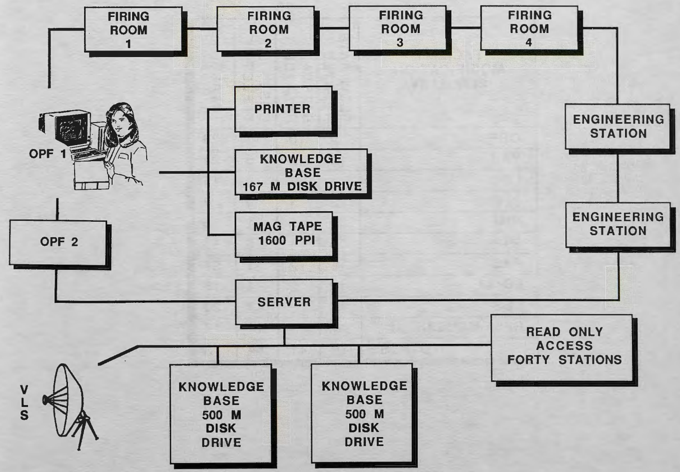

Figure 13 Shuttle Connector Analysis Network

FACILITY MODIFICATION SUMMARY	FLOW RATE RELATED	SAFETY RELATED	COST EFFECTIVE	TOTALS
OPF	2	10	11	23
VAB	14	2	5	21
LCC	1	4	6	11
SLF	-	1	3	4
HMF	2	3	1	6
MLP	4	4	5	13
PAD	6	12	21	39
LC-39	12	2	4	18
LES	3	-	17	20
RPSF-HANGAR AF	4	3	11	18
TOTALS	48	41	84	173

Figure 14 Facility Modification Summary