AN APPLICATION OF THE SYSTEMS ENGINEERING PROCESS TO THE DESIGN OF A SYSTEM OPERATIONS AND MAINTENANCE ORGANIZATION

By

Joe M. Crossett

Project and report submitted to the faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Systems Engineering

APPROVED:

H. A. Kurstedt, Chairman

B. S. Blanchard

D. Hammett

10 November 1995

Blacksburg, Virginia

Key words: Systems, Management, Operations, Maintenance

AN APPLICATION OF THE SYSTEMS ENGINEERING PROCESS TO THE DESIGN OF A SYSTEM OPERATIONS AND MAINTENANCE ORGANIZATION

By

Joe M. Crossett

Committee Chairman: Professor Harold A. Kurstedt
Systems Engineering

(ABSTRACT)

The systems engineering process and management systems engineering theory and applications is applied in the development of a systems operations and maintenance organization. The resulting operations and maintenance organization meets applicable system-level requirements and provides a responsive, efficient, and reliable organization to operate a complex communication system in world-class fashion.

A needs analysis establishes the need for re-design of an existing operations and maintenance organization to increase performance and system reliability. Detailed functional, operational, and maintenance requirements are developed through the systems engineering process. These requirements are allocated to specific units or areas of a system-support capability. The system-support capability including operations and maintenance is designed in detail to meet the developed system requirements.

The results of the systems engineering process is a preliminary design of an operations and maintenance organization to provide system operations services and meet applicable system requirements.

Acknowledgments

I wish to acknowledge the valuable assistance and extend a sincere thank you to all those who helped me towards the completion of this project. I would like to especially thank H. Todd Smith, David Biddinger, and Daniel Basil, three good friends who, through their support have made this project possible.

I would like to also acknowledge the assistance of Harold A. Kurstedt, his course in Management Systems Engineering taught at Telestar in the Spring of 1994 provided the vision and background behind the design of the operations and maintenance organization in this project. Without Professor Kurstedt's course this project would not have been possible.

For the structure and details of the systems engineering process I would like to acknowledge Dean Benjamin Blanchard. Dean Blanchard's textbook on the system engineering process aided in the completion of the project immensely.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

1. Introduction

1.1 Background Information

In the last few decades, an ever-increasing number of systems are being operated twenty-four hours a day to provide services to customers worldwide. Systems such as communications, power generating, and transportation have become very complex and are operated and maintained using special Operations and Maintenance (O&M) organizations. O&M organizations are typically responsible for operating and maintaining all system, and system-support equipment. O&M organizations have become an integral part of providing reliable, efficient, and profitable services to a variety of customers. Although the operations and maintenance performed on systems are extremely important, and receive the majority of effort from the O&M organization, very little effort and time is dedicated to the design, management process, and improvement of the O&M organization. Only through the original design and continuous process improvement of an O&M organization can it achieve and meet challenges required to sustain world-class systems operations performance.

1.2 Current O&M Organization Overview

The current O&M organization (considered and treated as a "system" in this project) is responsible for the operations and maintenance of a communications system that relays data and voice between ground based telephone or data communication companies using a space based communications system. Shown in Figure 1-1 is a diagram outlining the scope of the system operated and maintained by the current O&M organization.

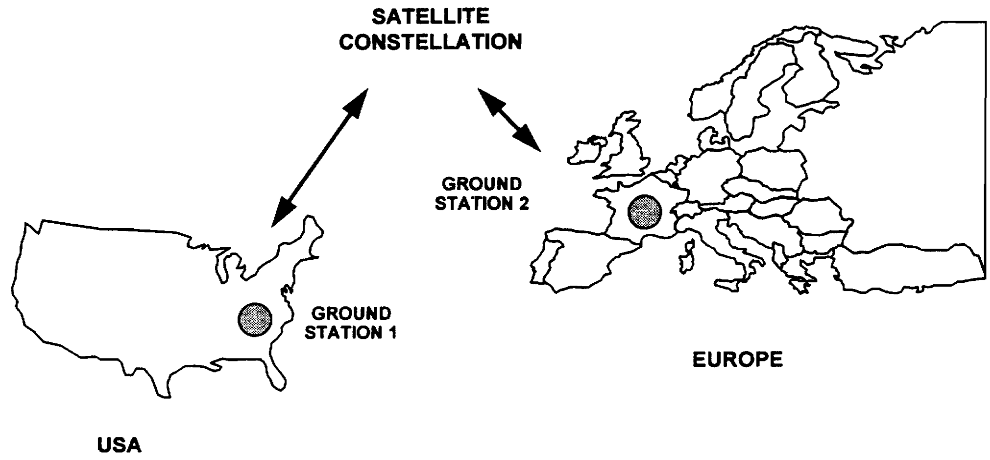

Figure 1-1 Overall System Scope.

The O&M organization is responsible for operating and maintaining ground station equipment and the space based communications satellites. Ground station 1 is the primary ground station responsible for the overall operation and maintenance of the communications equipment. Ground station 2 is the secondary ground station with identical backup capability to ground station 1. The top-level organization structure for a ground station is shown in Figure 1-2 with numbers of personnel shown in parenthesis.

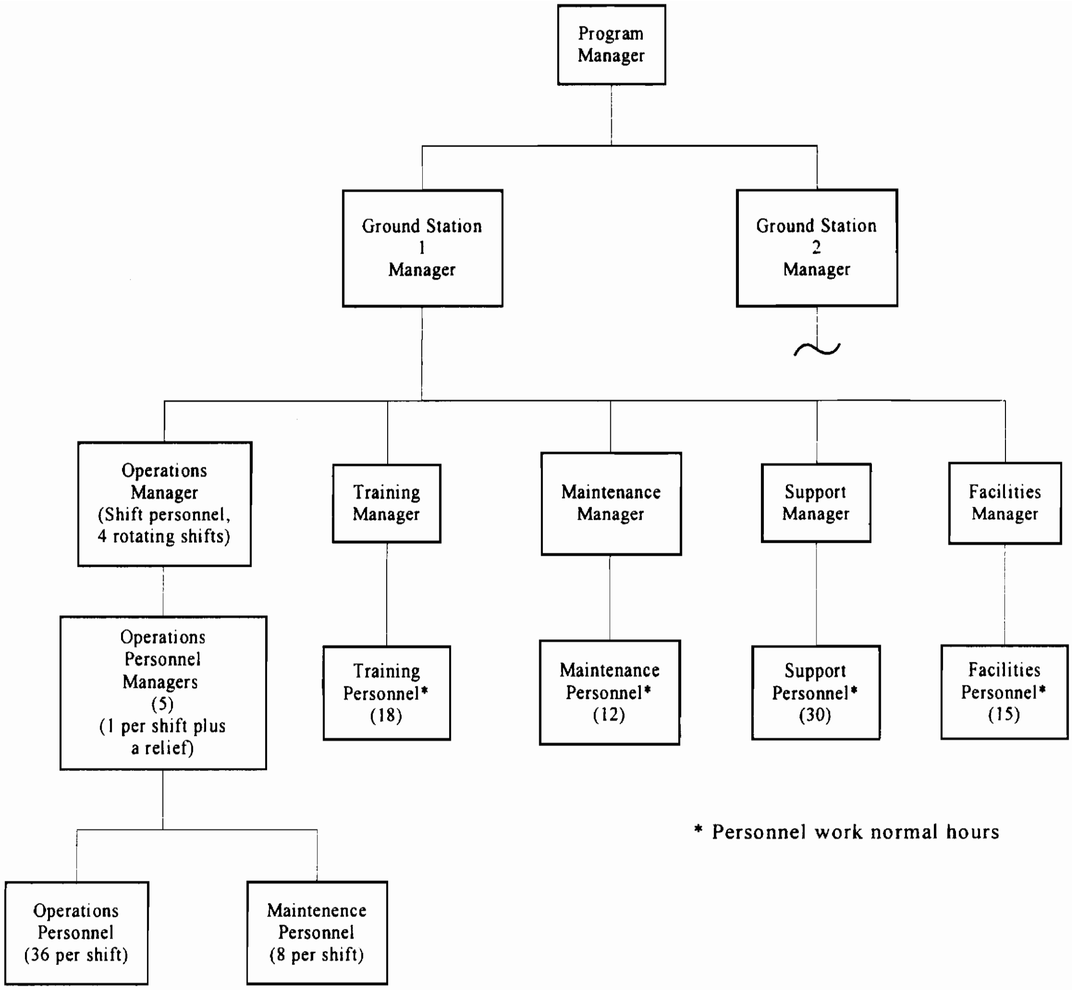

Figure 1-2 Current Organization Structure.

1.3 Major O&M Organization Deficiencies

Two of the major deficiencies within the current O&M organization are operations personnel errors and maintenance reliability. Shown in Table 1-1 are the current levels of performance and the desired levels of performance for operations personnel errors and maintenance reliability.

Table 1-1 Current and Desired Performance.

Performance Factor	Current Performance	Desired Performance
Operations Personnel Errors	8 per year	1 per year
Maintenance Reliability	0.97	0.999

These major deficiencies are only an introduction to organizational deficiencies, detailed descriptions of O&M organization deficiencies are contained in the Conceptual Design Phase of Chapter 2.

1.4 Problem Statement

The systems engineering process is a widely accepted and applied discipline to the design, development, and implementation of large complex systems. Most large complex systems require some level of support capability throughout the system life cycle. The design of the support capability often falls short in the area of O&M. An O&M organization is an unique organizational unit that requires unique design concerns. The systems engineering process can be directly applied to specific design requirements of an O&M organization, but often does not. The systems engineering process is typically applied very well in designing logistics, hardware maintenance schedules, and other hardware related concerns, but lacks detail in the area of management systems engineering. The lack of effort is typically in the detailed design of the O&M organization. Specific areas of detail design such as training programs and management tools are not considered. A typical example of this problem occurs in the area of performing maintenance. The design of the hardware system determines how often and what equipment requires periodic maintenance, operations research determines how many technicians are required and the order in which the maintenance task should occur, but no design work is accomplished in the process in which the maintenance evolution occurs. The process not considered includes items such as maintenance authorization forms and pre-maintenance checklists. Properly designed management tools, such as work authorization forms, ensure maintenance is properly approved, ensures double-checks occur, and overall, increases the reliability of maintenance and the performance of the system. The design of management tools, such as maintenance authorization forms, equipment logs, etc., are often left to the O&M organization to design by themselves within the first few weeks of system real-time operations. The O&M organization at this point is typically determining what management tools are required by lessons-learned, or through someone's past experience. Leaving this type of design task uncontrolled, and performed by the O&M organization, is a mistake and presents a problem in achieving sustained world-class performance throughout the life cycle of the system. The task of design, if left uncontrolled, results in poorly designed O&M organizations, management tools, and procedures. These poorly designed items lead an O&M organization to poor performance as outlined previously in the major deficiencies section.

1.5 Project Objective

The objective of this project is to apply the systems engineering process as described by Blanchard and Fabrycky in their book, Systems Engineering and Analysis, and to apply Kurstedt's theories and applications as described in his class text, Management Systems Theory, Applications, and Design, to the design and development of a world-class Operations and Maintenance organization. This project will take an existing communications system O&M organization and use the systems engineering process to design and develop a new O&M organization that corrects current system deficiencies and meets system-level requirements. Specifically, this project will take the current O&M organization with various deficiencies as described in the "Conceptual Design Phase" of Chapter 2, and design a new O&M organization that meets the developed requirements of section 2.4, "System Requirements Development."

1.6 The Systems Engineering Process

The systems engineering process used in this project is shown at a top-level in Figure 1-3. Details of the activities are described for each applicable section throughout this project.

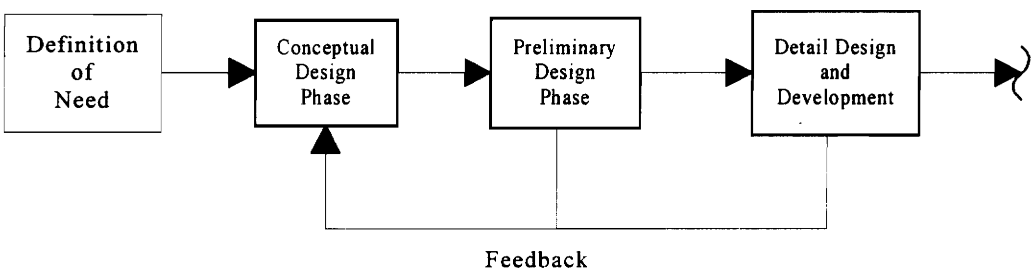

Figure 1-3 Overall Top-Level Systems Engineering Process.

2. Conceptual System Design

The conceptual system design stage is the first step in the system design process using the systems engineering approach. Figure 2-1 displays the major steps and the flow of activity in the conceptual system design phase.

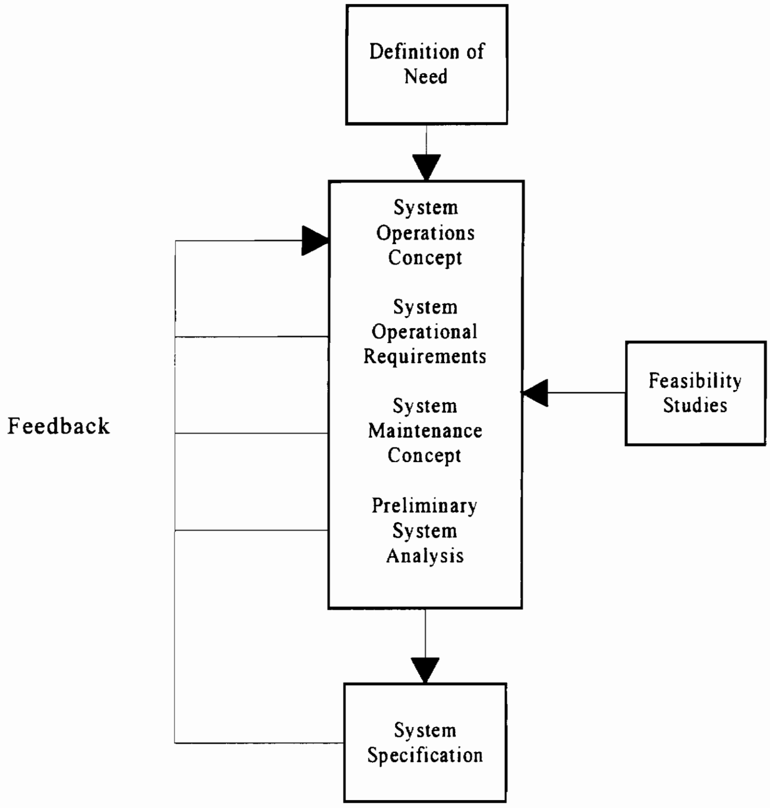

Figure 2-1 Conceptual Design Phase Activities

2.1 Conceptual System Design Process Overview

The conceptual system design process defines the system-level requirements. First, a definition of need is established from a set of perceived system deficiencies. Feasibility studies are performed in parallel with requirements definition efforts to determine applicable technological applications for use in system development. Second, a system operational concept at a top-level is developed. From the system operational concept, a set of operational requirements are determined. From the operational requirements, a maintenance concept is derived. Following the development of system-level requirements, a preliminary system analysis is conducted prior to the generation of the system specification. Third, a top-level system specification is developed from the operational and maintenance requirements and the preliminary design work.

2.2 Definition of Need

The need for an efficient, world-class O&M organization, is evident in the current organization to be re-designed in this project. This need is justified in the following sections, which describe in detail the O&M organizational system deficiencies. The current organization in use suffers from multiple organizational deficiencies. The system deficiencies are outlined in the next section and demonstrate a perceived need for system improvement and re-design.

2.2.1 System Deficiencies

This section on system deficiencies outlines in great detail the deficiencies existing within the current organization. From the defined deficiencies, an analysis is made to determine the need for system re-design.

2.2.1.1 Training Program

The O&M organization on average has eight personnel errors per year and loses system availability due to a maintenance reliability that exists at a level of 0.97. Both of these performance levels are deficient and it is desired to achieve a level of one personnel error per year and a level of 0.999 for maintenance reliability. A key component causing the noted deficiencies is the existing training program. The O&M organization lacks an adequate training program for the communications system being operated and maintained. The communications system is a large scale and complex system requiring quality training for all operations and maintenance personnel. The training program must maintain current the organization's knowledge of operations and maintenance procedures, tasks, and evolutions. The main task of a training program is to ensure operators are prepared with the required knowledge to perform all tasks with absolute correctness and acceptable efficiency. This main task is not being accomplished to a level of detail adequate to prevent operations personnel errors and maintenance errors. Training of operators, maintenance staff, and supervisors is one the most important factors in the continued success of an O&M organization. The lack of success and low performance level is a result of several training department design problems. One problem is the design and location of the training department within the overall organizational structure. The current organization has a training department consisting of eighteen personnel that is not integrated into the O&M organization. The training department as shown in Figure 1-2, organizationally does not work for operations or maintenance managers. This leads to a training department that is considered standalone, and is not responsive to operations and maintenance managers or personnel. The feedback from operations personnel concerning procedural changes, process changes, new training methods must be considered if the higher level performance requirements are to be met. Other problems within the training department are a direct result of the lack of requirements placed on the training department to perform tasks proven to improve personnel and operations performance. Three tasks that are not maintained or performed adequately by the training department are a continuous training program, certification process, and a lessons-learned program as described in the next sections. These programs or processes are a direct related component in the performance of personnel and the resulting personnel error rate and maintenance reliability.

2.2.1.1.1 Continuous Training Program

The organization does not have the requirement to maintain a formal continuous training program. The lack of continuous training is on average the cause of two personnel errors per year. Operators are not prepared for new procedures, new maintenance tasks, or tasks performed infrequently and the result is a operations or maintenance error. The training department has only the purpose or task of training and qualifying new personnel. This results in a lack of a continuous training program to keep personnel trained and prepared for new procedures, special testing, or new maintenance requirements. The purpose of a continuous training program is to refresh operators knowledge and skills on a periodic basis. The organization attempts to rely on individual self study to maintain continued performance. This approach lacks the use of teaming and shared ideas or concepts. Individual study is useful to prepare a basis of knowledge, but teamwork and group discussion is a necessity to maintain world-class operational performance within a team-based operational environment. The organization does not engage in teamwork or teaming-type activities that promote synergy and efficiency within a team of operators. The lack of a requirement to perform formal and well maintained continuous training is a component in the high number of personnel errors and low maintenance reliability currently shown by the O&M organization.

2.2.1.1.2 Certification Process

The certification process is the first step in the training program. The certification process consists of a combination of classroom and on-the-job training. The purpose of the certification process is to adequately train operations personnel to perform required operational tasks alone and unsupervised with a level of performance to prevent personnel errors. This initial process lasts six months and results in the certification as a basic operator. This process lacks formal administration to ensure an operator's knowledge is at a level necessary to perform all required operations. The documents and management tools used to validate an operator's knowledge and performance skills are inadequate. The current documents used are poorly designed, lack structure, and lack the means to track an operator's training progress. These design problems within the certification process are the direct cause of on average four personnel errors per year. This constitutes half of the total errors occurring per year. The lack of a formal, structured, and world-class certification program directly results in personnel errors.

2.2.1.1.3 Lessons-Learned Program

The training program does not have a requirement to maintain or use a lessons-learned program. During operations of complex large-scale systems, new unforeseen situations that affect normal operations are typically encountered over the life cycle of the system. Unforeseen situations such as multiple simultaneous equipment failures normally are solved by employing recovery steps that are undocumented or by employing a variation of current procedures. This informal process is a necessity to maintain real-time operations, but must be investigated by training personnel and support staff to evaluate the validity of the informal process as a candidate for incorporation into formal operational procedures. At the very least, pass-down or lessons-learned-type knowledge, acquired from unforeseen situations must be documented, understood, reviewed and incorporated into procedures, if applicable. The lack of a lessons-learned program results in on average one additional personnel errors per year and an additional loss of system availability. If a personnel error occurs due to an equipment or software problem this should be noted and corrected as soon as possible to prevent the same error from occurring. If a lesson is learned during the recovery of the system this lesson should be documented to save the operations personnel time when recovering the system from the same recovery situation. When this is not done, information previously learned is not applied, and system recovery time during anomalous situations does not improve. This adds to the loss of system availability. On average the lack of a formal well maintained lessons-learned program causes the system to be unavailable for 20 hours per year. The organization needs a formal "lessons-learned" program that captures acquired knowledge from situational lessons-learned and formally acknowledges, accepts, and processes this knowledge for its value and worth to the successful performance of the organization.

2.2.1.2 Personnel Errors

2.2.1.2.1.1 Response to Personnel Errors

Personnel errors as outlined previously are at an average level of eight errors per year which is considered deficient. The response to personnel errors is a key component in the reduction of personnel errors through a process of feedback. Overall, the organization is deficient in the response to personnel errors. When a personnel error occurs the organization lacks a formal process to conduct training or change procedures to ensure the same error does not occur again. This is the most significant deficiency within the realm of personnel errors. Over a period of one year, several personnel errors occur with only the most significant and damaging documented or reviewed. The errors can range from low to significant impact on system operations and communications continuity. The organization fails to recognize the usefulness of personnel errors in the further improvement of operations whether the error is of low impact or significant impact. The organizational system does not recognize that when personnel errors occur, for most cases it is not the fault of operator, it is the fault of the organizational system providing training and guidance, or the software/hardware system providing information to the operator. The system must respond to correct the deficiency within itself or within the software system to include changing procedures, conducting training, or changing the format in which information is provided to an operator.

2.2.1.2.1.2 Short Term Corrective Action

The organization simply is uneducated with respect to a world-class program to respond to personnel errors in the short term. Personnel errors that occur can be directly related to factors such as environment, information displayed, or quality of procedures. Following a personnel error the factors causing the error should be identified and corrected to prevent the error from occurring again. The current organization is deficient in this short term corrective action. In the short term (the first six hours following the error), a number of formal actions should take place within the structure of a complete process. The organization takes no immediate action (after the system is fully recovered and stable) to formally document all the specific details about the error and the surrounding reasons why it occurred. The details of a personnel error should be captured, reviewed, and accessed within the first few hours after the error. A complete review of the error should result in a short term solution and identification of the root cause. The solution and background reasons why the error occurred should be promulgated using a formal process to all operational personnel on all shifts. This formal process should consist of a formal memo or checklist requiring review and sign-off by all applicable operational personnel. Informing all operational personnel of the specific details and root cause of the error quickly and efficiently will prevent the error from recurring. The organization performs none of these tasks and takes the risk of the same personnel error occurring following shift change by an uninformed operator.

2.2.1.2.1.3 Long Term Corrective Action

In the long term, the organization fails to understand the personnel error from a systems perspective and a human factors perspective. A systems perspective must be taken to fully understand the complete environment and reasons why an operator would make the wrong choice. Using the systems perspective, the complete system environment is investigated and the root cause of the error is determined. The human factors perspective takes a look at the surrounding environment from an operator's perspective, such as length of time the operator is performing a task, lighting, or information displayed to the operator. In the long term, the organization simple fails to close the loop following a personnel error. There is no formal process in place to study, understand, document, or correct the reasons behind the personnel error in the long term. The majority of personnel errors are not the singular fault of the human operator. The majority of errors are a combination of several factors such as environment, procedures, or information provided to the operator. Many personnel errors are the product of poorly written procedures that are difficult to interpret properly or present ambiguous procedural steps or the product of poorly trained operators. If an operator is trained properly and follows well-written and maintained procedures, rarely will he or she make a purely human error. A pure human error is an error that can be attributed only to the human component and no other component within the system.

2.2.1.2.2 Lost System Performance

The organization lacks the vision to understand that both a short term and long term corrective action plan must be in place to reduce the number of personnel errors occurring. Personnel errors contribute to the loss of system availability. Personnel errors contribute to the lost availability of the system and with a redesign of the organization can be significantly reduced, and therefore increase system performance. Currently system availability is at a level of 0.95 which is a result of both personnel errors and equipment reliability. It is desired to increase the system available to a level of 0.975.

2.2.1.2.3 Lessons-Learned Program

A key to successfully reducing personnel errors is to maintain a formal lessons-learned program. This type of program is maintained and managed by both training personnel and operations personnel. A formal lessons-learned program should be an integral part of the training program as depicted in the previous training program deficiency section.

2.2.1.3 Equipment Maintenance

The organization lacks the proper tools to perform equipment maintenance activities with efficient and reliable results. Equipment maintenance in an operational environment must be controlled and well understood by all personnel involved. The tools used to control equipment maintenance lack proper control, coordination, and close-out of maintenance activities resulting in the improper control causing unreliable maintenance. Maintenance control problems have caused computer to computer connections to be lost during cable replacement (i.e. the incorrect cable removed). Maintenance reliability is currently at a level of 0.97 which is considered deficient and is desired to be increased to a level of 0.999.

2.2.1.4 Organizational Structure

The baseline structure of the organization prevents adequate communication and teamwork among subset teams within the organization. The structure of the organization divides the O&M organization into several groups that destroys necessary teamwork that should occur within the entire organization to maintain success.

2.2.1.5 Operating Procedures

2.2.1.5.1 Normal Operating Procedures

The organization is deficient in the maintenance of normal operating procedures used by operators. Operating procedures can be the direct cause of errors by both operational and maintenance personnel. Operating procedures are extremely important to the daily operations and maintenance of a communications system. Correct, easily understood and followed operating procedures are a necessity in quality, timely, and responsive operations.

2.2.1.5.2 Emergency Response Procedures

The organization lacks adequate emergency or anomaly response procedures. Emergency response procedures is an area that can make or break an O&M organization's performance. A well-understood and written emergency response procedure can provide stability to a potential confusing and demanding situation.

2.2.1.5.3 Special Test Procedures

The use and coordination of special test procedures within the organization lacks adequate coordination, structure, and attention to detail. Conducting testing of equipment is a common task within O&M activities. The organization lacks a structured process that requires adequate reviews, formal writing steps, or adequate coordination of special test procedures.

2.2.2 System Need Analysis

The previous system deficiencies outline an O&M organization in need of perceived redesign. The noted system deficiencies capture a system that is outdated, lacking vision, and missing the means to correct itself through continuous process improvement. If the organization was a hardware system, it would be recommended for complete replacement by a newly-designed system using the most current technology available. This is the very intent of this project. This project will design an O&M organization that replaces the existing O&M organization described previously. The design of the O&M organization in this project will use the most current organizational design technology to eliminate the noted deficiencies and meet all system requirements.

2.3 Feasibility Study

There are numerous technological approaches to design a new organizational system to correct the noted deficiencies within the current organization. This feasibility study will evaluate several management system engineering technological approaches to the design of an organization and choose the most appropriate technology for this project.

2.3.1 Organizational Models

When designing a management or organizational system, choosing a model to build the organization around is like choosing a particular computer technology for an information system. There are several basic model structures that can be used to accomplish the goals of an O&M organization. Three possible organizational structures are shown in Figure 2-2.

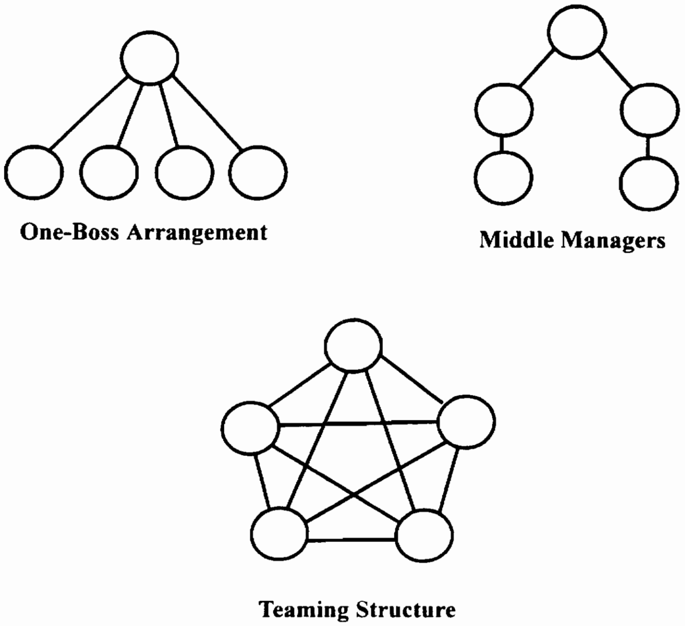

Figure 2-2 Basic Organization Structure Models.

2.3.1.1 Command and Control Organizational Structure

When evaluating the best model for the command and control function of the O&M organization, the environment and command structure within the organization must be taken into consideration. The command and control function is defined for the purpose of choosing an organizational model as the function of real-time decision making. Therefore, the organizational model for command and control does not define lines along which information flows, but rather defines lines along which decisions and directions flow in real-time operations. The O&M organization being redesigned in this project has the primary goal to maintain continuous space-based communications to customers twenty-four hours a day. In this type of environment, real-time decisions must be made quickly, efficiently, and correctly. This real-time decision requirement eliminates the Teaming Structure model from the best choice due to the fact that a teaming environment requires consensus to come to a final decision. Consensus-type decision making extends the time to make and disseminate a decision. This increase in decision time jeopardizes the required rapid response time of a quality O&M organization. Within real-time operations, decisions must be made quickly at all levels of the organization. With the Middle Managers structure, which resembles a traditional vertical management organization, decision making is taken to the level of management appropriate for the task and decision to be made. A decision can be made quickly based on that level of management's experience and training. The dissemination of a decision is made quickly and efficiently within the chain-of-command like traditional vertical management structure. The more traditional Middle Managers structure provides a simple, easily-understood chain-of-command for operators to learn and use to force quick decision making, and therefore is the structure of choice for command and control. The One-Boss Arrangement structure could be applicable if the organization is small and has a more limited scope. The organization being redesigned is too large in scope to be managed by a small one-boss type of structure. Therefore, for real-time operations command and control the Middle Managers structure is the evaluated correct choice.

2.3.1.2 Non-Real-Time Operations Organizational Structure

Tasks that are performed outside the realm of command and control require a much different approach to the choice of an organizational structure. When performing tasks such as long term continuous process improvement, the Middle Manager, or traditional vertical management structure is not considered the best vehicle to enhance creativity and encourage ideas from all members of the organization. The best choice of an organizational structure for encouraging creativity and using the best ideas of the organization, is to build non-command and control type organizational tasks around the Teaming Structure. This is mostly due to the Teaming Structure having all members at a more horizontal management level that removes barriers to a free dialogue. Free dialogue among all members of the organization then results in the best ideas for change and improvement. For this reason the One-Boss Arrangement organizational structure is not preferred because the one-boss would tend to place real or perceived barriers within the organization that limits the free discussion and flow of ideas. Therefore, the Teaming Structure organizational model is evaluated as the best choice to build the organization around for non-command and control tasks.

2.3.2 Building Management Tools

Designing tools to perform tasks, gather information, and make decisions is an extremely important task in the redesigning of the O&M organization. A tool can be as simple as an operational checklist to something as complicated as a several-hundred-page maintenance procedure. Each tool within an operational organization has a unique purpose and goal. The commonality between every tool used within the operational organization is that every tool has the purpose of helping personnel in the organization to perform tasks more efficiently and with absolute reliability. Tools are not only for managers, but for operators and personnel at every level and position of the organization. There are probably several methods to use to develop and design tools, but for this project one management systems engineering technology application is adopted. This application is from Kurstedt[1] and is the Management System Model used in the development of tools. This management systems technology available in the marketplace will provide the foundation to build all the necessary tools for the O&M organization to perform all required tasks. A diagram of this model in a basic form in shown in Figure 2-3. A complete diagram and explanation of the entire technology application is located in Appendix A.

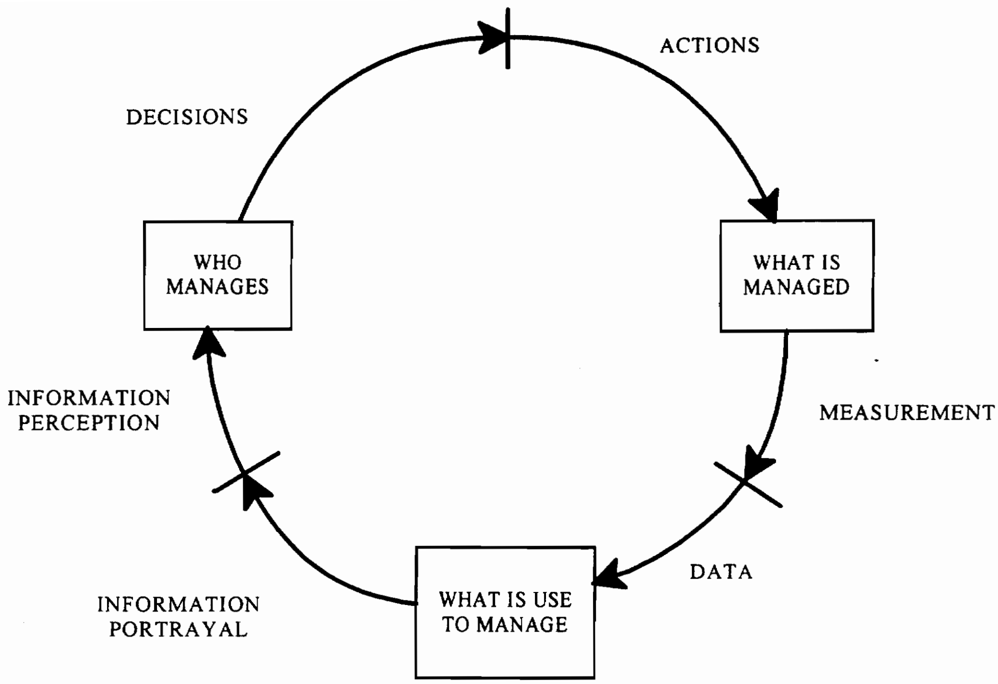

Figure 2-3 Basic Management System Model.

2.3.3 Feasibility Study Conclusion

The choice of the management systems engineering technologies in this feasibility study results in a basis for the development of the O&M organization throughout the life cycle of the system. The models, applications, or technologies evaluated as the appropriate choice for this project will be used throughout the life cycle much like the choice of a particular computer technology would be used as the hardware basis throughout the life cycle of an information system.

2.4 System Requirements Development

The system-level requirements are developed by first describing the system operational concept. From the system operational concept, a set of operational requirements are developed. From the operational concept and operational requirements, a maintenance concept is derived. From the maintenance concept, maintenance requirements are derived. These requirements then generate a system specification. For this project, emphasis is placed on system requirements that are likely to be allocated to the O&M organization.

2.4.1 System Operational Concept

To begin the process of developing a system operational concept, a general concept of operations is described. Prior to designing an O&M organization, it is a necessity to understand the hardware system from both a functional and physical perspective. In the concept of operations, the hardware system must be understood from a conceptual operations perspective to develop an organization capable of operating the system. So, it must be understood that this project is designing an organization, not a hardware system, but the hardware system must be understood to a certain degree to design an O&M organization to operate the system. Therefore, within the concept of operations for the O&M organization is imbedded a thorough top-level explanation of the hardware system, both functionally and physically. The system operational concept development is concluded by defining seven conceptual characteristics recommended from Blanchard and Fabrycky[2]. From these characteristics and the operational concept, operational requirements are then created.

2.4.1.1 System General Description

2.4.1.1.1 General Overview

Shown in Figure 2-4 is a diagram of the hardware system operated by the O&M organization. The system is a space-based communication system that relays telephone communications between ground station 1 and ground station 2. Ground station 1 is located on the East Coast of the United States and ground station 2 is located on the European Continent. Both ground stations are in view of three geosynchronous communication satellites positioned centrally over the Atlantic Ocean, and maintained slightly north of the Equator in geosynchronous orbits. Each ground station is equipped with four ground antennas, three for normal operations and one for backup and maintenance operations. Each ground station connects into a terrestrial gateway for access into ground based telephone communications.

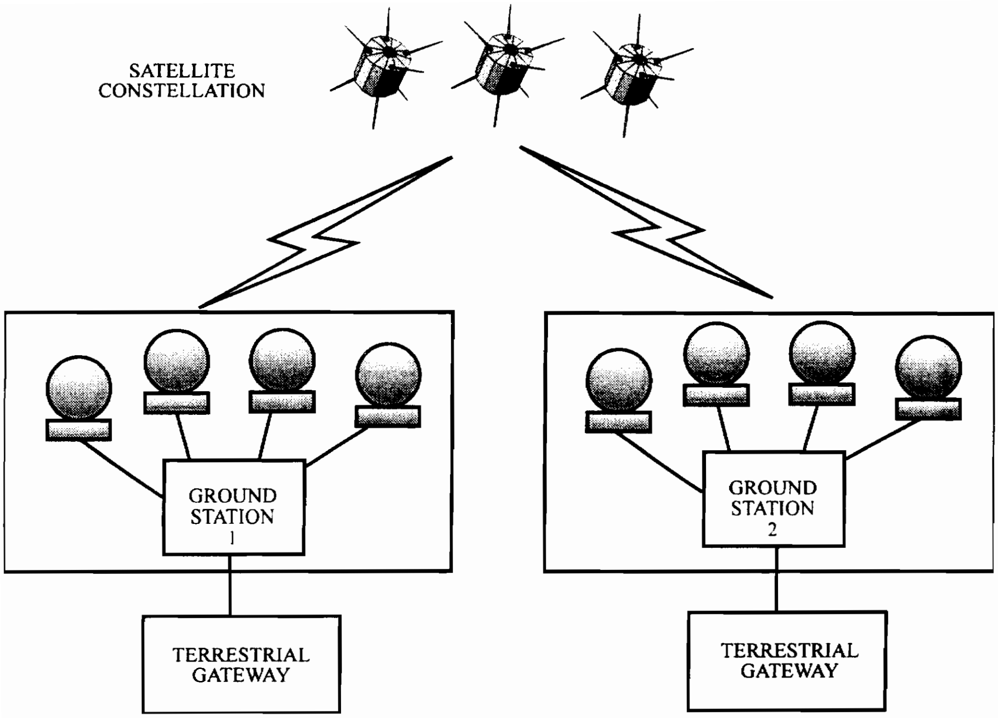

Figure 2-4 Space-Based Communications System

2.4.1.1.1.1 Functional System General Description

Shown in Figure 2-5 is a functional diagram of the hardware system within the ground station. Within an individual ground station resides three main functional rooms consisting of the Operations Control Room (OCR), the Terrestrial Communications Interface Room (TCIR), and the Receive Transmit Control Room (RTCR). The OCR is a large operations area where satellite control personnel reside. The TCIR is a hardware room for terrestrial communications interface equipment with local system equipment control and status available to hardware technicians. The RTCR is similar to the TCIR and is also a hardware room for receive-and-transmit system equipment with local control and status of equipment available to hardware technicians. Functionally telephone communications are received by the ground station from a terrestrial gateway and routed through the TCIR to the RTCR for uplink transmission to one of the three satellites. Ground equipment is controlled and status received using formatted commands and telemetry exchanged between the antenna rooms, the RTCR, and the TCIR. Functionally, the OCR controls equipment at the antenna equipment rooms (AER), in the RTCR, and in the TCIR to provide continuous continuity between the satellites and the ground-based terrestrial gateway.

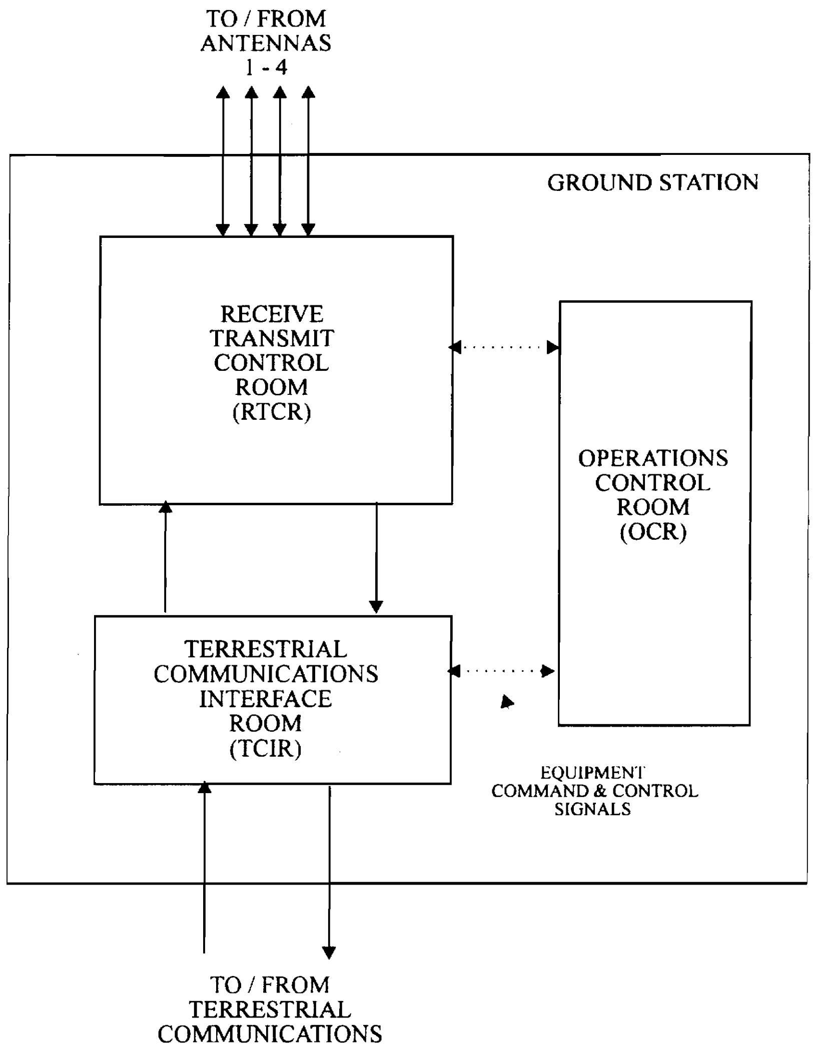

Figure 2-5 Ground Station Functional Diagram.

2.4.1.1.1.2 Physical System General Description

Shown in Figure 2-6 is a physical diagram of the operations facility.

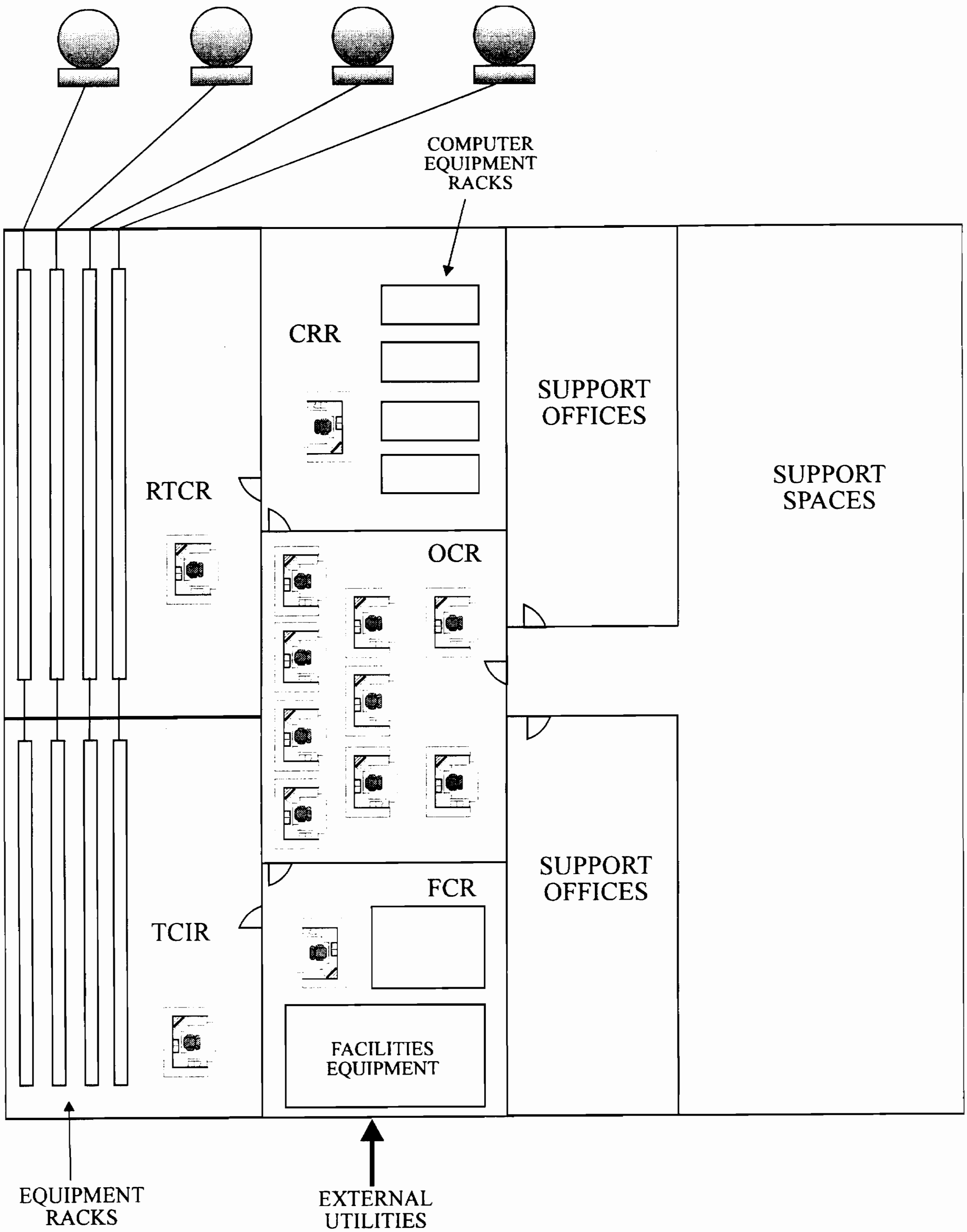

Figure 2-6 Ground Station Physical Diagram.

2.4.1.1.1.2.1 Receive Transmit Control Room (RTCR)

The RTCR has the physical purpose of housing the interface equipment between the ground antennas and the Terrestrial Communications Interface Room (TCIR). The equipment in the RTCR is separated into three major groups: the transmit equipment, the receive equipment, and the antenna control equipment. One control station resides in the RTCR for local control and status of the receiving, transmitting, and antenna equipment racks.

2.4.1.1.1.2.2 Computer Resources Room (CRR)

The CRR has the physical purpose of housing the main computer equipment that supports operations throughout the facility. The room houses file servers, mass storage, and system administrator computer equipment. The room contains one control station for control and status of computer resources throughout the facility.

2.4.1.1.1.2.3 Operations Control Room (OCR)

The OCR has the physical purpose of housing the major operations control stations within the facility. A total of nine control stations are located in the OCR. One station is provided for each of the four ground antennas and the associated ground equipment. Three control stations are dedicated to the on orbit satellites. The last two control stations are for an Operations Supervisor (OS) and an Operations Director (OD).

2.4.1.1.1.2.4 Terrestrial Communications Interface Room (TCIR)

The TCIR has the physical purpose of housing the interface equipment between the RTCR and the terrestrial gateway. The equipment in the TCIR is separated into two major groups: the gateway interface equipment, and the receive transmit interface equipment. One control station resides in the TCIR for local control and status of the TCIR equipment racks.

2.4.1.1.1.2.5 Facilities Control Room (FCR)

The FCR has the physical purpose of housing the major facilities equipment for the entire ground station. The equipment in the FCR consists of air conditioning, heating, and electrical distribution equipment. One control station resides in the FCR for control and status of the FCR equipment.

2.4.1.1.1.2.6 Support Offices and Spaces (SOS)

The SOS has the physical purpose of housing the offices for support personnel working day-shift to include: training, operations support, orbital support, facilities planning, and maintenance planning.

2.4.1.2 System Detailed Description

2.4.1.2.1 Functional System Detailed Description

The detailed functional system description can be divided into two major sections consisting of equipment command and control and telephone signal transmission.

2.4.1.2.1.1 Equipment Command and Control Functional Description

Shown in Figure 2-7 is a detailed diagram of the functional equipment command and control system for one ground antenna and one satellite. For each ground antenna and the associated ground equipment exists one control station located in the OCR. This control station is responsible for operating and configuring the ground antenna, receive equipment, and transmit equipment associated with one string of ground equipment. This control station receives equipment status from ground equipment and has the capability to send equipment configuration commands. The same functional capability of the Equipment Operator's (EO) control station also exists at the Operations Supervisors (OS) control station. A second control station shown in Figure 2-7 is responsible for the command and control of one satellite. This control station receives satellite telemetry for status and has the capability to send vehicle commands for equipment configuration.

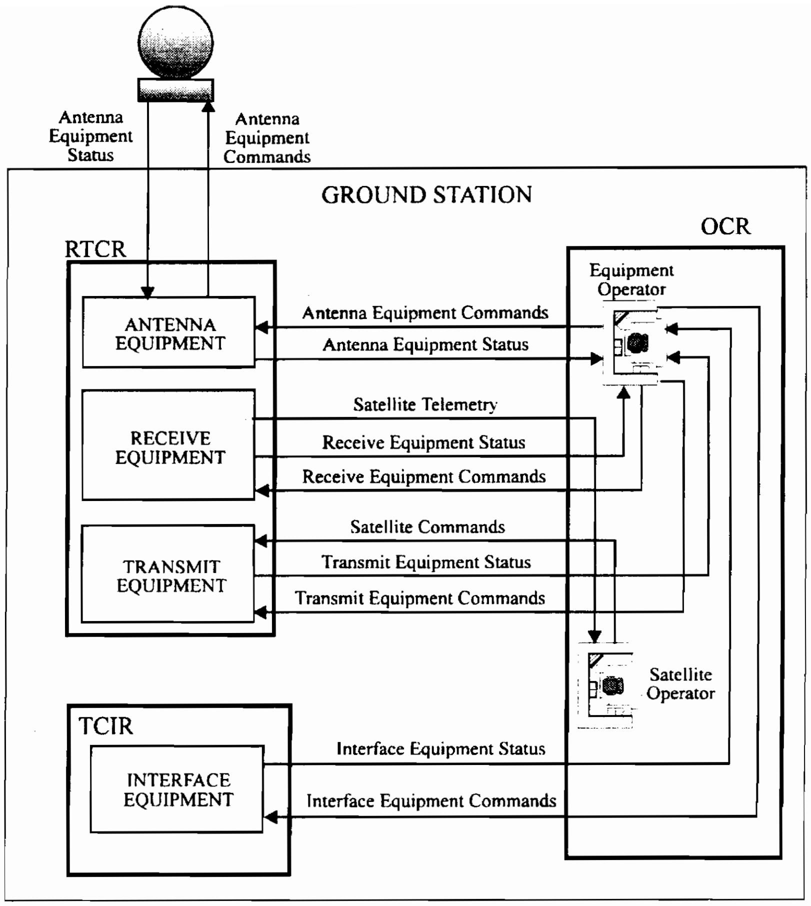

Figure 2-7 Detailed Equipment Command and Control Functional Diagram.

2.4.1.2.1.2 Telephone Signal Transmission Functional Description

Shown in Figure 2-8 is a detailed diagram of the functional telephone signal transmission system for one ground antenna and one satellite. The functional flow of telephone signal transmission begins with the receipt of up to 840 channels (5040 telephone calls) from a remote ground terrestrial gateway. The telephone channels are received from the gateway and routed to an in-use string of TCIR equipment. The TCIR equipment prepares the signals for transmission to the transmit equipment located in the RTCR. The RTCR receives the telephone signals from the TCIR and routes them to an active string of transmit equipment. The transmit equipment prepares the received signals for transmission to the satellite by the High Power Amplifier located in the antenna equipment room (AER). For telephone signals received from the satellite, the previous process is reversed with the use of a receive equipment string. The functional routing of telephone signals through the facility is extremely diverse. Shown in Figure 2-9 is a

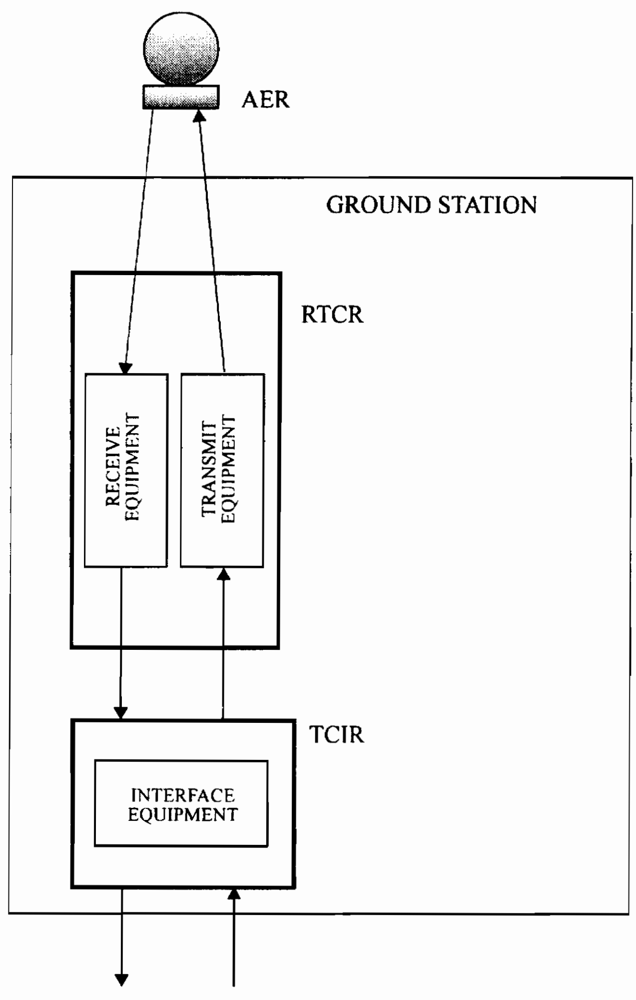

Figure 2-8 Telephone Signal Transmission Functional Diagram.

complete functional routing diagram of telephone signals.

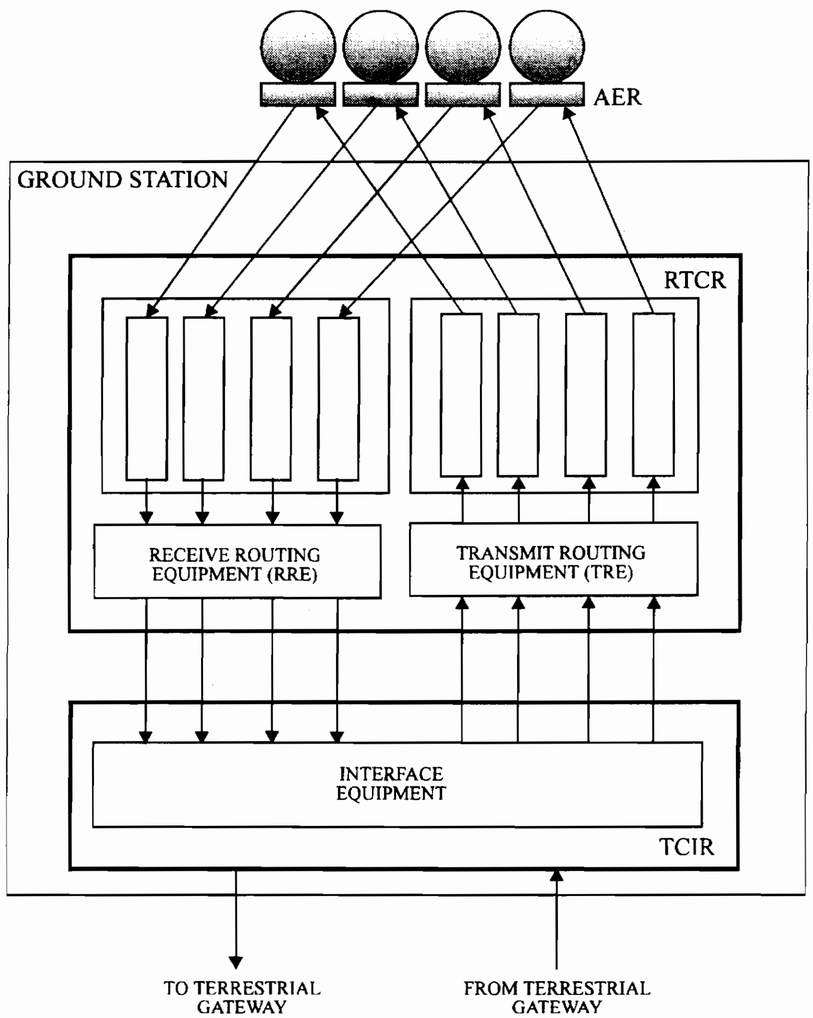

Figure 2-9 Telephone Signal Transmission Routing Diagram.

The routing diagram of Figure 2-9 depicts a routing system that allows incoming telephone signals from the terrestrial gateway to be routed to any of the four ground antennas. This functionality is built into the system to allow versatility in the operation of the system and to provide flexibility when performing maintenance. The flexibility of telephone signal routing is accomplished through the Transmit Routing Equipment (TRE) and the Receive Routing Equipment (RRE). The TRE provides a four-by-four routing matrix to allow connection between any incoming telephone signal from the TCIR to any active string of transmit equipment. The RRE provides the same service as the TRE but for the interface between the receive equipment and the TCIR.

2.4.1.3 System Concept of Operation

The system concept of operations is divided into two major sections consisting of normal and emergency operations.

2.4.1.3.1 Normal Operations

Normal operations consist of two subsets: normal operations during steady state conditions when no system changes are occurring and normal operations during planned system configuration changes.

2.4.1.3.1.1 Normal Steady State Operations

During normal steady-state operations, the ground station is receiving telephone signals from the terrestrial gateway and routing these signals through three transmit equipment strings to three geo-synchronous satellites that route the telephone signals overseas to the second ground station. The second ground station receives these telephone signals and routes them to a ground based terrestrial gateway for delivery to a local telephone company. Therefore, the concept of operations for the system is to provide transmission continuity between two long-distance telephone companies, one located in the United States and a second located on the European Continent.

2.4.1.3.1.1.1 Operations Control Room (OCR) Operator Responsibilities

During normal steady-state operations, each operator has specific equipment to monitor and control as outlined in the following sections:

2.4.1.3.1.1.1.1 Satellite Operator (SO)

During normal steady state operations, the SO monitors telemetry from an on orbit satellite to ensure the safety of the spacecraft is maintained. Each satellite is controlled from a dedicated ground station control station located in the OCR. The SO has the responsibility to monitor a satellite for proper equipment operation to include monitoring equipment thermal control, receiver and transmitter parameters, and orbital sensing equipment operation. During normal operations, if satellite equipment operating specifications drift out of specification, corrective action takes place in accordance with applicable procedures.

2.4.1.3.1.1.1.2 Equipment Operator

During normal steady operations, the EO monitors telemetry from a set of antenna, receive, and transmit equipment that is associated with one ground antenna. The EO has the responsibility to monitor all the ground equipment supporting the receiving and transmitting of telephone signals to and from a single ground antenna. The EO monitors the equipment to ensure transmission and receipt of telephone signal are within specification. During normal operations, if ground equipment operating specifications drift out of specification, corrective action takes place in accordance with applicable procedures.

2.4.1.3.1.1.1.3 Operations Supervisor(OS)

The OS located in the OCR has supervisory responsibilities over the equipment operators and the satellite operators. During normal operations, the OS monitors telemetry from the interface equipment located in the TCIR and the routing equipment located in the RTCR. The operations supervisor provides back-up operations support to the satellite operators and the equipment operators.

2.4.1.3.1.1.1.4 Operations Director (OD)

The OD located in the OCR has supervisory responsibilities for the entire ground station facility. The OD has an assistant located at the second ground station who has supervisory responsibilities for that facility. The OD has complete responsibility for all operations and maintenance of the system from the output of one terrestrial gateway to the input of the receiving terrestrial gateway.

2.4.1.3.1.1.2 Facilities Control Room (FCR) Operator Responsibilities

2.4.1.3.1.1.2.1 Facilities Operator (FO)

During normal steady operations, the FO has the responsibility to monitor telemetry from various sets of facilities equipment to include air conditioning, heating, and electrical distribution. The FO monitors the facilities equipment to ensure proper operation and performance within specification. The FO is also the lead technician in the FCR who has the responsibility to monitor and control equipment maintenance performed by additional maintenance personnel in the FCR. During normal operations, if facilities equipment operating specifications drift out of specification, corrective action takes place in accordance with applicable procedures.

2.4.1.3.1.1.3 Computer Resources Room (FCR) Operator Responsibilities

2.4.1.3.1.1.4 Computer Operator (CO)

During normal steady operations, the CO has the responsibility to monitor computer resource equipment to include file servers, mass storage, and system administrator computer equipment. The CO monitors the computer resource equipment to ensure proper operation and performance. The CO is also the lead technician in the CRR who monitors and is responsible for equipment maintenance performed by additional computer maintenance personnel in the CRR. During normal operations, if computer resource equipment fails, corrective action takes place in accordance with applicable procedures.

2.4.1.3.1.1.5 Receive Transmit Control Room (RTCR) Operator Responsibilities

2.4.1.3.1.1.5.1 Receive Transmit Operator (RTO)

During normal steady operations, the RTO has the responsibility to monitor telemetry from receive transmit equipment. The RTO monitors the receive transmit equipment to ensure proper operation and performance. The RTO is a local operator who during normal operations does not configure or change receive transmit equipment. The RTO monitors more technically detailed telemetry from the receive transmit equipment than the EO receives in the OCR. The RTO is also the lead technician in the RTCR to monitor and control equipment maintenance performed by additional maintenance personnel in the RTCR. During normal operations, if receive transmit equipment drifts out of correct operating specification, corrective action takes place in accordance with applicable procedures. The RTO during anomaly periods has the ability to control and configure equipment using local equipment control methods located in the RTCR.

2.4.1.3.1.1.6 TC Interface Room (TCIR) Operator Responsibilities

2.4.1.3.1.1.6.1 Terrestrial Communications Operator (TCO)

During normal steady operations, the TCO has the responsibility to monitor telemetry from terrestrial communication interface equipment. The TCO monitors the interface equipment to ensure proper operation and performance. The TCO is a local operator who during normal operations does not configure or control interface equipment. The TCO monitors more technically detailed telemetry from the interface equipment than the OS receives in the OCR. The TCO is also the lead technician in the TCIR who is responsible for monitoring and controlling equipment maintenance performed by additional maintenance personnel in the TCIR. During normal operations, if receive transmit equipment drifts out of correct operating specification, corrective action takes place in accordance with applicable procedures. The TCO during anomaly periods has the ability to control and configure equipment using local equipment control methods located in the TCIR.

2.4.1.3.1.2 Normal System Configuration Changing Operations

2.4.1.3.1.2.1 System Configuration Changes

The system must be capable of handling the entire bandwidth of telephone signals received from the terrestrial gateway while at the same time performing periodic maintenance. This operations scenario requires changing the system configuration from one in-service ground antenna to an out-of-service ground antenna to allow down-time for maintenance.

2.4.1.3.1.2.1.1 Transferring Ground Antennas

The operation of transferring from one ground antenna to another is performed during low usage times. The concept of operation is to maintain 2.5 antennas in service at all times. This operation involves switching over the receive equipment at one ground station then the transmit equipment in series. This operations scenario maintains at least two full antennas with receive and transmit capability in service with at least the receive or transmit string from the third antenna in operation simultaneously. The switchover operation involves only one ground station at a time. Pre-coordination and maintenance planning occurs to ensure only one ground is performing switchover operations at any one time. The switchover operation from an on-service antenna to a off-service antenna is complex and described generally in the following steps:

1. The on-coming ground antenna is verified fully operational using a operational check off procedure.
2. The on-coming ground antenna acquires the downlink beacon of the satellite currently in contact with the ground antenna going to maintenance.
3. The interface equipment in the TCIR is configured to mux all incoming telephone signals to the two ground antennas remaining in operation.
4. The EO operating the off-going ground antenna stops transmitting signals to the satellite.
5. The EO operating the on-coming ground antenna performs a test signal transmission to the second ground station via the newly acquired satellite.
6. Following verification of transmit continuity interface equipment is configured in the TCIR to mux incoming telephone signals onto all three ground antennas.

7. The receive signal path switchover begins with the second ground station configuring the interface equipment to use the two satellites remaining in use by ground station number one.
8. The EO operating the ground antenna in contact with the satellite newly acquired by the on-coming antenna at ground station one sends a verification signal.
9. Following verification of continuity of the receive signal path at ground station number one the OS at ground station number two configures the TCIR equipment to mux telephone signals on all three operating ground antennas.

2.4.1.3.2 Emergency Operations

Emergency operations are in effect when either a hardware, software, or personnel error failure occur. Therefore, emergency operations consist mainly of recovering the system in a timely manner to meet system availability requirements. Recovery operations require operations personnel to place back-up equipment into service. Major emergency situations requiring operations and maintenance response are as follows:

- Loss of commercial external power requiring switching to back-up power sources.
- Satellite subsystem failure requiring switching to a redundant string of equipment or a redundant subsystem component.
- Computer hardware resource failure requiring switching to back-up hardware resources.
- Computer resources software failure requiring a re-boot or restart of application software.

- Failure of ground based equipment directly supporting the receipt and transmission of telephone signals requiring the switching to a back-up string of equipment.

2.4.2 Operational Requirements

The operational requirements are derived using seven system operating characteristics as recommended from Blanchard and Fabrycky [3].

2.4.2.1 Mission Definition

2.4.2.1.1 Prime Operating Mission

The system has the primary mission to provide reliable space-based communications to the customer twenty-four hours a day. This is to be accomplished through efficient, competent, and knowledgeable operation of a large, complex, world-wide, space-based communications system.

2.4.2.1.2 Secondary Mission

The system has a secondary mission to operate and maintain a satellite constellation of three geosynchronous satellites with reliability and efficiency to maintain the design life and spacecraft vehicle safety.

2.4.2.1.3 Performance and Physical Parameters

1. The system shall be capable of transmitting telephone signals received from ground-based terrestrial gateways between two ground stations using three geosynchronous satellites.

2. The system shall be capable of supporting 80,640 telephone signals (connections) per geosynchronous satellite.
3. The system shall be capable of supporting a maximum of 241,920 telephone signals at any one time.

2.4.2.1.4 Use Requirements

The system shall be capable of operating twenty-four hours a day 365 days a year.

2.4.2.1.5 Operational Deployment and Distribution

The system shall consist of three major components:

- Ground Station 1 (located in the United States)
- Ground Station 2 (located on the European Continent)
- Geosynchronous Satellite Constellation (3 communications satellites)

The systems major components shall be deployed as shown in Figure 2-10.

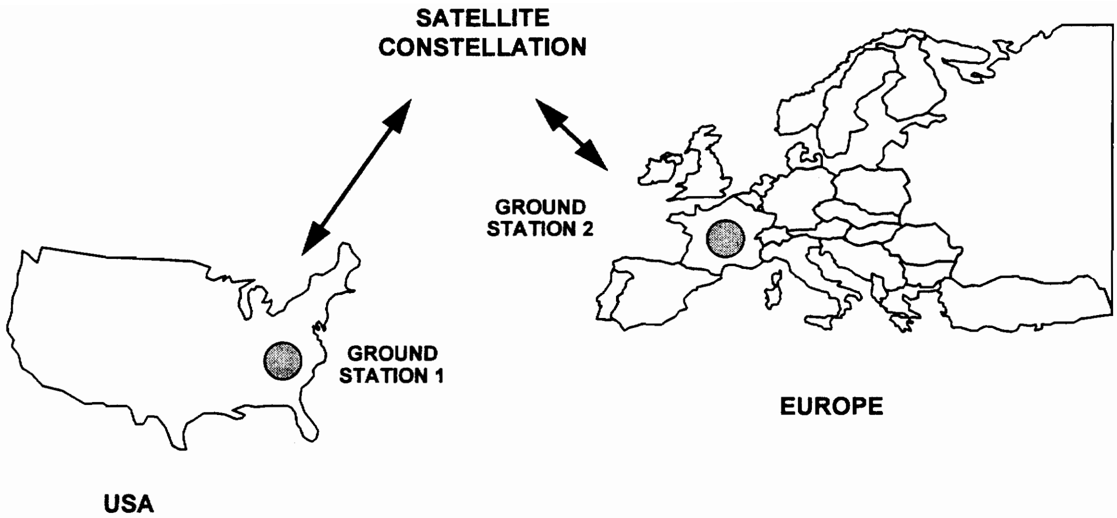

Figure 2-10 System Deployment Diagram.

One ground station shall be located on the East Coast of the United States and the second ground station shall be located on the European Continent.

2.4.2.1.6 Operational Life Cycle

The system shall be capable of operations until the year 2010.

2.4.2.1.7 Effectiveness Factors

1. Operational Availability - System availability shall be at least 0.975
2. Dependability - Reliability shall be at least a rating of 0.999
3. Mean Time Between Maintenance (MTBM) - System MTBM shall be 240 hours of system use.

4. Mean Time Between Failure (MTBF) - System MTBF shall be greater than 720 hours of system use.
5. Maintenance Downtime (MDT) - System MDT shall not exceed 6 hours.

2.5 System Maintenance Concept

The system-support concept is an integral part of the overall operations and maintenance of the described hardware system.

2.5.1 Levels of Maintenance Support

The system will require three levels of maintenance support and follows the basic outline as given by Blanchard and Fabrycky[4]. The overall support and logistic flow of equipment is shown in Figure 2-11.

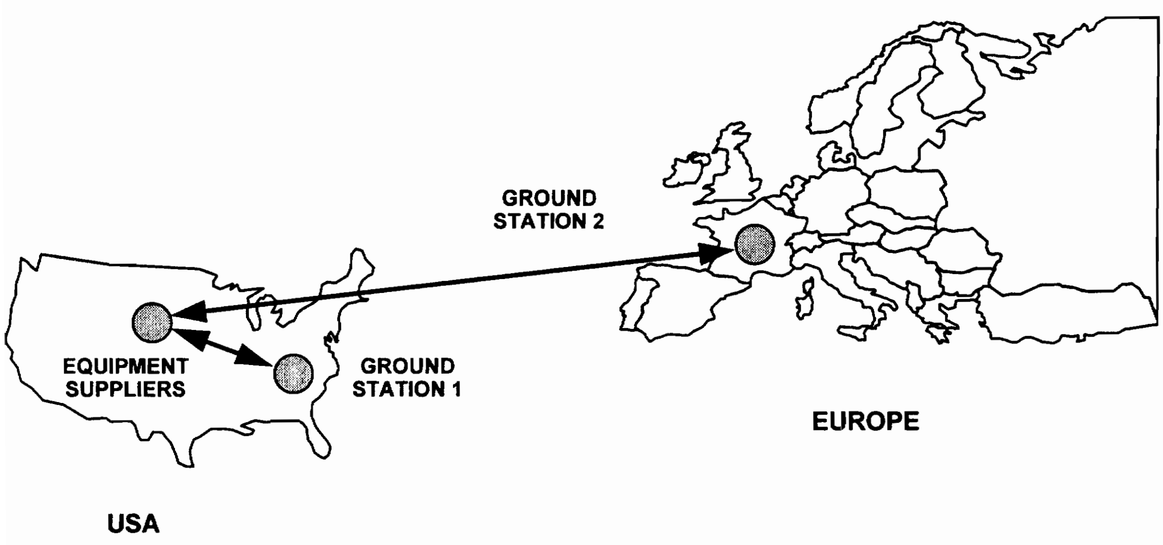

Figure 2-11 Overall System Equipment Support Flow.

In Figure 2-11, it is shown that maintenance will be performed at two types of locations. First is the operations site (ground station 1 or 2) and second is the equipment supplier locations. The equipment supplier locations provide equipment to the ground stations as subsystem-level units. Component-level supplies are provided to equipment suppliers via sub-contract logistics support. Shown in Figure 2-12 is a more detailed equipment logistic and maintenance flow.

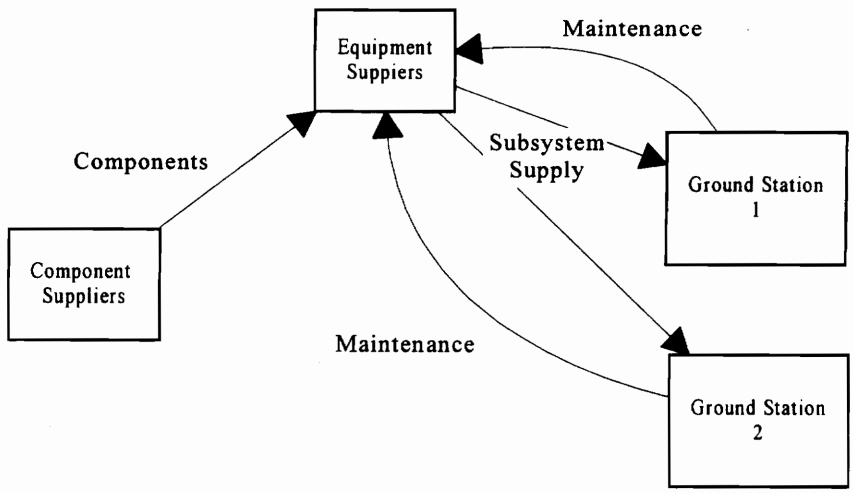

Figure 2-12 System Maintenance and Logistics Flow.

The level of maintenance occurring at each site is given by Table 2-1.

Table 2-1 Level of Maintenance Performed by Site.

	SITE	
Level of Maintenance	Ground station	Equipment Supplier
Organizational	✓	
Intermediate	✓	✓
Depot-Producer		✓

From Table 2-1, it is shown that intermediate maintenance occurs at both the ground station and the equipment supplier. This overlap is a sharing of intermediate maintenance activities but not a sharing of actual tasks. Shown in Table 2-2 is a detailed outline of maintenance activities at each site.

Table 2-2 Maintenance Activities at Each Site.

	SITE	
Level of Maintenance	Ground Station	Equipment Supplier
Organizational	• System-level Corrective and Preventative • Built-in System Testing • Built-in Subsystem Testing • Visual Inspections • External Adjustments • Removal and Replacement of Subsystem Units	
Intermediate	• Minor Calibration • Subsystem-level Corrective and Preventative • Minor External Test	• Major Calibration • Subsystem-level Corrective • Major External Test Equipment

	Equipment • Subsystem Supply Support	
Depot-Producer		• Subsystem Unit Overhaul • Factory Test Equipment • Manufacturing • Initial Calibration • Component Supply Support

2.5.2 Basic Responsibilities for Support

- Operational Site - Responsible for maintaining equipment subsystem spares at the operational site.
- Equipment Supplier - Responsible for supplying upon request from the operational site subsystem unit spares to the operational site.

2.5.3 General Repair Policy

The repair policy for the system adopts a philosophy that enables fast and reliable corrective maintenance to occur. The repair policy requires that no equipment repair shall occur at the operational site. All equipment repair shall occur at the equipment supplier location. This repair policy requires a supply of "Hot" subsystem-level unit spares to be available at the operational site. This policy allows quick identification and replacement of the failed subsystem unit to restore the system to full operations. Therefore, the majority of corrective maintenance occurring at the operational sites require only the replacement of a subsystem unit (individual unit in an equipment rack).

2.5.4 Maintenance Effectiveness Factors

- Supply Responsiveness - Logistics supply and support shall maintain at least one "Hot" subsystem unit spare available at each ground station.
- Maintenance Reliability - System maintenance reliability shall be at least 0.999.
- Personnel Efficiency - Operations personnel efficiency shall not exceed one error per year for the entire system.

2.5.5 Maintenance Environment

- Maintenance Tasks - All maintenance will be performed at either the operational site or the equipment supplier locations. These locations will adhere to normal facility environmental conditions for all levels of maintenance.
- Logistics Equipment Transportation - Equipment will be required to withstand transportation via multiple means (ground transportation, air transportation, and overseas transportation) between several different operational and equipment supplier sites.

2.6 Preliminary Systems Analysis

This preliminary systems analysis will investigate the ability of current technology meeting the operational and maintenance requirements. The steps in this analysis follow the basic outline as identified by Blanchard and Fabrycky[5].

2.6.1 Define the Problem

The problem is more of a concern in this analysis. The concern is in the area of the ability of the O&M organization to meet the requirements outlined in the previous generation of operational and maintenance requirements. To understand this concern, a background discussion must occur. The view of this project is that there are three areas of system design involved in the design of a system meeting a particular requirement. The three areas of system design are hardware, software, and the support system. The support system includes system operations, maintenance, support, and logistics. For the final system to meet a system-level requirement, all three areas of design (hardware, software, and support) must be analyzed using the systems approach. Figure 2-13 demonstrates the flow down of a system-level requirement such as reliability into all three system areas.

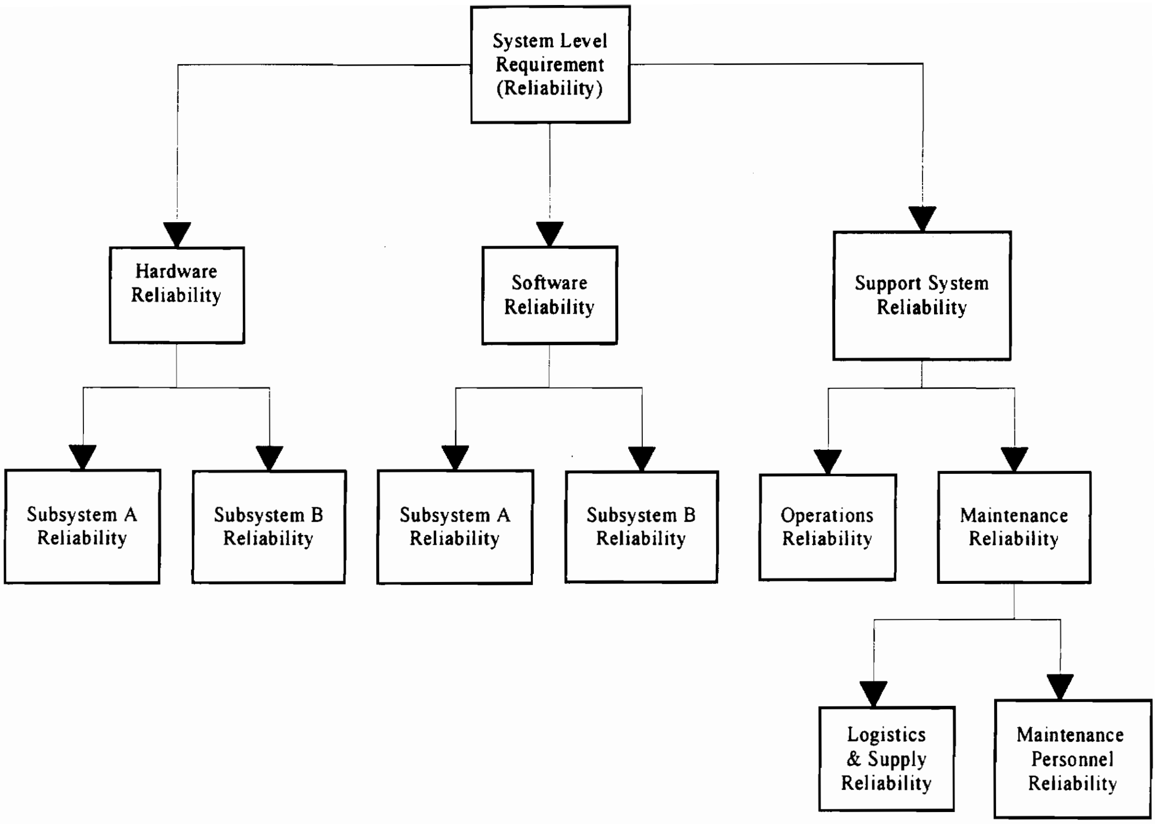

Figure 2-13 System-Level Requirement Flow Example.

The concern of this preliminary systems analysis is of meeting requirements placed on the support system.

2.6.2 Feasible Alternatives

At this point in the system design, the question of concern is: can a support system (Operations and Maintenance Organization) be designed to sufficiently meet the system-level requirements? The alternative is to recommend designing the system with more automation, less maintenance, and less support required. This alternative can be costly and is probably not the best solution. A good balance between support system involvement in mission success (meeting system-level requirements) and overall system cost is probably the best approach. Therefore, the support system is an integral part of the system that will have requirements placed on it.

2.6.3 Evaluation Criteria

The concern as stated above is the ability to design a support system to meet the system-level requirements. The evaluation criteria in this analysis reside for the most part in the qualitative judgment of support-system performance based on either qualitative design concepts or past historical data. Until real-time data is collected and statistically analyzed that directly relates to the performance of the support system, the design of the organization is for the most part a best-guess. Unlike the design of hardware where testing can provide data directly relating to performance prior to Initial Operational Capability (IOC) of system, the design of the support system is limited on the testing available to ensure the human component meets system-level requirements. The approach that must be taken to ensure the support system meets system-level requirements is a life cycle approach. The human component and organizational nature of the support system is truly unique in the fact that this component is the one component that can continuously change without extreme monetary costs to the system, such as, when a hardware change would incur. Therefore, it is determined that a design approach professed by Kurstedt can be applied to ensure that the support system meets system-level requirements. It must be understood that this design approach requires a life cycle approach and must embrace continuous process improvement. Overall, the initial design may not meet the system-level requirements (e.g., personnel errors cause reliability to fall below the system-level requirement) but the life cycle approach to design uses Kurstedt's techniques in the design of management tools and Kurstedt's philosophy on continuous process improvement to eventually meet and maintain the support-system performance requirements. This is accomplished through Kurstedt's organizational design philosophy. In the design of an organization from Kurstedt[6], a set of performance criteria are necessary to make interventions (corrections) for improvement. The system requirements are a good set of top-level performance criteria for the entire support organization. Using the management systems engineering technologies from Kurstedt such as the Management System Model to build management tools, and the overall framework for the management process, an organization can be designed and maintained to meet all system-level requirements. The maintenance of the organization is provided through feedback from performance criteria using the management process framework from Kurstedt. Shown in Figure 2-14 is a top-level diagram of the management system engineering technology applied to design and maintain an organization that meets system-level requirements.

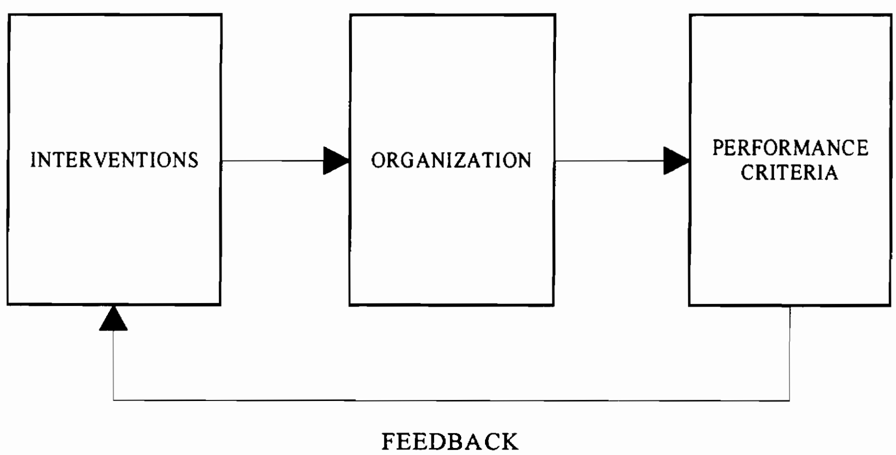

Figure 2-14 Framework for the Management Process.

2.7 Preliminary System Analysis Conclusion

The problem addressed in this preliminary systems analysis is a valid concern. The support-system initial design can not be verified to meet system-level requirements in the same traditional design and test manner as a hardware string can be. Therefore, using the organizational design approach of Kurstedt and the life cycle approach a support system can be designed that will meet system-level requirements through continuous process improvement and interventions (changes) to the initial design.

2.8 System Specification

From the operational and maintenance system-level requirements, a system specification "Type A" specification as defined by Blanchard and Fabrycky[7] is assembled. For this project, the system specification is a composition of the operational and maintenance requirements generated previously. Shown in Table 2-3 is the system specification generated from the developed requirements.

Table 2-3 System Specification.

Requirement	Performance Measure
Supply Responsiveness	Logistics supply and support shall maintain at least one "Hot" subsystem unit spare available at each ground station.
Maintenance Reliability	System maintenance reliability shall be at least 0.999.
Personnel Efficiency	Operations personnel efficiency shall not exceed one error per year for the entire system.
Prime Operating Mission	The system has the primary mission to provide reliable space-based

	communications to the customer twenty-four hours a day. This is to be accomplished through efficient, competent, and knowledgeable operation of a large, complex, world-wide, space-based communications system.
Secondary Mission	The system has a secondary mission to operate and maintain a satellite constellation of three geosynchronous satellites with reliability and efficiency to maintain the design life and spacecraft vehicle safety.
Performance Parameter	The system shall be capable of transmitting telephone signals received from ground based terrestrial gateways between two ground stations using three geosynchronous satellites.
Performance Parameter	The system shall be capable of supporting 80,640 telephone signals (connections) per geosynchronous satellite.
Performance Parameter	The system shall be capable of supporting a maximum of 241,920 telephone signals at any one time.
Use Requirement	The system shall be capable of operating twenty-four hours a day 365 days a year.
Operational Deployment	The system shall consist of three major components: • Ground Station 1 (located in the United States) • Ground Station 2 (located on the European Continent) • Geosynchronous Satellite Constellation (3 communications satellites)
Operational Distribution	One ground station shall be located on the East Coast of the United States and the second ground station shall be located on

	the European Continent.
Operational Life Cycle	The system shall be capable of operations until the year 2010.
Operational Availability	System operational availability shall be at least 0.975.
Dependability	Reliability shall be at least a rating of 0.999
Mean Time Between Maintenance (MTBM)	System MTBM shall be 240 hours of system use.
Mean Time Between Failure (MTBF)	System MTBF shall be greater than 720 hours of system use.
Maintenance Downtime (MDT)	System MDT shall not exceed 6 hours.

The system specification shown in Table 2-3 is only a small part of a truly complete system specification. Following from Blanchard and Fabrycky, the system specification should include:

1. General description of the system and its function
2. Operational requirements
3. Maintenance concept definition
4. System functional diagram and functional interfaces
5. Performance characteristics
6. Physical characteristics
7. Effectiveness characteristics
8. Design characteristics
9. Construction
10. Logistic support

11. Design documentation

12. Quality assurance provisions

The majority of this information exists in previous sections of this chapter, but for this project will not be compiled into a formal complete system specification.

Chapter 3: Preliminary System Design

3. Preliminary System Design

The preliminary system design phase is the next step after the conceptual system design work of Chapter 2. The preliminary system design phase uses the technical baseline established as the system specification and begins the design process. The preliminary system design activities are shown in Figure 3-1.

3.1 Preliminary System Design Process Overview

The preliminary system design process primarily performs a system functional analysis and allocation of system-level requirements to subsystem or sub-subsystem units. First, a functional analysis is performed on the operational and maintenance functional areas of the system to identify the major areas of concern to the development of the organization in this project. Second, top-level system requirements are allocated to subsystem units within the organization. Third, a trade-off and optimization analysis is performed to evaluate specific design alternatives available to meet the allocated requirements.

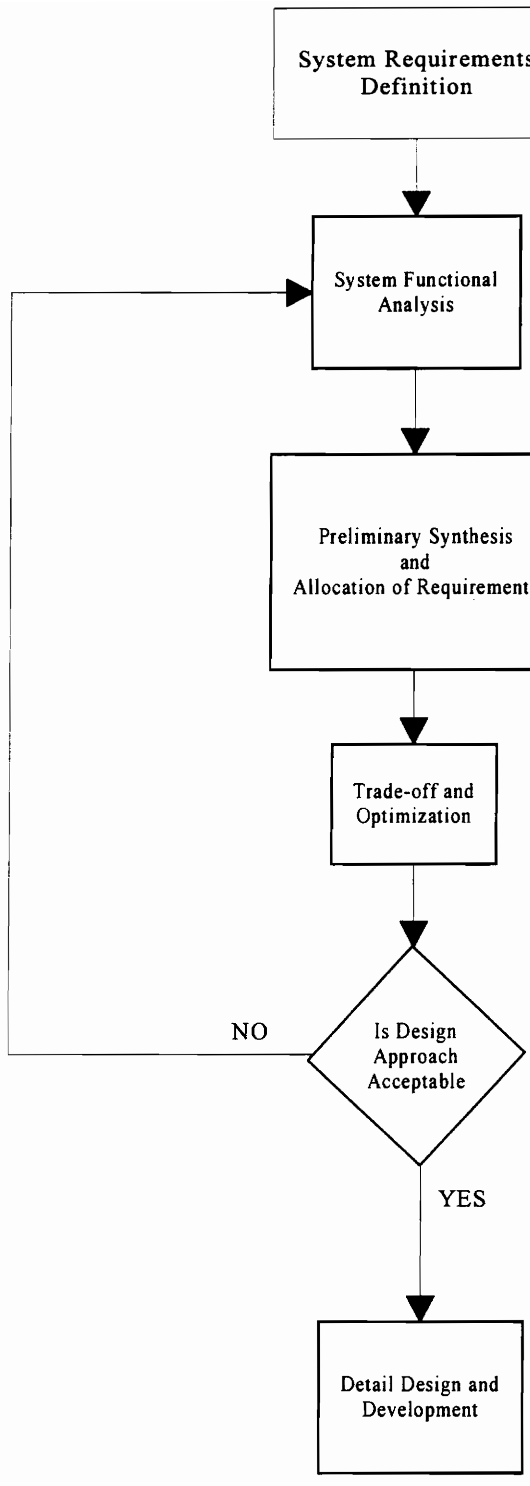

Figure 3-1 Preliminary System Design Activities.

3.2 Functional Analysis

The functional analysis in the systems engineering process is a useful tool to begin understanding the detailed functionality of the system. For this project, concentration on the operational and maintenance functional flow diagrams occurs in preparation for detail design of the O&M organization.

3.2.1 Top-Level Functional Flow Analysis

Shown in Figure 3-2 is the top-level functional flow for the system. Block 1 in the system functional flow defines the system operational requirements determined from Chapter 2. Block 2 shows the performance of a feasibility study that was performed as part of the conceptual system design in Chapter 2. Blocks 3 and 4 show the design of the system and support elements. Block 5 shows the system integration. Blocks 6,7, and 8 show the production and the procurement of the complete system. Block 9 shows the distribution and setup of the system for customer use. Blocks 10 and 11 show the operations and maintenance of the final system.

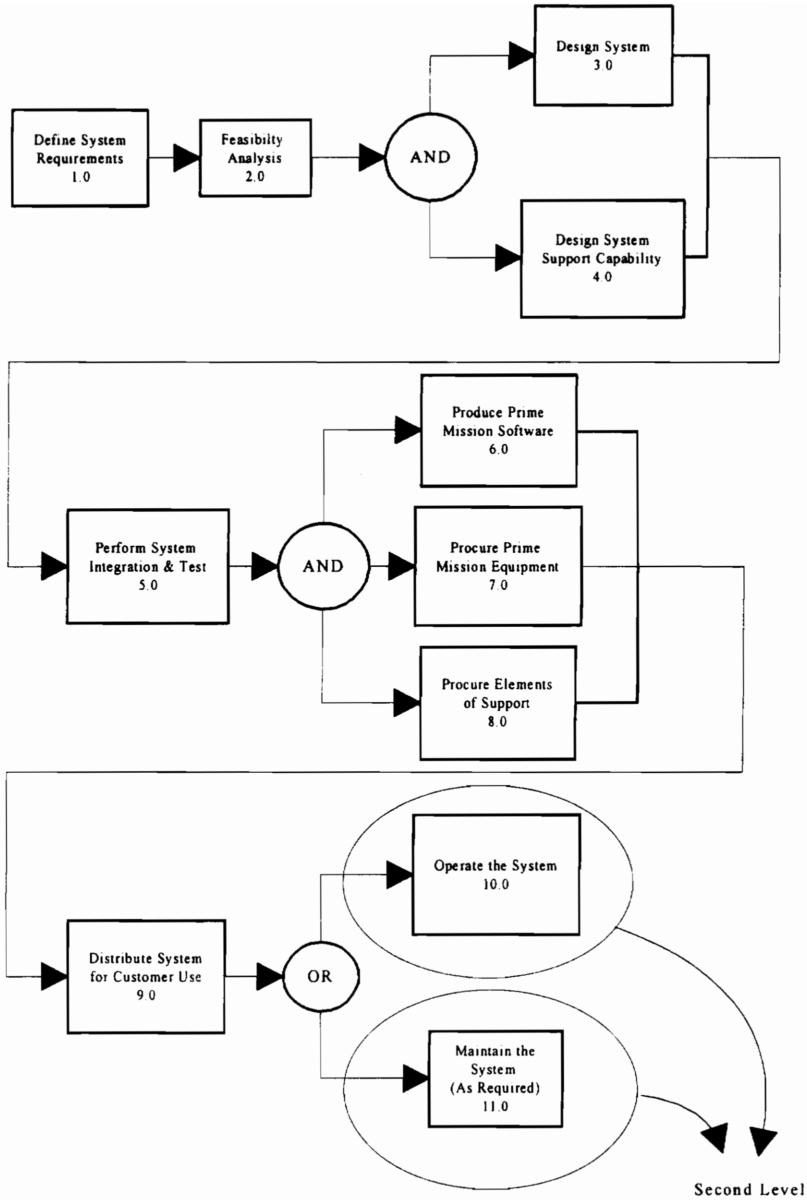

Figure 3-2 System-Level Functional Flow.

3.2.2 First-Level Functional Flow Analysis

For this project, the area of concentration is on the design of the system-support capability with specific concentration on the operations and maintenance of the system. Therefore, in the first-level functional flow analysis, only the operational and maintenance blocks (Blocks 10 and 11) from Figure 3-2 are carried to a first-level. Shown in Figure 3-3 is the first-level functional analysis of the "operate the system" block. There are three areas of operations associated with the system. Block 10.1 identifies normal system operations where system monitoring occurs, block 10.2 identifies system configuration changes, and block 10.3 identifies system emergency (recovery) operations.

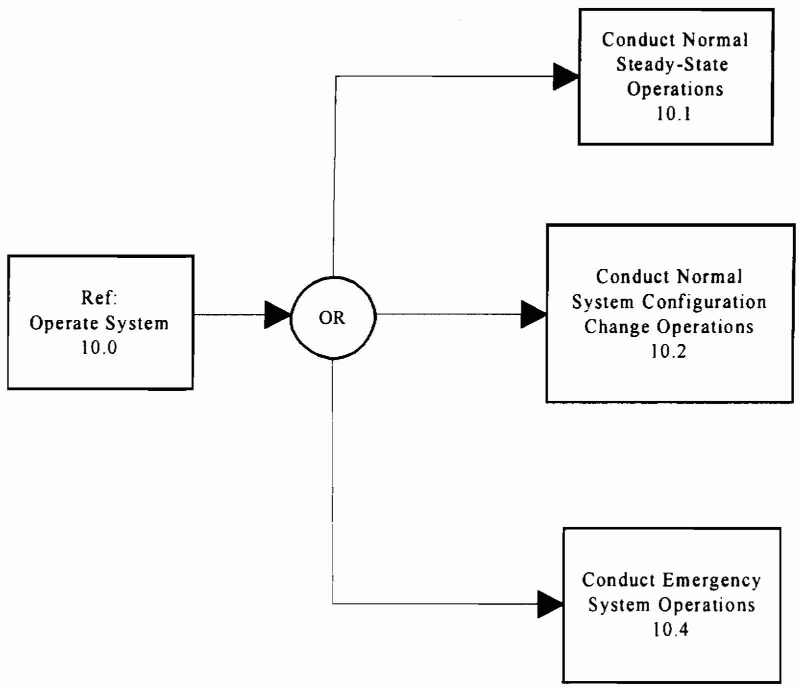

Figure 3-3 First-Level Operational Flow.

Shown in Figure 3-4 is the first-level functional analysis of the maintain-the-system block from Figure 3-2. There are four major areas of maintenance that occur to support the system. The four areas are hardware, software, computer resource, and facilities maintenance.

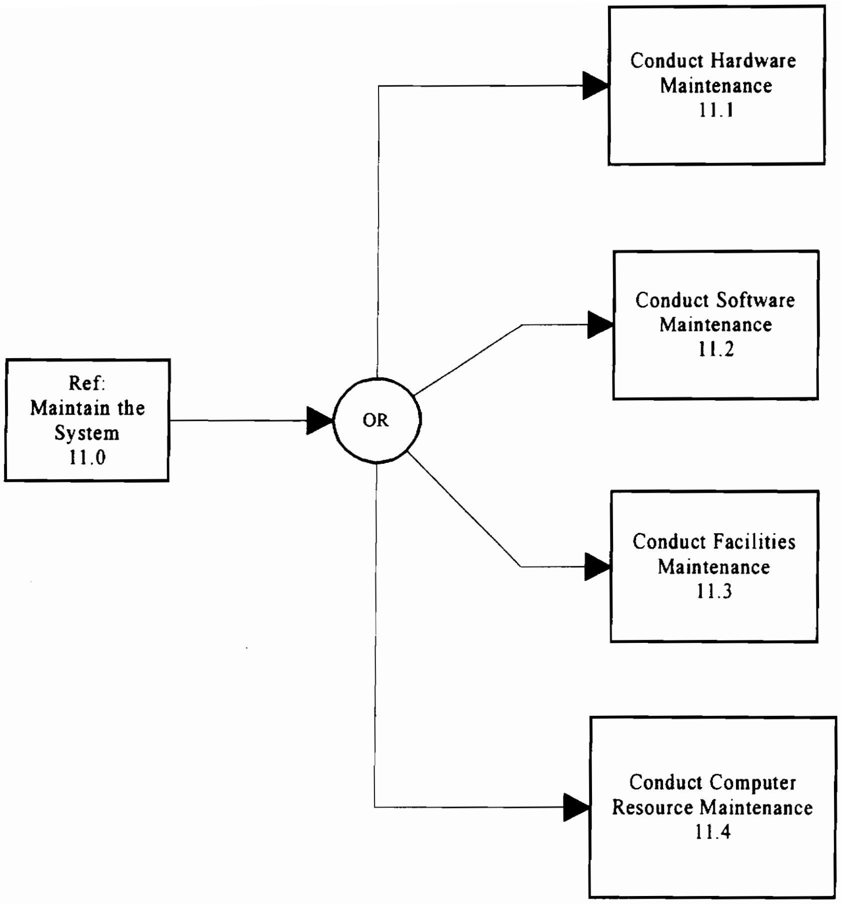

Figure 3-4 First-Level Maintenance Flow.

3.2.3 Second-Level Functional Flow Analysis

3.2.3.1 Second-Level Operational Functional Flow

For each first-level operational flow block, an analysis is completed for a second-level. Shown in Figure 3-5 is the second-level flow for "conduct normal steady-state operations" of block 10.1 from Figure 3-3.

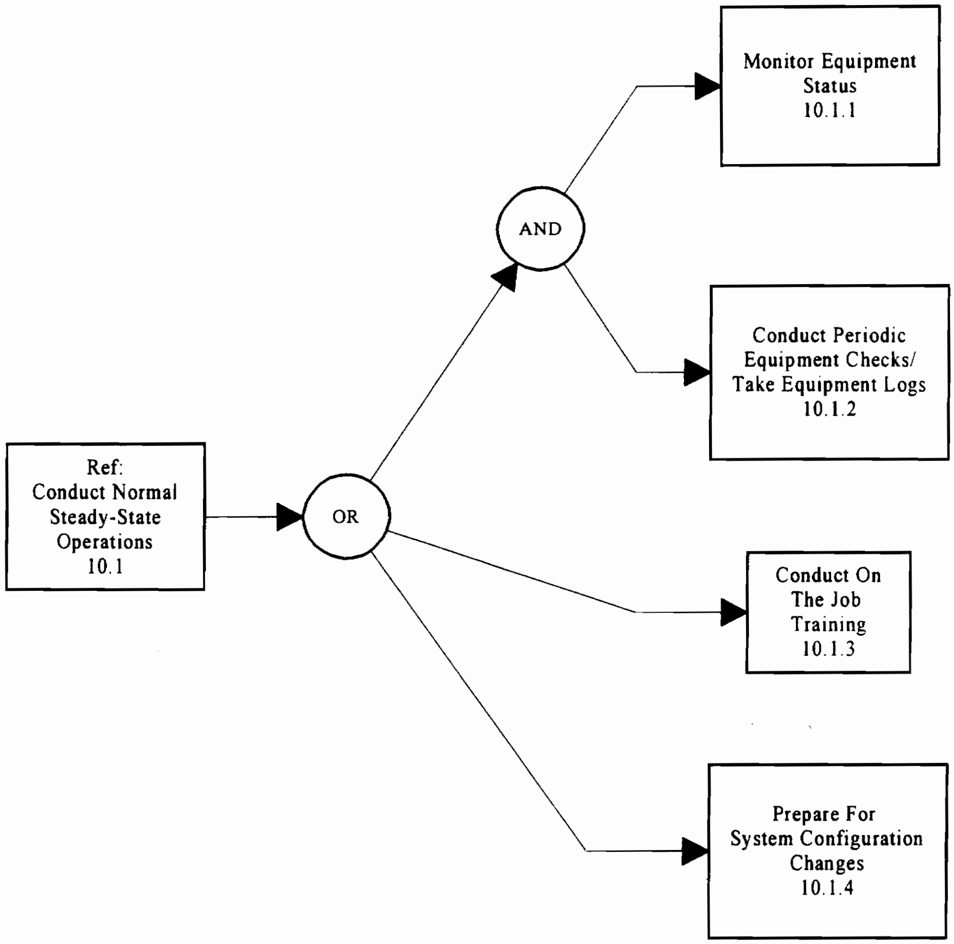

Figure 3-5 Second-Level Normal Steady-State Operations Flow.

Normal steady-state operations consist of four major tasks. First is the task of monitoring equipment status. Second is the task of performing periodic duties of logging equipment status and performing equipment checks. Third is the task of conducting on-the-job training. Fourth is the task of preparing for system configuration changes.

Shown in Figure 3-6 is the second-level flow for "conduct normal system configuration change operations" of block 10.2 from Figure 3-3.

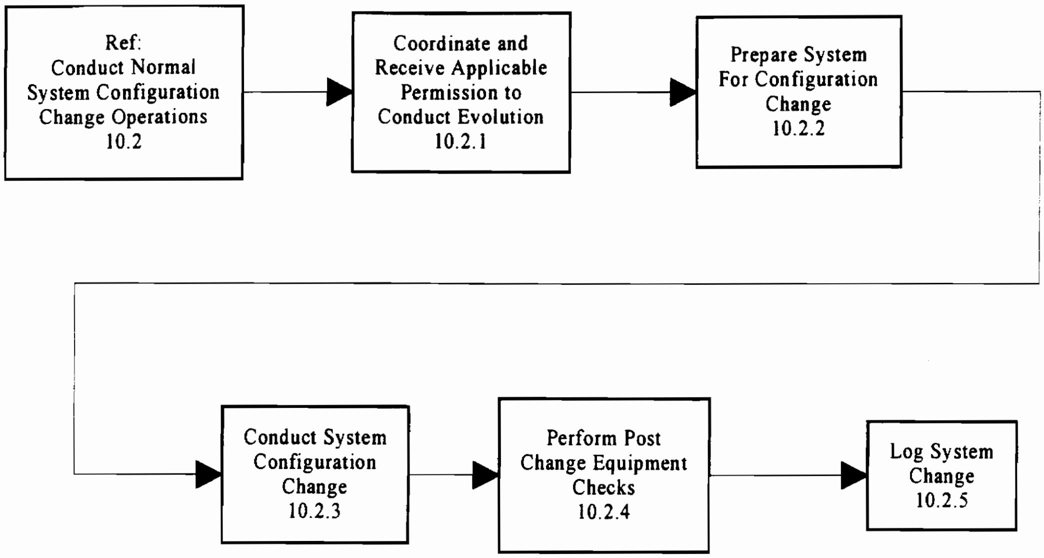

Figure 3-6 Second-Level Normal System Configuration Change Operations Flow.

Shown in Figure 3-7 is the second-level flow for "conduct emergency system operations" of block 10.3 from Figure 3-3.

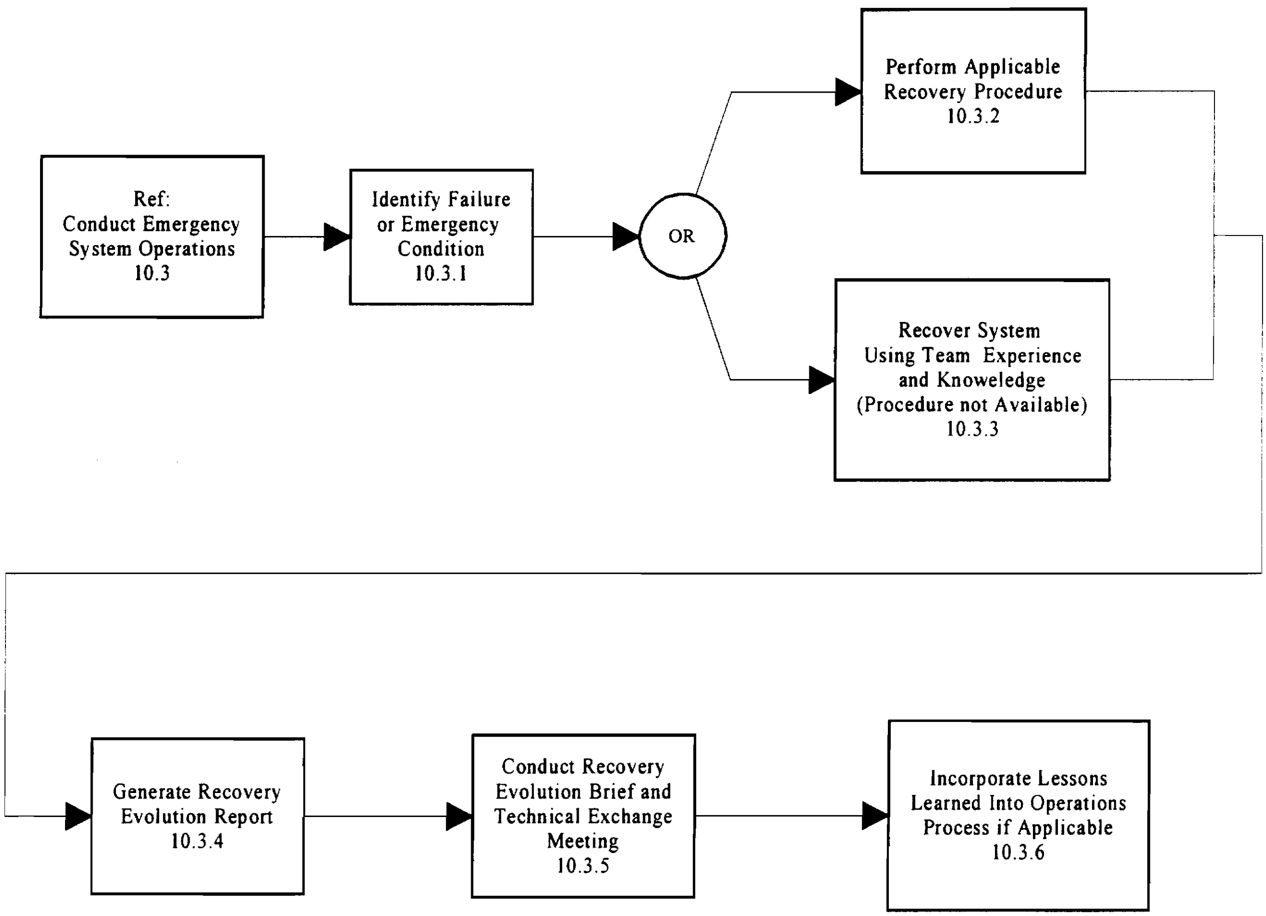

Figure 3-7 Second-Level Emergency System Operations Flow.

3.2.3.2 Second-Level Maintenance Functional Flow

For each first-level maintenance flow block, an analysis is completed for a second-level. Shown in Figure 3-8 is the second-level flow for "conduct hardware maintenance" of block 11.1 Figure 3-4.

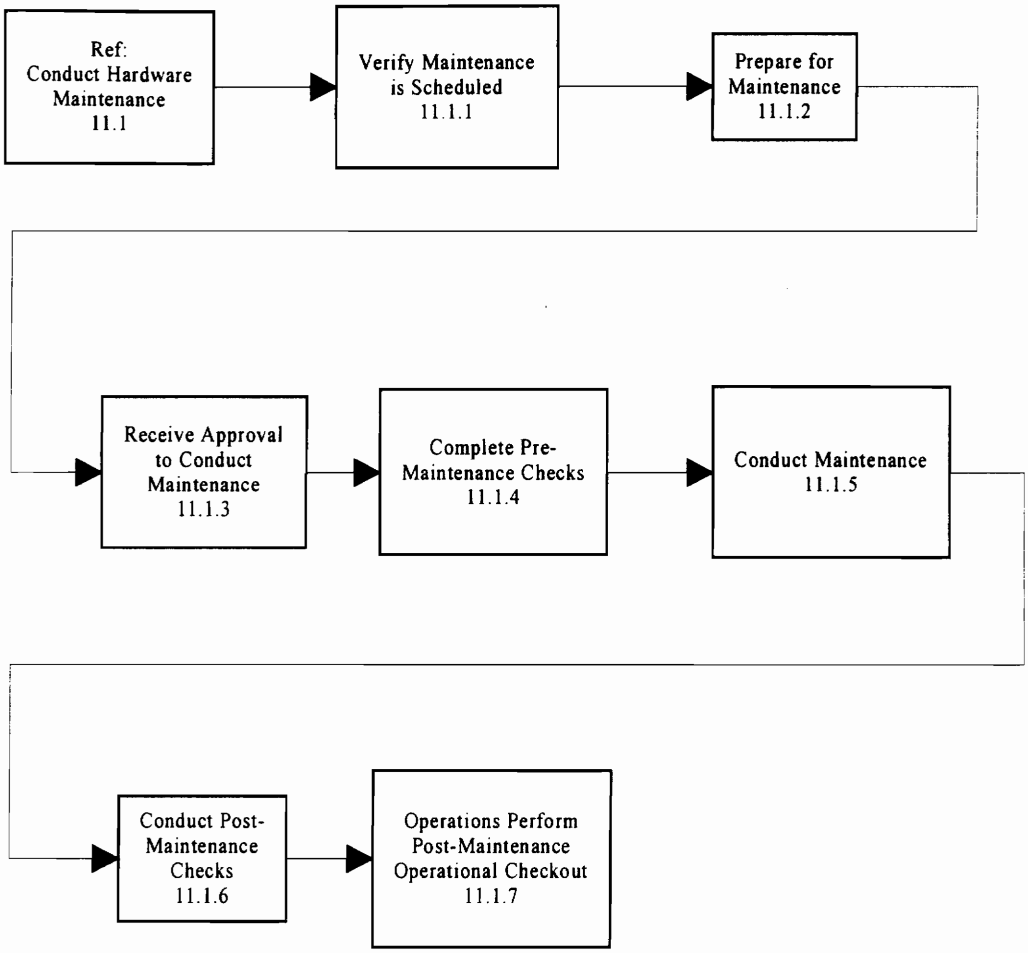

Figure 3-8 Second-Level Hardware Maintenance Flow.

Shown in Figure 3-9 is the second-level flow for "conduct software maintenance" of block 11.2 from Figure 3-4.

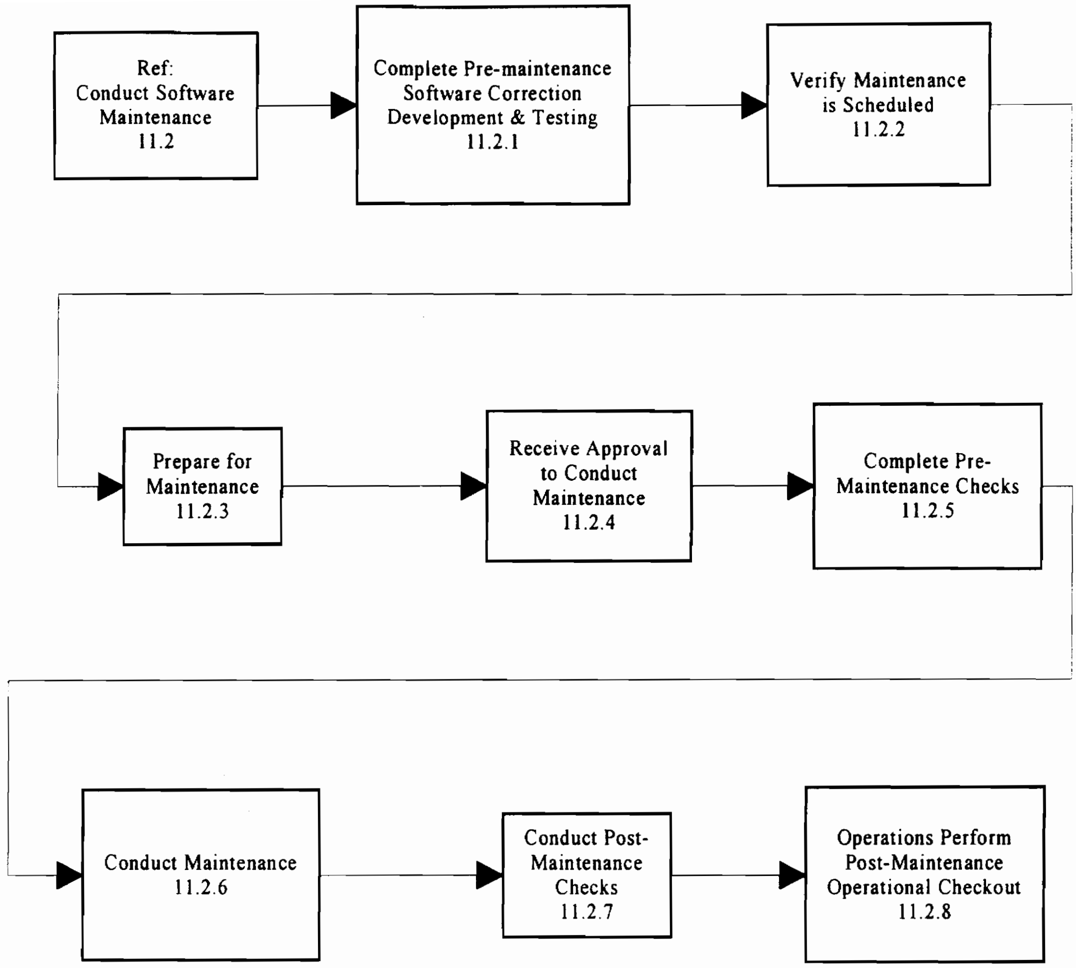

Figure 3-9 Second-Level Software Maintenance Flow.

Shown in Figure 3-10 is the second-level flow for "conduct facilities maintenance" of block 11.3 from Figure 3-4.

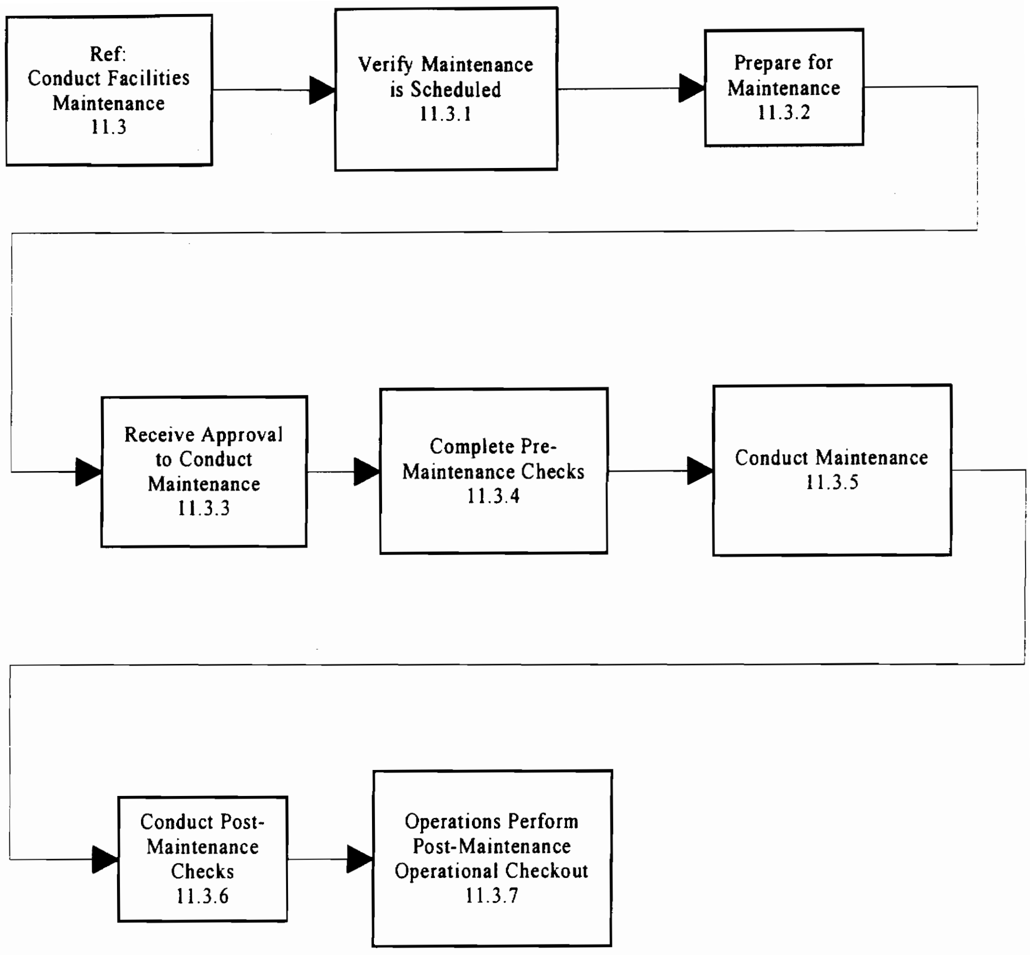

Figure 3-10 Second-Level Facilities Maintenance Flow.

Shown in Figure 3-11 is the second-level flow for "conduct computer resource maintenance" of block 11.4 from Figure 3-4.

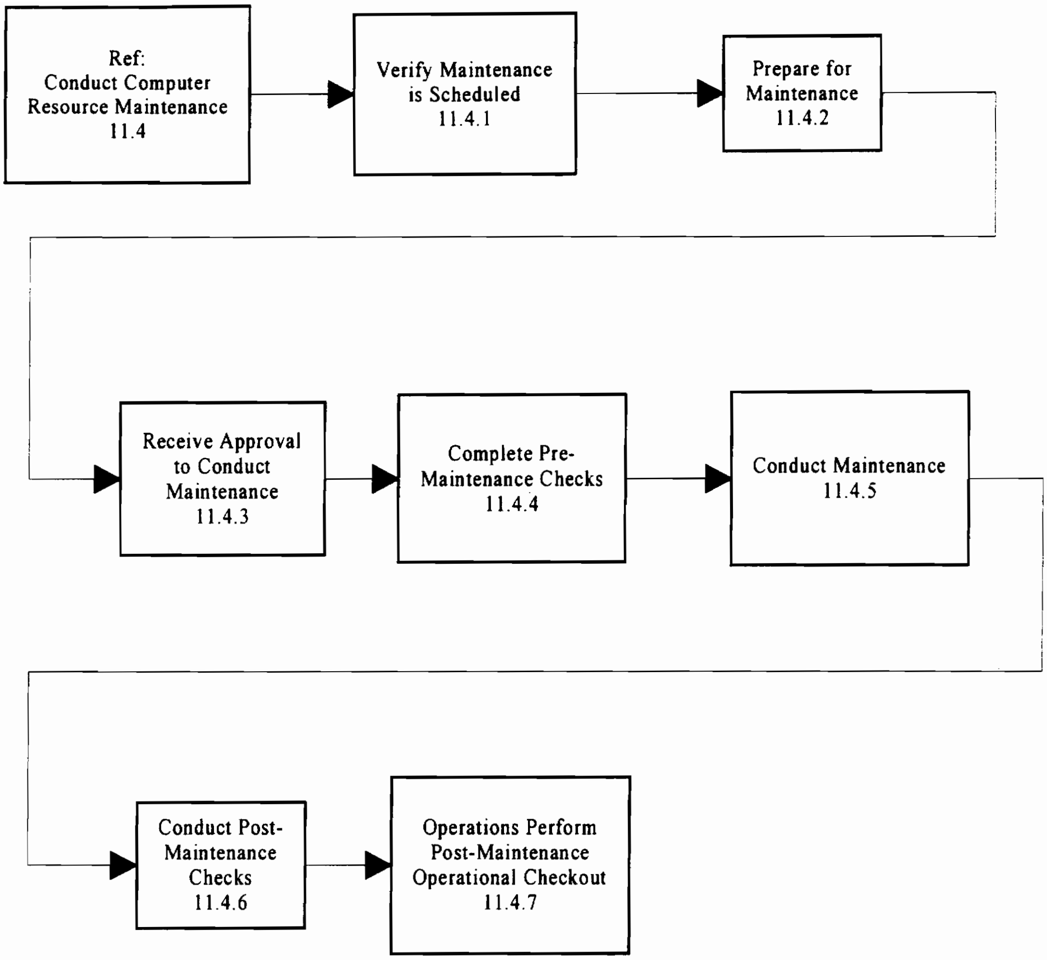

Figure 3-11 Second-Level Computer Resource Maintenance Flow.

3.2.4 Functional Analysis Conclusion and Results

The system functional analysis performed on the operational and maintenance areas of the system provides a top-level picture of the major steps involved in the operation and maintenance of the system. The third, fourth, and fifth operational and maintenance levels exist but are not completed as a part of this project. The details of an individual operation or maintenance task are not of concern. What is of concern is the overall process the O&M organization uses to accomplish the detail tasks. Therefore, the functional analysis completed to a second-level provides adequate insight into the top-level process that requires detailed engineering. From this top-level functional analysis, functional units within the O&M organization can be defined much the same way a functional analysis of a hardware system determines hardware units. From the functional analysis and the concept of operations from chapter 2, a basic top-level O&M organizational chart is determined and shown in Figure 3-12.

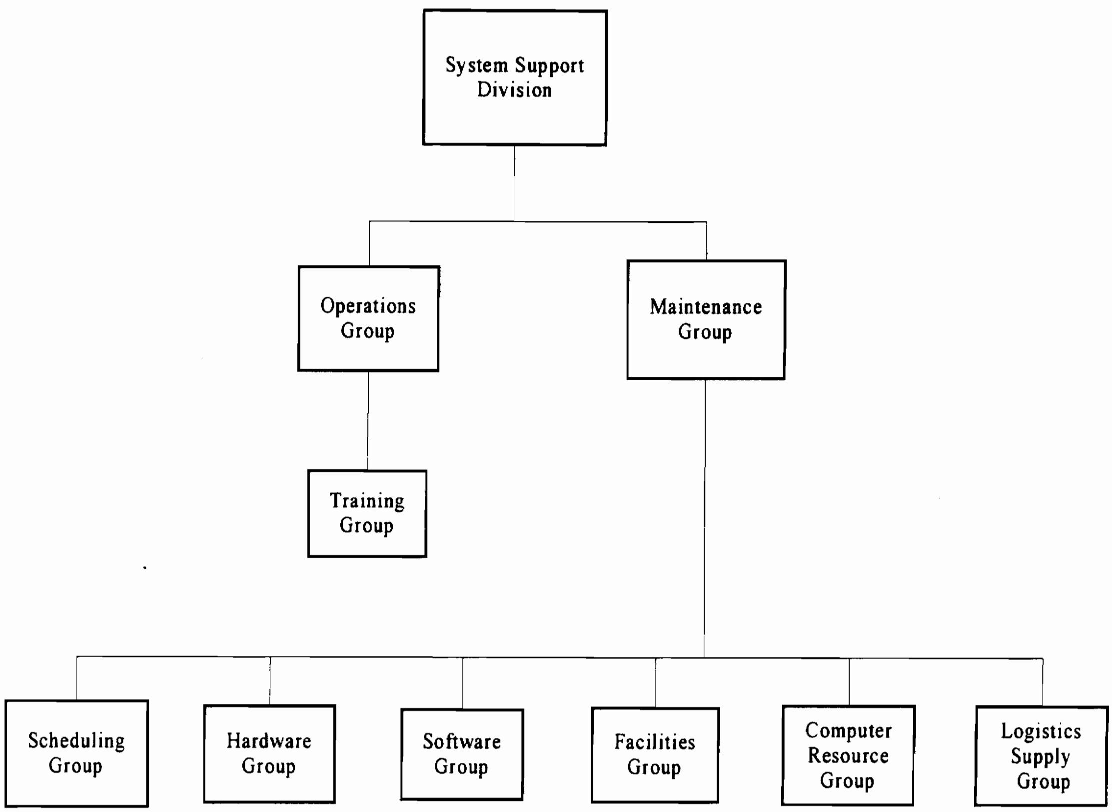

Figure 3-12 Basic Top-Level O&M Organization Units.

The basic units determined from the functional analysis are the units that top-level system requirements will be flowed to using the allocation of system requirements process. The units determined via the functional analysis and shown in Figure 3-12 are only representative of the functional analysis results. The structure and content is simple and in no way is a true organizational chart. The unit diagram does not begin to demonstrate or determine the number of personnel necessary, the interrelations between units/groups, or the complexity of an O&M organization. The units determined from the functional analysis provide a means to allocate requirements to the O&M organization.

3.3 Allocation of Requirements

From the system specification, top-level system requirements are allocated to the system-support division and subunits through an allocation process. An overall graphic of the allocation flow is shown in Figure 3-13.

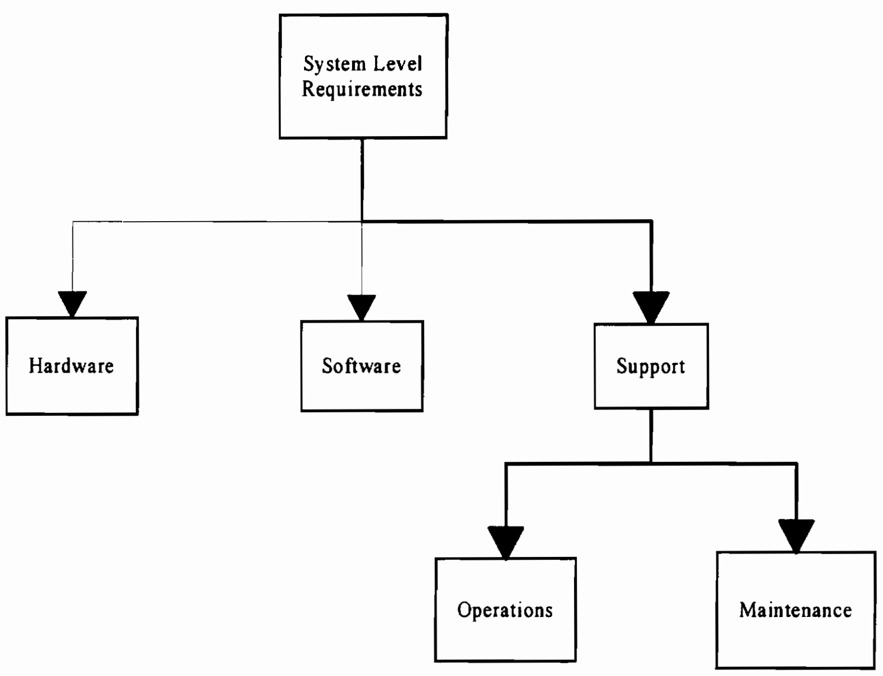

Figure 3-13 Overall Requirements Flow.

The highlighted flow of requirements shown in Figure 3-13 is the limit to the scope of allocations for this project. It is assumed that the system requirements are properly allocated to hardware and software. For each requirement in the system specification created in chapter 2, a flow-down of the requirement is shown in either a table or graphic. The system-level requirements have been divided into two major groups for allocation as described in the following two sections.

3.3.1 Requirements Allocation Group One

The first group of system-level requirements is allocated to units within the system-support capability as shown in Table 3-1.

Table 3-1 Allocation of Requirements.

Requirement	Allocated To
Supply Responsiveness: Logistics supply and support shall maintain at least one "Hot" subsystem unit spare available at each ground station.	System-support, Maintenance Support, Logistics and Supply Support
Prime Operating Mission: The system has the primary mission to provide reliable space-based communications to the customer twenty-four hours a day. This is to be accomplished through efficient, competent, and knowledgeable operation of a large, complex, world-wide, space-based communications system.	All Support Units
Secondary Mission: The system has a secondary mission to operate and maintain a satellite constellation of three geosynchronous satellites with reliability and efficiency to maintain the design life and spacecraft vehicle safety.	All Support Units
The system shall be capable of operating	System-support

twenty-four hours a day 365 days a year.	
Deployment: One ground station shall be located on the East Coast of the United States and the second ground station shall be located on the European Continent.	System-support

The requirements shown in Table 3-1 are selected requirements from the system specification that are qualitative in nature. For each allocation shown in Table 3-1, a justification of the allocation is provided.

- Supply Responsiveness - this requirement is allocated to the system-support capability, the maintenance unit, and the logistics and supply unit. The sole responsibility for meeting this system-level requirement rests within the support capability and specifically the logistics and supply unit.
- Prime and Secondary Operating Missions - This requirement is allocated to all units within the system-support capability. This type of qualitative requirement must be promulgated to operations and maintenance personnel. A mission requirement of this type is directly related to an organizations mission statement and is applicable to all units within the support capability.
- System Operating Year-Round - This requirement is allocated to only the system-support capability and not specifically to any sub or lower level units. This requirement is directly related to ensuring personnel are on station to conduct operations. Responsibility for meeting this requirements rests solely in the manning process implemented by the system-support capability.
- Deployment - This requirement allocation justification is similar to that of the system operating year round requirement. The O&M organization must be capable of supporting operations on two different continents and the

responsibility of this capability rests on the system-support capability and no other lower-level units.

3.3.2 Requirements Allocation Group Two

The remaining system-level requirements to be allocated to lower-level units within the system-support capability are shown in Table 3-2. The requirements are allocated to units within the system-support capability as shown in Figure 3-14.

Table 3-2 Group Two Requirements.

Maintenance Reliability	System maintenance reliability shall be at least 0.999.
Personnel Efficiency	Operations personnel efficiency shall not exceed one error per year for the entire system.
Operational Availability	System operational availability shall be at least 0.975.
Dependability	Reliability shall be at least a rating of 0.999
Mean Time Between Maintenance (MTBM)	System MTBM shall be 240 hours of system use.
Mean Time Between Failure (MTBF)	System MTBF shall be greater than 720 hours of system use.
Maintenance Downtime (MDT)	System MDT shall not exceed 6 hours.

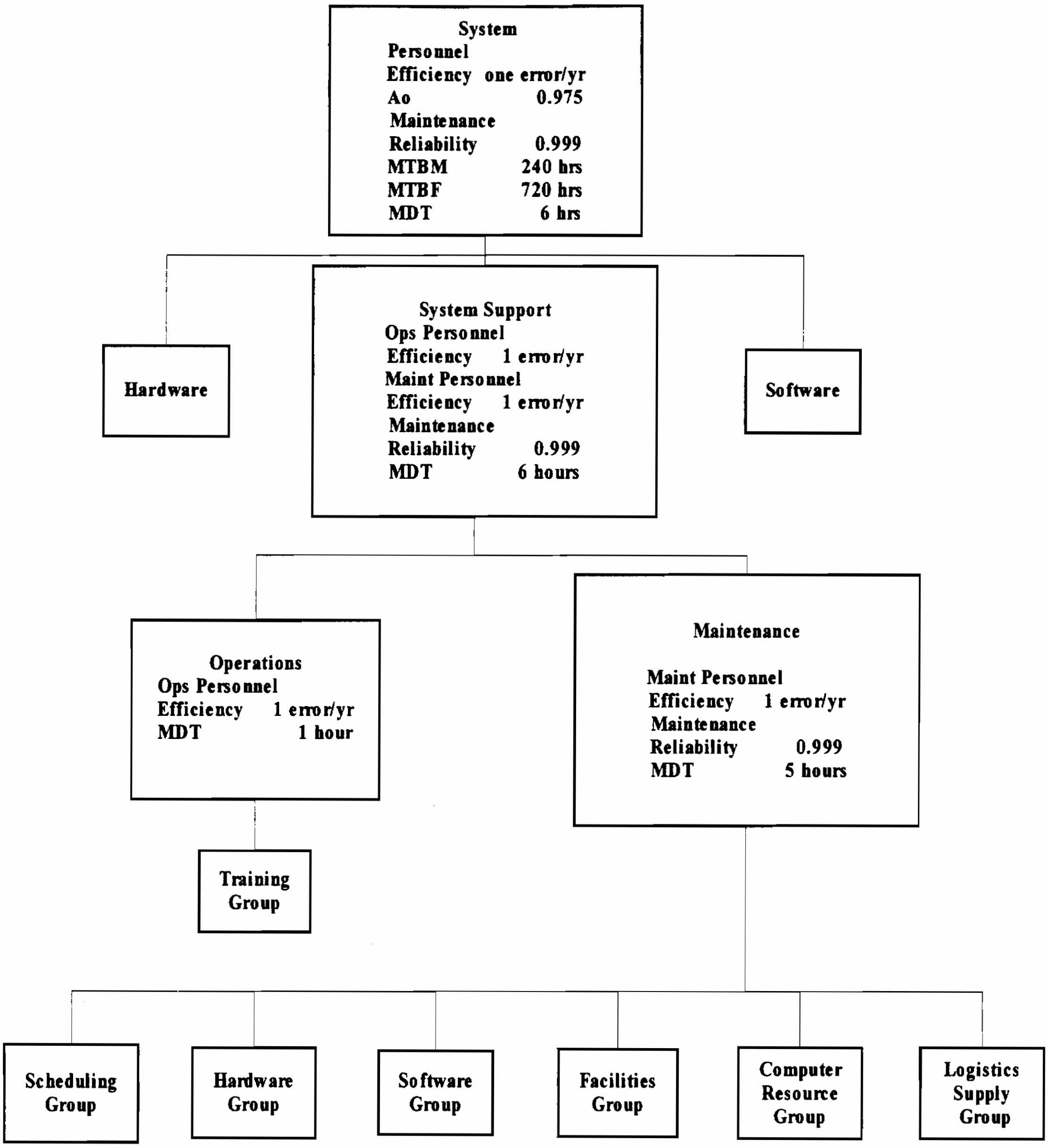

Figure 3-14 Requirements Allocation Group Two.

For each requirement allocation shown in Figure 3-14, a justification of the allocation is provided.

- Maintenance Reliability - this requirement is directly related to the performance of maintenance actions. The requirement is allocated to system-support and the maintenance group.
- Personnel Efficiency - this requirement is directly related to operations and maintenance personnel. The requirement is allocated to system-support, operations, and maintenance.
- Operational Availability - this requirement is a top-level system requirement which is allocated to system-support as a top-level requirement only. The allocation of MTBM, personnel efficiency, and MDT factor into the overall operational availability of the system.
- Dependability - this requirement is considered directly related to system hardware or software design and is not allocated to the system-support capability.
- Mean Time Between Maintenance (MTBM) - this requirement is allocated to several subunits within the system-support capability. The requirement has a wide reaching responsibility into both operations and maintenance. Since operations and maintenance level activities do not directly contribute to the MTBM the requirement it is not allocated beyond the system-level for the system-support capability.
- Mean Time Between Failure (MTBF) - this requirement is considered directly related to system hardware or software design and is not allocated to the system-support capability.
- Maintenance Downtime (MDT) - this requirement is allocated to several subunits within the system-support capability. The requirement has a wide-reaching responsibility into both operations and maintenance. The

requirement is allocated to system-support, operations, and maintenance. Each of these units is involved and has an effect on meeting the MDT system-level requirement.

3.3.3 Other System-level Requirements

Several system-level requirements where considered either related to another system unit (hardware or software) or requirements not applicable to allocation.

Table 3-3 Other System-level Requirements.

The system shall be capable of transmitting telephone signals received from ground based terrestrial gateways between two ground stations using three geosynchronous satellites.
The system shall be capable of supporting 80,640 telephone signals (connections) per geosynchronous satellite.
The system shall be capable of supporting a maximum of 241,920 telephone signals at any one time.
The system shall consist of three major components: • Ground Station 1 (located in the United States) • Ground Station 2 (located on the European Continent) • Geosynchronous Satellite Constellation (3 communications satellites)

Chapter 4: Detail Design and Development

4. Detail Design and Development

The detail design phase is the next step after the preliminary system design work of Chapter 3. The detail design phase in this project has the primary goal of describing in detail a system-support capability (operations and maintenance) that provides a means to satisfy the system-level requirements from the preliminary system design of chapter 3. The major process used in the detail design phase is shown in Figure 4-1.

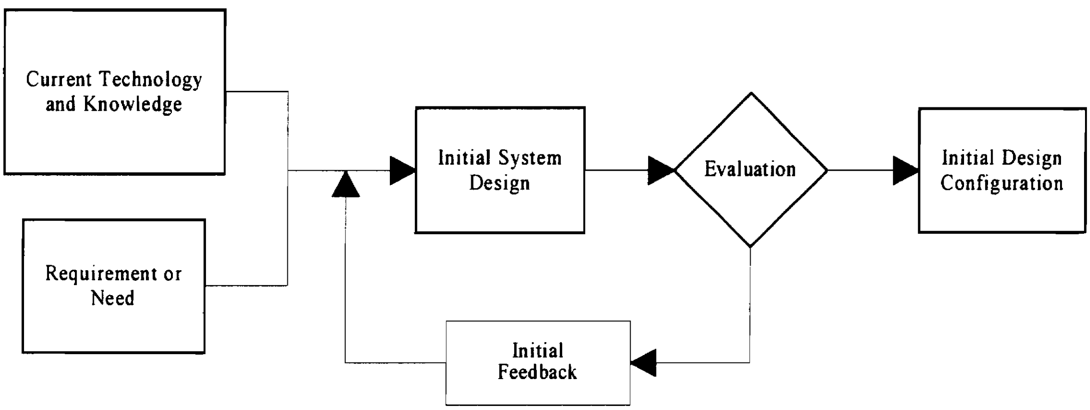

Figure 4-1 Detail Design Process Overview.

4.1 Detail Design Process Overview

The detail design phase for this project concentrates on the description of the system-support capability with emphasis on the O&M organization. The major goal of the detail design phase is to design for functionality and performance. The overall purpose of the final design follows the structure of the management system process as described by Kurstedt[8]. The O&M organizational system performance is measured using allocated requirements as the measure of quality performance from the organization. The simplistic view of this life cycle design goal is shown in Figure 4-2.

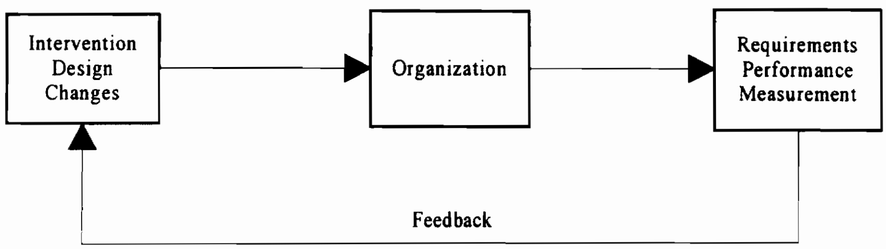

Figure 4-2 Life Cycle Overall Design Process.

The initial design of the organization is implemented into the model shown in Figure 4-2 as the organization. Over the life of the organization, continuous process improvement is employed through the measurement of performance and feedback of required design changes into the organization for increased performance. This design process resembles a Technical Performance Measurement (TPM) philosophy that is used throughout the system life cycle.

The initial design of the system is accomplished using management systems engineering theory and applications from Kurstedt. The detail design of the system follows the Management System Model (MSM) placed within the management system framework shown in Figure 4-2. Concentration is placed on the three areas of the MSM in the detail design.

4.2 Detail Design

The detail design of the system-support capability will follow a bottom-up design approach. Each sub-unit will be designed first, then the system-support capability will be built as a whole functioning unit from the previously designed sub-units. The design is broken into the two major areas of operations and maintenance.

4.2.1 Operations Organization Design

Operations is responsible for three major tasks as outlined in the functional analysis of the preliminary design phase. The three tasks are listed:

- Conduct Normal Steady-State Operations
- Conduct Normal System Configuration Change Operations
- Conduct Emergency System Operations

The organization is designed to perform these major tasks and meet the requirements allocated to operations from the allocation process of the preliminary design phase. The requirements allocated to operations are listed:

• Personnel Efficiency	One Error/Year for the System
• MTBM	240 Hours
• MDT	6 Hours

4.2.1.1 Designing for Personnel Efficiency

The personnel efficiency requirement is directly related to operations personnel. The requirement places a goal on the operations group to limit the number of personnel errors causing a loss of system availability to one error per year. There are a number of design factors within the operations organization that play a role in the performance of operations personnel. Shown in Figure 4-3 is a diagram depicting the multiple areas of design concern to ensure quality performance from operations personnel.

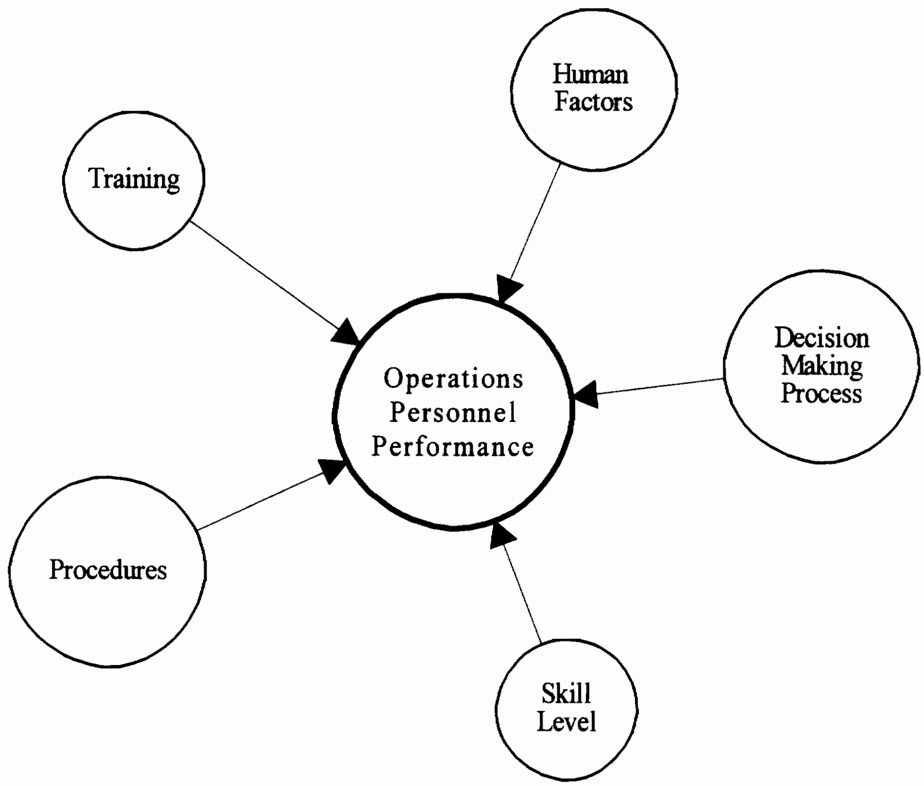

Figure 4-3 Operations Personnel Performance Design Concerns.

4.2.1.1.1 Human Factors

The human factors concern in operations personnel performance is one of hardware and software design characteristics that must be incorporated into the design of the system with early design input from operations personnel. For this project the hardware system is already in place and for the most part a lost opportunity for design. Human factors concerns in the area of hardware design such as environment, lighting, and workstations are in place at the facility containing the system in question for this project and are considered satisfactory. The human factors within the software component for this project can be changed in areas to enable increased performance. Software changes are outside of the scope of this project, but the following interaction with operations personnel and management systems engineering should occur to ensure quality performance. First, display screens used by operations personnel should be considered management tools used to gather data and display information for operations personnel to make decisions. Therefore, management systems engineering techniques should be applied to the development of display screens along with the cooperation of software engineers and human factors engineers. Second, a life cycle continuous process improvement approach should be employed in the development of display screens for operations personnel.

4.2.1.1.2 Decision Making Process

The decision making process within operations is truly an organization design feature. From the conceptual design phase, the traditional vertical management structure is the organizational structure to employ to produce timely and accurate decisions. Operational procedures define the specific circumstances under which supervisory or management decisions must be made. For the specific times when, by procedure, a management decision must be made to complete a timely task (emergency or normal), the organization structure shown in Figure 4-4 is designed. The organization structure employs a traditional vertical structure for timely decision making. The personnel blocks shown in the structure are developed from the detailed concept of operations from the conceptual design phase.

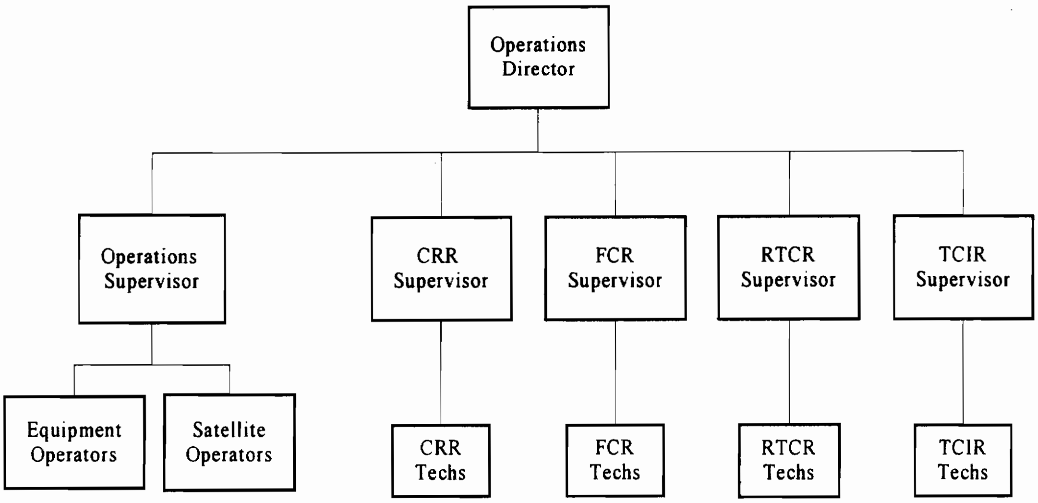

Figure 4-4 Operations Organization Chart.

The structure shown in Figure 4-4 is designed for real-time decision making and operations.

4.2.1.1.3 Skill Level

The skill level of operators is an area strongly related to the design of the operations organization. When placing personnel into designated operations positions a certain level of prior skill is required. The level of skill is determined based on the complexity and required base knowledge to satisfactorily make decisions to operate the system. Using the detailed system concept of operations as a basis for skill level, it is determined that each operator or supervisory position requires at a minimum a four-year degree in a technical discipline. This determination is based on the level of errors allowed by the personnel efficiency requirement. The system operated is highly technical in nature and requires a technical background. Since the majority of personnel errors in system operations are a result of a lack of knowledge, an initial technical degree knowledge base is required. The technician positions require at a minimum two years of technical education. The number of years of experience to fill a specific position is shown in Figure 4-5.

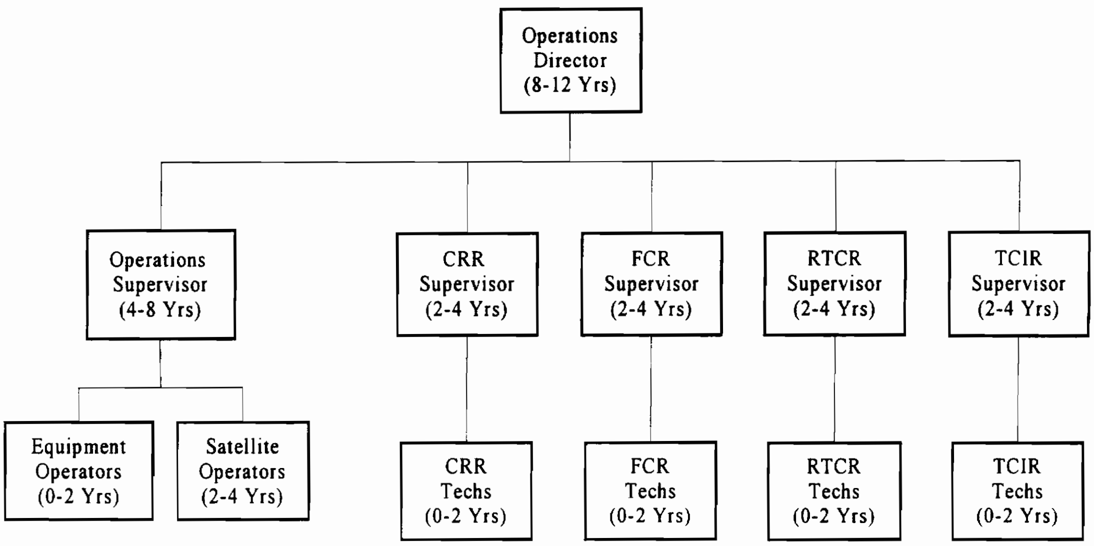

Figure 4-5 Years of Experience by Operations Position.

4.2.1.1.4 Procedures

Procedures are a special category of management tools that operators use to perform tasks and maintain the system operational. The quality of procedures directly influences the performance level of operations personnel. Specific procedures are not designed in this project, but rather a general design philosophy is outlined. There are three categories of procedures to be employed in an operational environment. The three categories follow from the functional analysis and relate directly to the three major functional operations areas: normal steady-state operations, normal system-configuration-change operations, and emergency operations. Procedures are therefore divided among the three possible categories. When designing a system of procedures, the following characteristics must be adhered to:

- Easily identifiable
- Easily understood and readable
- Directions must be clear and concise
- Rapidly accessible at all times
- Use checklists when applicable and appropriate
- Complete beginning to end tasks must be contained within one procedure

Specific design characteristics for each major concept are described as follows:

1. Easily identifiable - each task requiring a procedure must have a uniquely identifiable procedure. There never should be any guessing or interpretation of which procedure applies to a given task.
2. Easily understood and readable - procedures must be understood and written for the users (operations personnel).
3. Directions must be clear and concise - specific direction within an individual procedure must be clearly written to avoid any interpretation of the required task. If a step in a procedure is written, then a singularly unique decision or task should be completed for that step alone.
4. Rapidly accessible at all times - procedure should be available in easily accessible hardcopy binders which are available at all times. Softcopy procedures are a nice feature in theory, but a power failure at the wrong time causes the loss of operational

guidance. It is recommended that the best features of both softcopy and hardcopy procedures be employed. Softcopy procedures should be used for the majority of the procedures for cost-effective maintenance and updating of procedures. For frequently used procedures that must be followed much like a checklist it is recommended that a hardcopy system be incorporated.

5. Use checklists when applicable and appropriate - checklists are an extremely useful tool in an operational environment and must be used inside and as attachments to procedures. Checklists are a supplement to complete well-written procedures. Checklists provide a rapid process to double check the completion of a task or organize the completion of several procedures in a complex lengthy evolution.
6. Complete beginning-to-end tasks must be contained within one procedure - a single task to be completed should be self-contained within one procedure. The temptation to skip between several procedures simply to avoid duplication of a step that appears elsewhere must be avoided. The chance of causing an operator to lose his or her position within the middle of a complicated procedure is too costly not to simply duplicate the step from another procedure. There should always be an identifiable conclusion and completion of an individual procedure. Overall, procedures are an extremely important feature to the performance success of an operations organization and must be properly written and maintained.

4.2.1.1.5 Training

From the functional analysis of the preliminary design phase, the training group was placed under the operations group. Functionally, training and operations are directly related, but administratively the training group is designed into the maintenance group. In this section a complete functional description of the training group is presented.

Training is one of the most important factors in the successful performance of an operations organization. The training group is designed into the overall (system-support) organizational structure as shown in Figure 4-6. The training group fits better into the maintenance area because there is an easily identifiable separation between personnel who operate equipment real-time and personnel who participate more in a support role for the system. Therefore, training is placed administratively into the maintenance group, but as depicted by Figure 4-7 the training group interacts functional with other groups within the system-support manager's domain.

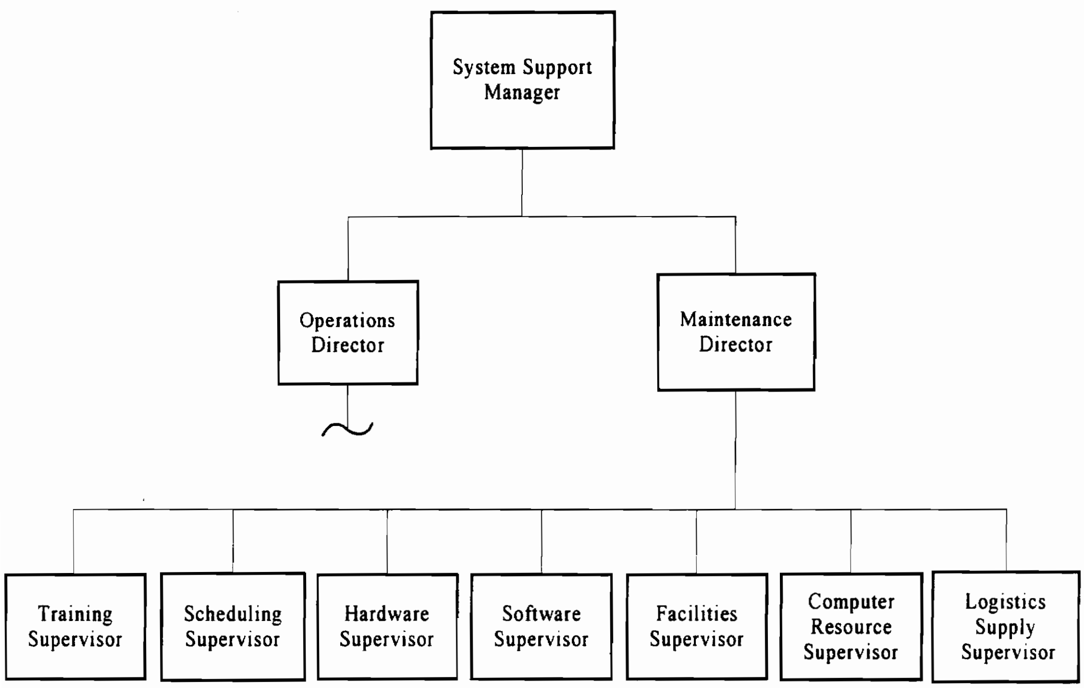

Figure 4-6 Maintenance Organizational Chart.

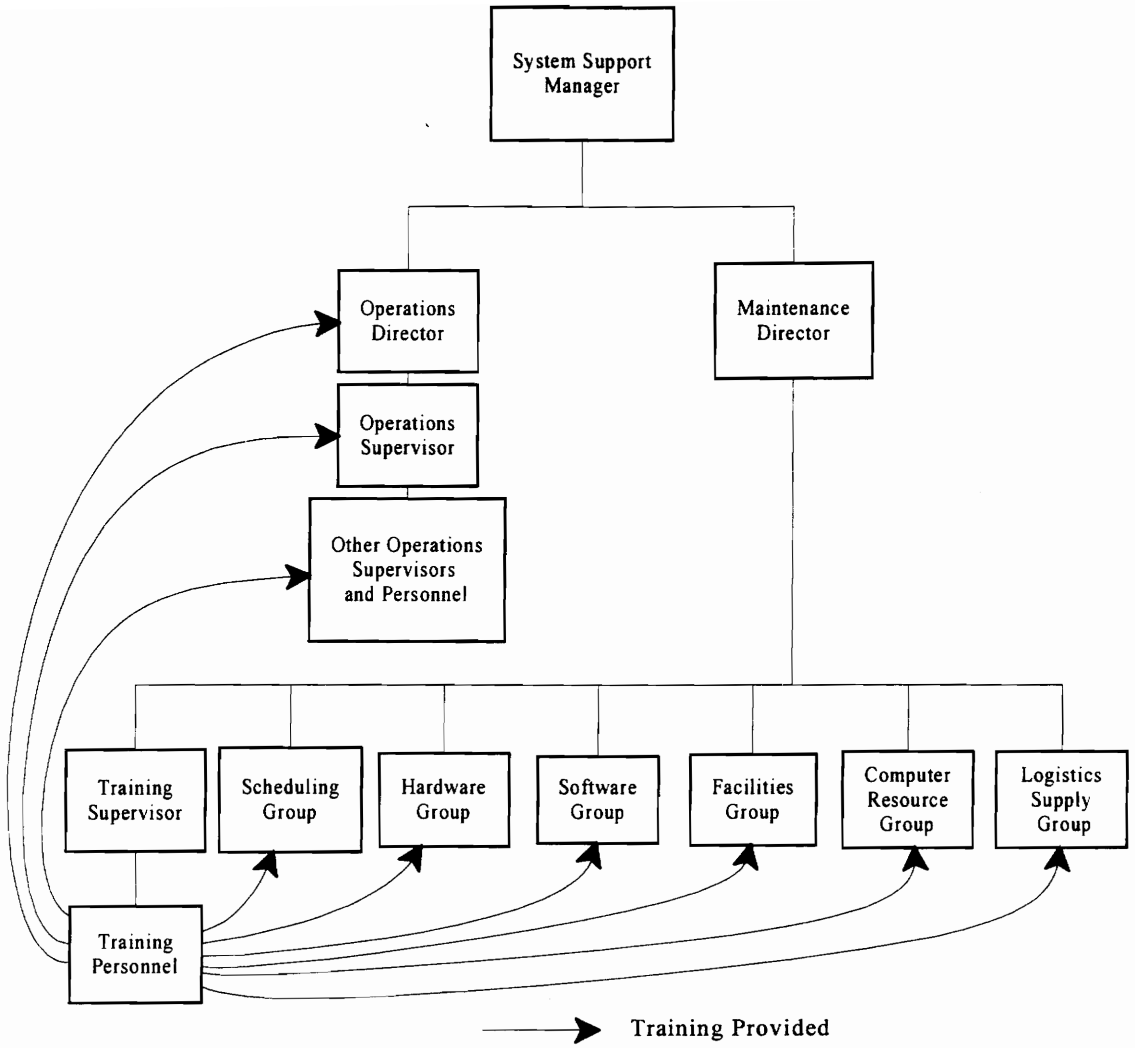

Figure 4-7 Training Group's Functional Interaction.

In the design of the training group, the group is assigned the following responsibilities:

- Manage the qualification and certification program.
- Maintain and update procedures.
- Manage a continuous training program.
- Manage a lessons-learned program.

The domain of activities assigned to the training group is large and diverse. This is due to the fact that the training program is a very important component in the success of an O&M organization. The training group in this design is considered the focal point for continuous process improvement (CPI), and, therefore, is assigned as the guardian of many CPI-type activities. Each of the above activities is designed in detail in the following sections.

4.2.1.1.5.1 Qualification and Certification Program

The training group is made responsible for the certification of all O&M personnel. This process is very important to ensure O&M personnel are adequately trained prior to allowing new personnel to conduct operational tasks solo. The certification process consists of a combination of classroom training and on-the-job training. On-the-job training is performed by personnel on duty rather than a training staff member, but the content and pace of training is defined, monitored, and controlled by training staff personnel. The certification program must be considered a quality assurance program, and should be designed and maintained as such. The certification process quality is maintained through the use of certification standards. A certification standard is a formal document that provides detailed guidance to trainees to aid them in the completion of their certification process. The certification standard contains required tasks each trainee must perform successfully to become certified as a qualified operator. Once complete with the certification standard, both written and oral exams (via on-the-job examination) are conducted to ensure adequate retention of knowledge and adequate level of performance is present prior to formally certifying a trainee. The certification standard is a very useful management tool to track and guide a trainee to a required level of operational knowledge. When completed, the certification standard provides a trainee with a baseline level of knowledge and ensures all O&M personnel have a common base of knowledge to function and grow professionally. Overall, the training group is responsible for the certification program and all of its collateral duties, to include classroom training, maintaining certification standards, monitoring trainee progress, and conducting exams. The certification program is the first step towards maintaining personnel efficiency at very high levels. Without a quality certification program, the personnel efficiency requirement will not be met.

4.2.1.1.5.2 Maintain and Update Procedures

The training group is assigned the responsibility to maintain and update procedures. As stated in section 4.2.1.1.4 on procedures, the importance of creating and maintaining quality procedures is of a priority such that the training staff is determined the most qualified to perform the task. Training staff personnel have the task of maintaining the most up-to-date knowledge on new procedures, new equipment installations, and generally any knowledge required to be promulgated to O&M personnel formally in a training atmosphere. This provides the training staff with a clear advantage in maintaining procedures.

4.2.1.1.5.3 Manage a Continuous Training Program

To ensure the personnel efficiency requirement is met and efficiency is sustained throughout the life cycle of the system, a continuous training program (CTP) is required. A CTP can consist of almost any kind of training as the training staff deems necessary or applicable. Methods of continuous training should consist of periodic written and oral exams, lectures on procedural changes, and lectures on new equipment installations. The most important feature and goal of the CTP must be to refresh operator's knowledge and skills to ensure the best possible performance. One area of concern that should be of priority in the CTP is of emergency operations. Emergency operations are typically not encountered often enough to remember the procedures adequately or practice the steps to recovery. The CTP can promote the use of what-if discussions and training among operators during normal steady-state conditions to refresh operators skills in the areas of emergency response. Overall, the CTP is the responsibility of the training staff and has the goal of maintaining operators skill levels sufficiently high enough to ensure satisfactory performance.

4.2.1.1.5.4 Manage a Lessons-Learned Program

A lessons-learned program (LLP) is a form of CPI within the O&M organization. The training staff is once again given the responsibility for this type of program due to its position in the functional process of the O&M organization. The training department interfaces with every group within the O&M organization is most qualified to manage a LLP. A LLP is a key program in providing structured feedback into the operations and maintenance process. Shown in Figure 4-8 is a depiction of how a LLP functions within the O&M organization. The LLP input form is a tool that gathers data from O&M personnel on real or perceived lessons-learned. These input forms are evaluated by a LLP evaluation team consisting of representative members from training, operations, and maintenance staffs.

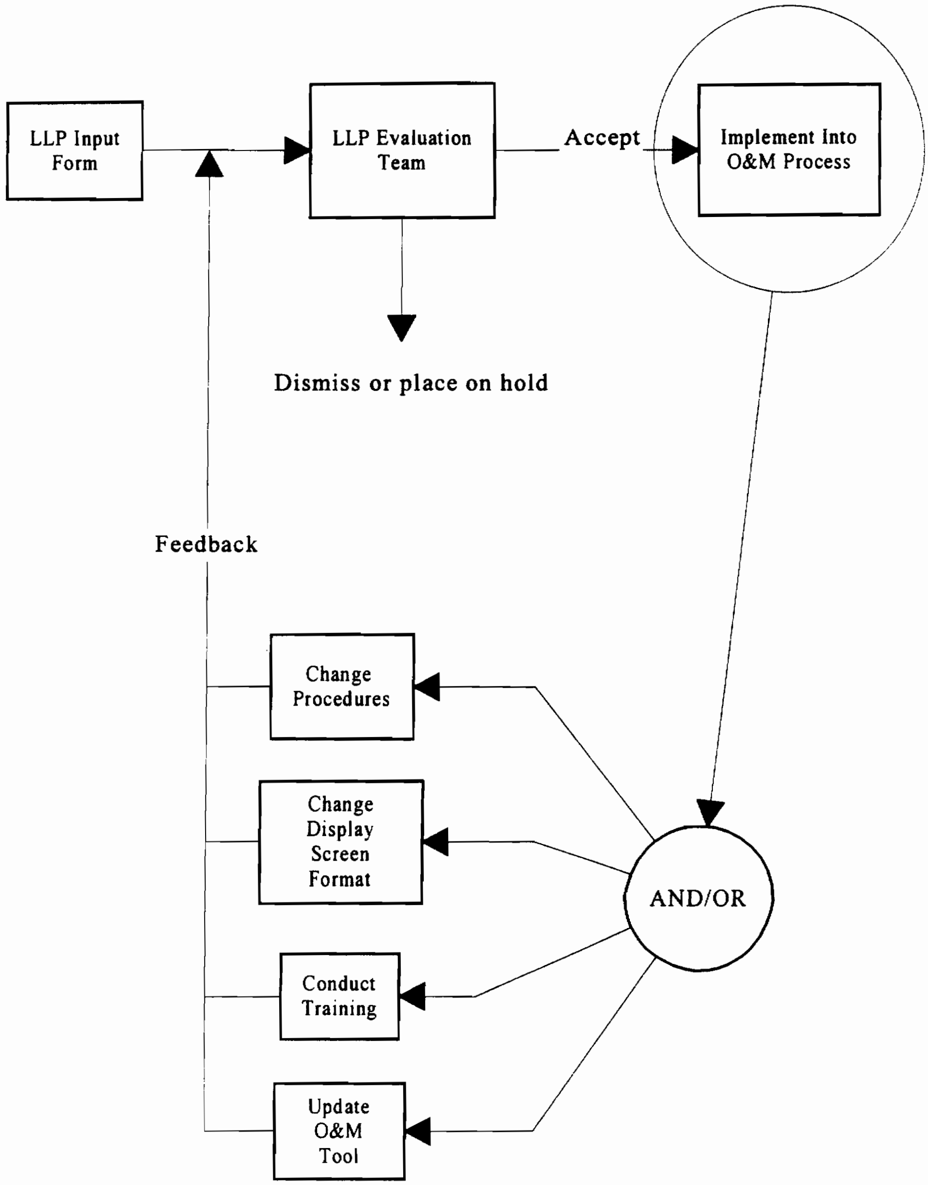

Figure 4-8 Lessons-Learned Program Process.

The LLP evaluation team employs team-based decision making and the structure of the team's organization is shown in Figure 4-9. The team membership is diverse and applies a systems approach to the evaluation of LLP input forms. The LLP input form encourages the input of any information concerning discovered problems with procedures, checklists, or processes.

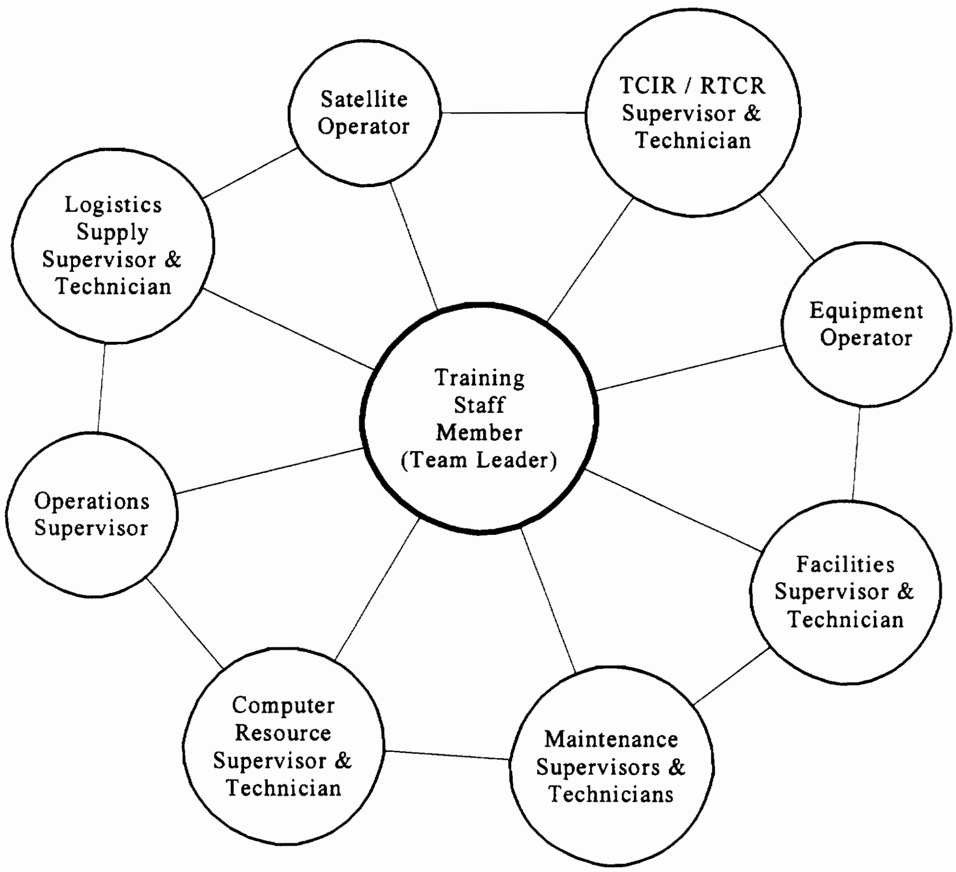

Figure 4-9 Lessons-Learned Evaluation Team Organization Structure.

The inputs should be limited to something learned through the execution of a procedure or process. Other forums for corrective action or CPI will be designed and described in a CPI section later in this design phase. The LLP input form is a management tool and requires a design process to build this tool. Using the MSM and the analysis and synthesis functions as described in Appendix A from Kurstedt, the tool is developed using the five analysis functions as follows:

Step 1 - The domain of the tool encompasses only lessons-learned from performance of a procedure or the use of a checklist. This should be stated clearly on the form to limit the domain of the information gathered.

Step 2 - The decision required from the information on the form is to either reject the recommended changes or accept the changes and put into action an implementation plan.

Step 3 - The information required to support an effective decision is a well supported recommendation to change a procedure or checklist to improve clarity or performance.

Step 4 - The data required to produce the required information is listed:

1. Operator's name
2. Operator's position
3. Operators experience
4. Procedure in question
5. Step(s) where problem was noted
6. Specific explanation of system conditions
7. Detailed explanation of lesson learned

Step 5 - The measurement indicator for this tool is the personnel efficiency requirement. If the procedural step in question continues to cause problems or a personnel error, then the tool may need to gather additional or different information. Due to the initial failure of the decision based on the initial information produced by the tool, some of the analysis steps may need to be repeated.

The management system synthesis steps apply more to a tool that is in use. The initial tool designed here will be improved by the training staff as part of a CPI process using Kurstedt's management system synthesis techniques.

4.2.1.1.6 Continuous Process Improvement to Maintain Personnel Efficiency

To maintain a high level of personnel efficiency, CPI is employed on the factors effecting performance. The specific design of CPI consists of teams formed from the same type of diverse membership as the LLP evaluation team. The CPI teams are dedicated to improving the factors that affect personnel efficiency. Shown in Figure 4-10 is a graphic of the overall CPI process to maintain and improve personnel efficiency. The CPI teams are responsible for conducting surveys, initiating discussions, and encouraging recommended changes for improvement. This is the forum in which any operations personnel are welcome and encouraged to provide recommended improvements to the system. A CPI tool similar to that of the LLP input form is used as an administrative process to receive and evaluate recommendations. A special case of CPI is that of the response to personnel errors when they occur. A very formal and responsive process is designed in the next section.

4.2.1.1.6.1 Response to Personnel Errors

The response to personnel errors when they occur is a very important type of CPI that must occur within a formal process. Shown in Figure 4-11 is the overall process designed to make rapid improvements to the system to prevent the personnel error from re-occurring.

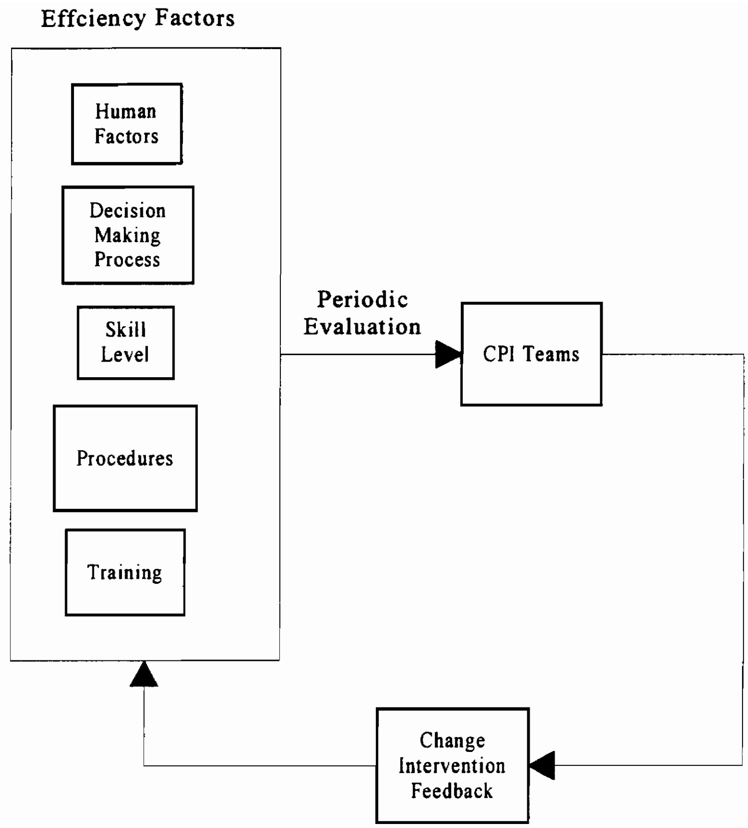

Figure 4-10 CPI Team Periodic Evaluation Process.

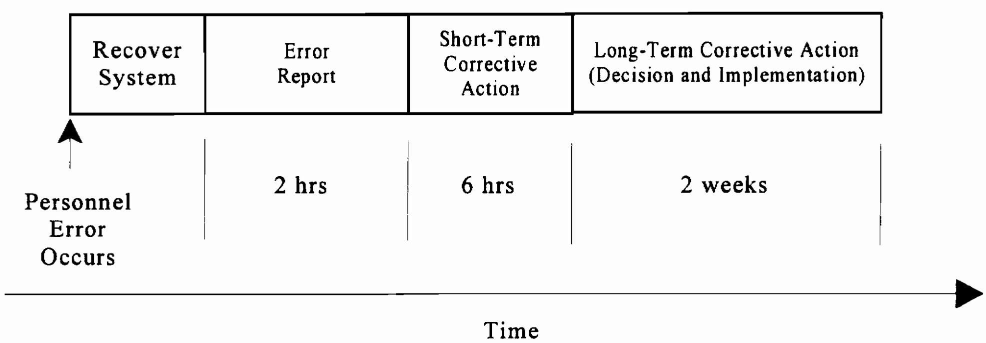

Figure 4-11 Personnel Response Formal Process Timeline.

After the personnel error occurs, the system recovery is of the highest priority and is accomplished first. Following system recovery, and within two hours, an error report is completed. This report is a management tool, used by a personnel error response team that gathers data from operations personnel involved in the error to make a decision on the required short term corrective action. The short term corrective action decided by the personnel error response team is at a minimum a formal memorandum promulgated to all O&M personnel outlining the error, the root cause, and the actions required in the future to avoid making the same mistake. Long term corrective action uses the CPI teams described previously to evaluate and determine the cause and corrective action required to avoid the error in the future. The long term corrective action looks at all the factors involved in personnel efficiency and determines what areas directly caused the error. This type of formal process to respond to personnel errors assumes the philosophy that errors are rarely ever purely the operator's fault. Errors are normally a combination of several factors that cause human judgment to fail. Therefore, the goal of the process is one of determining what area can be improved to increase performance. Common areas requiring improvement are typically poorly written procedures, display screens that are difficult to rapidly read, and decision making processes that cause confusion. The long term corrective action should be determined and completely implemented within two weeks following the personnel error.

4.2.1.1.7 Designing for Personnel Efficiency Conclusion

From the previous section, it is easy to identify with the complexity of designing an efficient and quality operations organization that has a high level of personnel efficiency. The previous sections outline an initial design of many programs or concepts within an operations organization that are designed to meet the personnel efficiency requirement. Overall, the personnel efficiency requirement will be met with the right skill level, training, and teamwork among operations personnel. To ensure the requirement is met and maintained over the life cycle of the system, a life cycle measurement and feedback process is designed into the system-support capability. This process for personnel efficiency is shown in Figure 4-12.

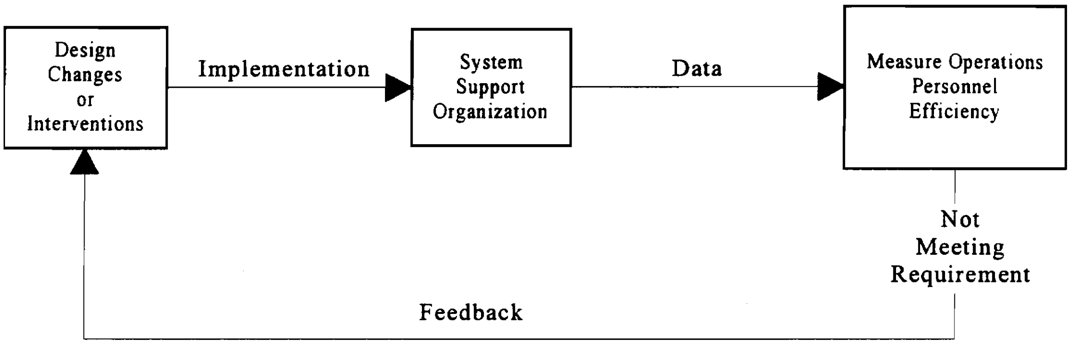

Figure 4-12 Life Cycle Personnel Error Measurement Process.

Using the measurement, feedback, and change process, the stage is set to implement the previously designed system and have the system meet the personnel efficiency requirement for the entire system life cycle.

4.2.1.2 Designing for Mean Time Between Maintenance (MTBM)

This requirement is allocated to operations due to the fact that operations personnel must understand the maintenance philosophy and MTBM is a key effectiveness factor in conducting system maintenance. The requirement is met by the operations organization by designing procedures and training to ensure operations personnel provide backup to maintenance and scheduling personnel. The MTBM requirement includes both periodic and corrective maintenance. It must be understood and trained to operations personnel the big picture behind maintenance. Operations personnel play a significant role in system maintenance and should understand requirements that they can affect. Overall, the MTBM requirement is met by the operations organization by designing the requirement into procedures as a back-up and redundant checks to scheduling and maintenance personnel.

4.2.1.2.1 Designing for Maintenance Downtime (MDT)

The MDT requirement is directly affected by the operations organization. MDT is a combination of logistics delay time (LDT), administrative delay time (ADT), and mean active maintenance time as defined by Blanchard and Fabrycky[9]. The ADT includes the time in which the system is not available for operations but is still under the control of operations. Operations personnel must first place the portion of the system to go into maintenance into a maintenance configuration. This time must be reduced to minimize the effect on the required MDT. This requirement is met by ensuring operations procedures and training are designed to require, at a maximum, 30 minutes to place a system into or out of maintenance. This leaves 5 hours of mean maintenance time to maintenance personnel.

4.2.1.3 Operations Organization Design Conclusion

The previous sections outlined an operations organization that is designed to meet the allocated requirements. The organizational system consists of an organizational chart used for administrative purposes such as human resources, career counseling, decision making during real-time operations, and overall management direction. The designed CPI teams, LLP evaluation team, and personnel response team are working-level teams given the purpose of making decisions over specified periods of time to make improvements and changes to the organizational system as necessary.

4.2.1.4 Maintenance Organization Design

Maintenance is responsible for four major tasks as outlined in the functional analysis of the preliminary design phase. The four tasks are listed:

- Conduct Hardware Maintenance
- Conduct Software Maintenance
- Conduct Facilities Maintenance
- Conduct Computer Resource Maintenance

The maintenance organization is designed to perform these major tasks and meet the requirements allocated to maintenance from the allocation process of the preliminary design phase. The requirements allocated to operations are listed:

• Maintenance Reliability	0.999
• MTBM	240 Hours
• MDT	6 Hours

4.2.1.4.1 Designing for Maintenance Reliability

The maintenance reliability requirement is directly related to the performance of the maintenance group. The requirement places a goal on the maintenance group to maintain the reliability of maintenance performed to 0.999. There are a number of design factors within the maintenance organization that play a role in the reliability of maintenance performed. Shown in Figure 4-13 is a diagram depicting the multiple areas of design concern to ensure reliable maintenance is performed by the maintenance group.

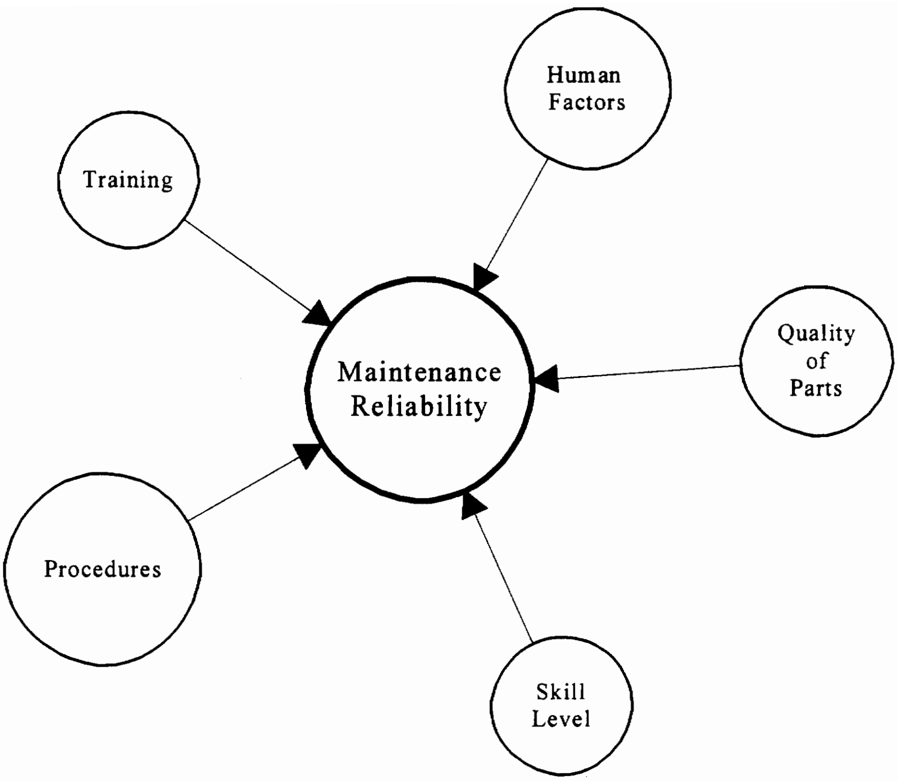

Figure 4-13 Maintenance Reliability Design Concerns.

4.2.1.4.1.1 Human Factors

The human factors concern in maintenance reliability much like that of operations is one of hardware and software design characteristics that must be incorporated into the design of the system with early design input from maintenance personnel. Equipment must be designed for human maintenance personnel to performance maintenance with relative ease and elimination of error. For this project, the hardware system is already in place and for the most part a lost opportunity for design. Human factors concerns in the area of hardware design such as environment, lighting, access panels, maintenance indicator lights, and test and verification systems are in place at the facility containing the system in question for this project and are considered satisfactory.

4.2.1.4.1.2 Quality of Parts

The quality of parts plays an important role in the reliability of maintenance. The design of the hardware system determines the specifics of size, complexity, and numbers of replacement parts. The design of the maintenance organization concentrates on the process in which maintenance is performed. The primary tool designed to ensure reliability of maintenance is the Work Authorization Form (WAF). The design of this tool is presented in section 4.2.1.4.2.2. The WAF is a tool that gathers data in the form of completed and authorized steps that ensure quality process control in the performance of maintenance. One specific step on the WAF is the verification of equipment or parts inspection. This verification ensures any parts being placed into the system have been properly inspected by qualified personnel in accordance hardware design inspection procedures.

4.2.1.4.1.3 Skill Level

The skill level of maintenance personnel is an area strongly related to the design of the maintenance organization. When placing personnel into designated maintenance positions, a certain level of prior skill is required. The level of skill is determined based on the complexity and required base knowledge to satisfactorily perform system maintenance. Using the detailed system concept of operations as a basis for skill level, it is determined that each technician position requires at a minimum two years of formal technical training. The system is highly technical in nature and requires a quality technical background to perform quality maintenance. The number of years of experience to fill a specific position is shown in Figure 4-14.

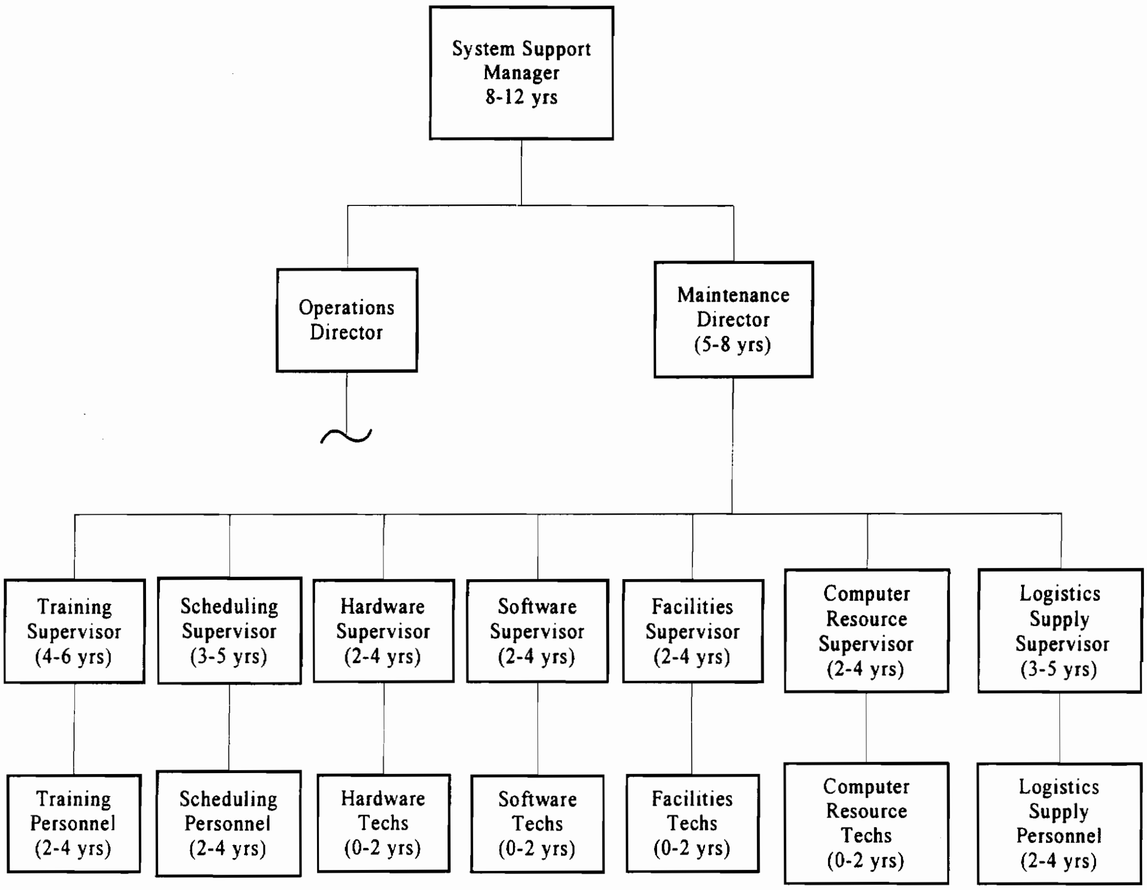

Figure 4-14 Years of Experience by Maintenance Position.

4.2.1.4.2 Procedures

Procedures are a special category of management tools that maintenance personnel use to perform tasks and maintain the system operational. The quality of procedures directly influences the maintenance reliability. Specific procedures are not designed in this project, but rather a general design philosophy is outlined. This outline has been described in detail as part of the operations organization design in section 4.2.1.1.4.

4.2.1.4.2.1 Training

The O&M training group and how it interacts within the organization was described in detail in section 4.2.1.1.5. The general philosophy, CPI programs, and specific processes discussed in the design of training previously all apply to the maintenance organization as well as the operations organization.

4.2.1.4.2.2 Design of the Maintenance Work Authorization Form (WAF)

The maintenance WAF is a management tool and requires a design process to build. Using the MSM and the analysis and synthesis functions as described in Appendix A from Kurstedt, the tool is developed for the five analysis functions as follows:

Step 1 - The domain of the tool encompasses the end-to-end process of completing a maintenance task.

Step 2 - The decision required from the information on the form is to authorize the performance of the listed maintenance task.

Step 3 - The information required to support an effective decision is a complete set of pre-maintenance tasks complete and verified.

Step 4 - The data required to produce the required information is listed:

1. Name of maintenance task
2. Description of task
3. System conditions to perform maintenance
4. Maintenance on schedule
5. Parts inspected properly

6. Tools and personnel on station and ready to start
7. Maintenance procedure available and reviewed
8. Related lesson learned reviewed

Step 5 - The measurement indicator for this tool is the maintenance reliability requirement. If maintenance tasks continue to cause problems or a lack of reliability, then the tool may need to gather additional or different information.

The WAF is a combination of tool, checklist, and procedure. Maintenance personnel are required to use the WAF to perform any maintenance, however simple or complex the maintenance may seem. The WAF is a control tool that requires authorizations at every major step in the maintenance process. This type of tool aids in double checking system conditions, required completion of steps, and in general provides a step-by-step guide through the maintenance process. This type of tool is required to ensure the maintenance reliability requirement of 0.999 is met. Semi-controlled maintenance, as exists with the current O&M organization in re-design, can allow mistakes to be made that greatly reduce the reliability of maintenance performed on the system. The management system synthesis steps of Appendix A apply more to a tool that is in use, and will not be completed in this project. The initial tool designed here will be improved by the training staff as part of a CPI process using Kurstedt's management system synthesis techniques.

4.2.1.4.3 Designing for Maintenance Reliability Conclusion

The previous sections outline an initial design of a maintenance organization with the purpose of meeting the maintenance reliability requirement. Overall, the maintenance reliability requirement will be met with the right personnel skill levels, training, control of maintenance through the WAF, and teamwork among O&M personnel. To ensure the requirement is met and maintained over the life cycle of the system, a life cycle measurement and feedback process is designed into the system-support capability. This process for maintenance reliability is shown in Figure 4-15.

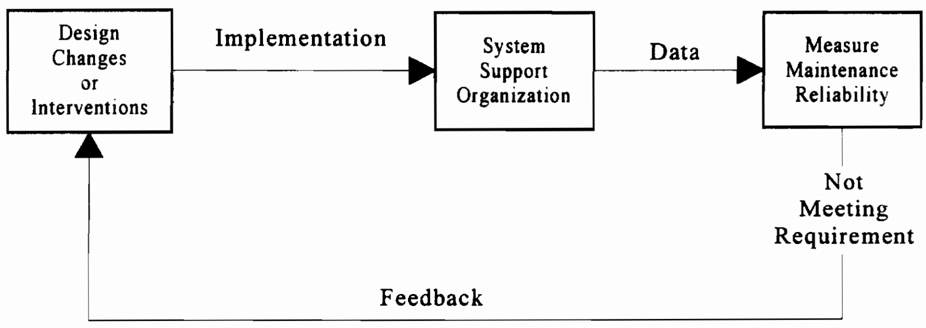

Figure 4-15 Life Cycle Maintenance Reliability Measurement Process.

Using the measurement, feedback, and change process, the stage is set to implement the previously designed system and have the system meet the maintenance reliability requirement for the entire system life cycle.

4.2.1.5 Designing for Mean Time Between Maintenance (MTBM)

The requirement is met by the maintenance organization mostly through the design of procedures to ensure maintenance personnel adhere to the requirement. Adherence to the requirement consists mostly of performing maintenance only at specified periodicity and following recommended maintenance schedules provided through the design of the hardware. Overall, the MTBM requirement is met by the maintenance organization by designing the requirement into procedures and placing the requirement on scheduling as a planning standard.

4.2.1.5.1 Designing for Maintenance Downtime (MDT)

The MDT requirement is directly affected by the maintenance organization. MDT is a combination of logistics delay time (LDT), administrative delay time (ADT), and mean active maintenance time as defined by Blanchard and Fabrycky[10]. The mean maintenance time is the time allowed by maintenance personnel to complete on average a maintenance task. This time is calculated as five hours from the discussion in the operations design section. The maintenance organization must track the time they spend on performance of maintenance and make adjustments if they exceed the required mean maintenance time. The forum for this type of change is the use of a CPI team for improvement of maintenance as described previously in the operations design section.

4.2.1.6 Maintenance Organization Design Conclusion

The previous sections outlined a maintenance organization that is designed to meet the allocated requirements. The organizational system consists of an organizational chart used for administrative purposes such as human resources, career counseling, maintenance performance, and overall management direction. The designed CPI teams from the operational design section are O&M wide, and are working-level teams given the purpose of making decisions over specified periods of time to make improvements and changes to the organizational system as necessary.

4.2.2 Detail Design Conclusion

The combination of the operations organization and maintenance organizations previously described, make-up the complete O&M organization and the system-support capability. The initial design is the first step in designing and maintaining an efficient and world-class O&M organization.

Chapter 5: Future Study Recommendations

5. Future Study Recommendations

5.1 Continuing the System Design

The most important future design recommendation is that of employing continuous process improvement. The initial design of the system-support organization in this project will require further improvement and refinement to ensure quality performance throughout the system life cycle. The organizational system providing system-support must be treated as a system that can be designed, changed, and adjusted for peak performance.

5.2 Interfaces With Hardware and Software Design

One area of recommended future design involvement is that of the interaction between system-support design, hardware design, and software design. This project placed emphasis on the design of the system-support capability with little effort toward the overall design of the system from a systems approach perspective. This was intentional to limit the scope of the project, but as a future study, the interactions between hardware design, software design, and system-support design should be investigated and implemented into the initial design presented in this project.

5.2.1 Refining the Systems Engineering Process

The systems engineering process used in this project can be refined and applied more to the design of an organization. The systems engineering process historically has been applied mostly to the design of hardware and software, while leaving the system-support capability to be designed mostly outside the process. The recommended refinements would be to treat the system-support capability much the same way as this project has attempted to do. The system-support capability can be treated as a system and specific requirements should be allocated to the O&M organization.

Chapter 6: Conclusion

6. Conclusion

6.1 Summary of the Application of the System Engineering Process

The systems engineering process, as used in this project appears to have successfully designed an initial organizational system using management systems engineering as the specific engineering discipline. The systems engineering process, as outlined by Blanchard and Fabrycky, provides the structured means to perform logical design tasks in an orderly fashion required to design from a system-level top-down approach an initial organization. The integration of management systems engineering applications into the systems engineering process of designing organizational systems requires further study as recommended in Chapter 5.

6.2 Project Goals Completed

This project was undertaken to design and develop an O&M organization. The objective of the designed O&M organization was to provide an organization that corrected noted deficiencies. The conceptual design and preliminary design phases in this project where the first steps in the development of a new O&M organization. The detail design phase provided the process to design an organizational system consisting of organizational charts, management tools, and continuous process improvement teams. The final organization and the tools are designed to meet all the system-level requirements and correct the noted system deficiencies from the system need analysis.

6.3 Overall Conclusion

The combination of the systems engineering process from Blanchard and Fabrycky and management system engineering applications from Kurstedt provided a logical and systematic approach to the design of an O&M organization. The organization designed in this project is fully capable of being implemented in an actual O&M environment, and with refinement should provide an excellent organizational structure and process to perform world-class operations, maintenance, and system-support.

Appendix A

Description of the Management System Organizational Model

This description is summarized from Kurstedt[11]. The Management System Organizational Model represents a structured approach for understanding, building, and using management tools. The Management System Model provides a simple framework for describing a management system, its components, and their relationships. Shown in the figure below is a complete model for building management tools which includes the Management System Model, Management System Analysis, and Management System Synthesis.

The Management System Model is shown below. Inside the figure five Management System Analysis functions and nine Management System Synthesis Functions are shown. The five management system analysis functions flow counterclockwise around the basic Management System Model and the nine management system synthesis functions flow clockwise around the basic Management System Model. The model is an application or tool that is used to build management tools.

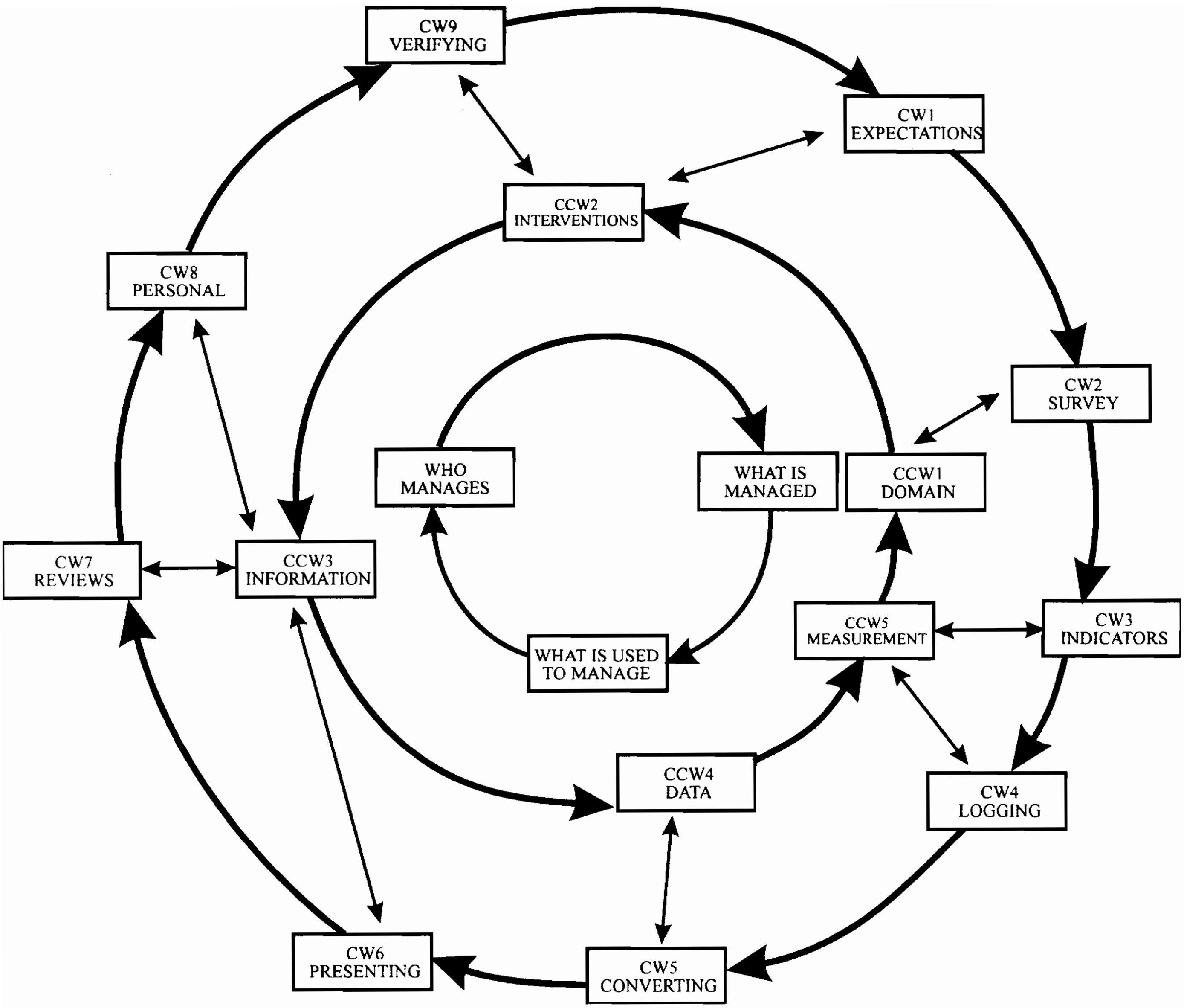

Figure A-1 Management System Model.

Endnotes

[1] Kurstedt, pp. 237-257.

[2] Blanchard and Fabrycky, pp. 37-38.

[3] Ibid., p. 38

[4] Ibid., pp. 42-43.

[5] Ibid., pp. 45-48.

[6] Kurstedt, pp. 302-337.

[7] Blanchard and Fabrycky, pp. 48-49.

[8] Kurstedt, pp. 276-277.

[9] Blanchard and Fabrycky, p. 403.

[10] Ibid., p. 403.

[11] Kurstedt, pp. 256-257.

References

Blanchard, Benjamin S. and Wolter J. Fabrycky. Systems Engineering and Analysis. Prentice Hall: New Jersey. 1990

Bolman, Lee G. and Terrence E. Deal. Reframing: Organizations *Artistry, Choice, and Leadership*. Jossey-Bass: San Francisco. 1991.

Fink, Stephen L., Jenks, R. Stephen, and Robin D. Willits. Designing and Managing Organizations. Richard D. Irwin. Homewood, Illinois. 1983

Galbraith, Jay. Designing Complex Organizations. Addison-Wesley: London. 1973.

Galbraith, Jay R. Organization Design. Addison-Wesley: Reading, Massachusetts. 1977.

Kurstedt, Harold A. Jr. Management Systems Theory, Applications, and Design. Virginia Polytechnic Institute Class Draft Text, 1994.

Riis, Jens Ove. Design of Management Systems: *An Analytical Framework*. Akademisk Forlag: Copenhagen. 1978.

Robbins, Stephen P. Organization Theory: The Structure and Design of Organizations. Prentice-Hall: Englewood Cliffs, New Jersey. 1983.

Rudwick, Bernard H. Solving Management Problems: *A Systems Approach to Planning and Control*. John Wiley & Sons: New York. 1979.

Scott, William G. Organization Concepts and Analysis. Dickenson: Belmont, California. 1969.

Sisk, Henry L. Principles of Management: A Systems Approach to the Management Process. South-Western: Chicago. 1969.

Vita

Joe Miles Crossett was born in a small town outside of Rochester, New York in the winter of 1965, while his father was working for the Xerox Corporation and his mother was working for the Eastman Kodak Corporation.

In 1983, Joe graduated from Bloomfield Central School in East Bloomfield, New York. After graduating from High School Joe went on to attend college at the L.C. Smith College of Engineering at Syracuse University. Joe graduated Magna Cum Laude from Syracuse University in 1987 with a Bachelors Degree in Electrical Engineering. He became a member of both Eta Kappa Nu and Tau Beta Pi Engineering Honor Societies while attending Syracuse University.

In 1987, Joe went on to join the United States Naval Nuclear Power Officer Program. He attended Officer Candidate School in Newport, Rhode Island where he graduated as a Naval Distinguished Graduate and received his commission as an Ensign in the United States Navy. Following his commission Joe went on to attend Naval Nuclear Power School, Naval Nuclear Power Prototype Training School, and Naval Officers Submarine School. Following his Nuclear Power Officer training Joe served as a Nuclear Power Officer onboard the USS Daniel Webster (SSBN-626), the USS Simon Bolivar (SSBN 641), and the Navy Prototype Training Unit Moored Training Ship 2.

Following his service as a United States Naval Officer Joe went on to work for General Electric Aerospace in Springfield, Virginia. Following two corporate mergers, Joe now works as a Systems Engineer for Lockheed Martin in the Systems Engineering and

Integration Division as part of Lockheed Martin's Washington, D.C. area Management and Data Systems Operations.