A Life-Cycle Analysis of a Multi-media Teleconferencing Network

by

Mark A. Zurich

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: --
Benjamin S. Blanchard, Chairman

-- --
Wolter J. Fabrycky Ira Jacobs

September, 1991

Blacksburg, Virginia

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Committee Chairman: Benjamin S. Blanchard
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(Abstract)

A large defense contractor has a need to acquire a teleconferencing network to link two factory locations to the customer site where systems operations are performed. The teleconferencing network will be used to conduct productive meetings with key personnel with no time or expenses lost to travel. The network must be on-line 24 hours a day and be able to transmit video, voice, audio, and fax data. The network is designed to send video, audio, and fax data over a satellite link via the use of a video codec. The network is also capable of performing a stand-alone audio conference using the fiber-optic phone lines. The two factory locations are located in Philadelphia and Los Angeles and the customer site is located outside of Washington, D.C.

The objective of the life-cycle analysis is to define system operational requirements, the maintenance concept, and required program planning information so that the system configuration and life-cycle cost can be

determined. The life-cycle analysis includes a cost breakdown structure of the subsystem components of the teleconferencing network and a calculation of the total system cost. The total system cost is used in a lease versus buy analysis to determine the most cost effective method of acquisition. The life-cycle analysis shows that the teleconferencing network meets the communication needs of the customer/contractor party and, if implemented, can potentially result in a $500,000 annual savings in T&L expenses. Sensitivity to variations in the reduction in operating expenses estimate and the interest rate are also considered. A figure showing the relationship between the reduction in operating expenses estimate and the interest rate is developed to determine the best method of network acquisition for any given set of parameters.

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1.0 **Definition of Need**

A need has been identified for the installation of a teleconferencing network to link three sites. The one customer site is located outside of Washington, D.C. and the two contractor sites are located near Philadelphia, PA and Los Angeles, CA, respectively. The driver for the teleconferencing network is to save money on travel between the three sites and to reduce the loss of key personnel as a result of travelling. The concept is to keep the key personnel at their home base with only brief breaks to attend important meetings.

The customer and the contractor have estimated that over 520 one-hour meetings are conducted each year between the three sites. The two parties have also estimated that 1.5 million dollars are spent annually on travel and living (T&L) to attend the various meetings. Both parties estimate that a teleconferencing network can reduce operating expenses by $500,000 per year as a result of saving in T&L expenses..

A need for a life-cycle analysis has been identified to determine the total system cost. The total system cost will be used to determine the best way to acquire the system. The basis for the life cycle analysis is the influencing factors and relationships between the prime ingredients of the system shown in Figure 1.1. The system in this case relates to the planning, design, development, production, deployment, installation, and operation of the

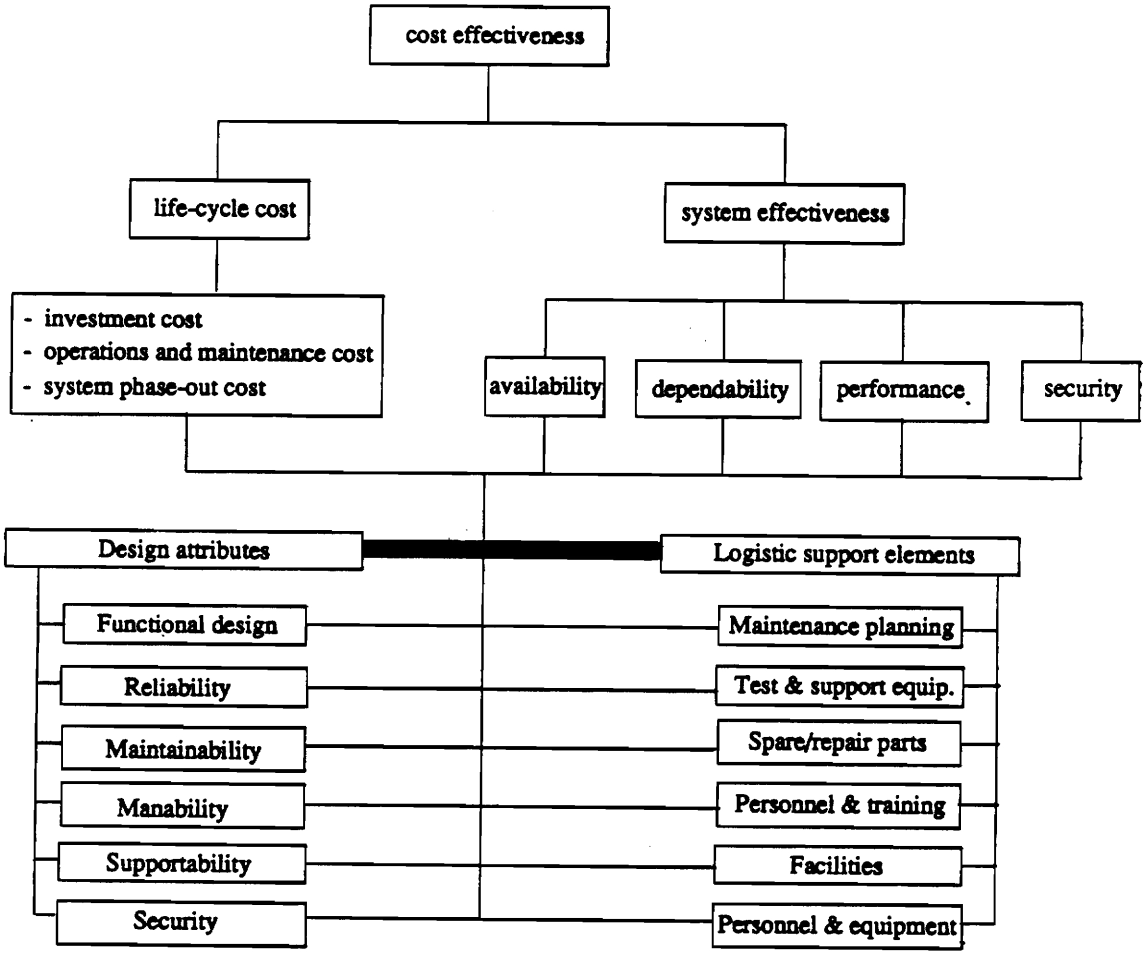

Figure 1.1 - Elements of Cost Effectiveness[1]

teleconferencing network. Every element in Figure 1.1 must be addressed by the system analysis. The elements in Figure 1.1 establish guidelines that the supplier must follow when designing and developing the network. The intent of the guidelines is to drive the supplier to implement cost-effective measures during network design and development to lower total network cost.

The network supplier offers acquisition plans which include buying the system outright or leasing the system for a yearly rate. The total system cost becomes integral in the lease versus buy decision process. An engineering economic evaluation will follow the life-cycle cost analysis to weigh the buy versus lease alternatives.

2.0 Operational Requirements

The system operational requirements define the technical parameters for system design. These parameters evolve from the needs analysis and the feasibility of various technology applications. The breakdown of the operational requirements leads to the definition of system operating characteristics, the maintenance support concept, and the identification of specific design criteria.

2.1 Mission Definition

The mission definition is to provide a cost-effective teleconferencing network to allow for the exchange of audio, video, and hardcopy data between three vastly separated sites. Cost-effectiveness in this case refers to providing a teleconferencing network which is more economical than the high cost of travelling between the three sites. A detailed schematic of the three-site configuration complete with communication links is shown in Figure 2.1. The network must be able to support a teleconferencing environment that can include up to 25 participants at each of the sites. The network must also ensure that the integrity of the data be maintained so as to protect the sensitive nature of the information. The network must also possess a mean time between failure (MTBF) of 3120 hours, or greater, with a mean corrective maintenance time (M_{ct}) not to exceed 24 hours. The MTBF criterion was determined by customer/contractor party engineers who requested that the network experience less than 2.5 failures over the useful

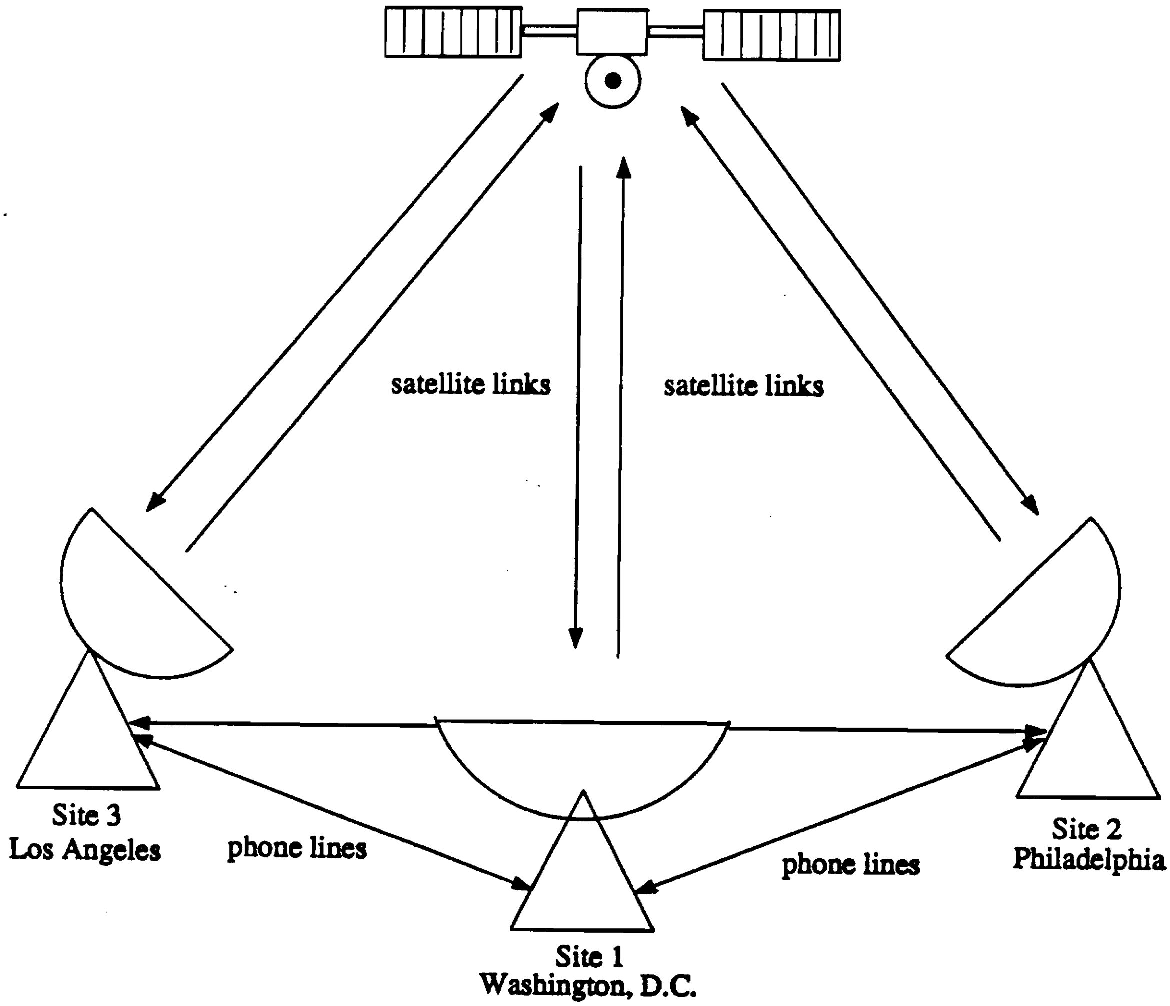

Figure 2.1 - Three site configuration complete with communication links

life for the three-site configuration. The assumption was made that the network is in the steady-state and would be in operation 2600 hours per site over the useful life. The value for the mean corrective maintenance time was also determined by customer/contractor party engineers as the maximum time that the network would be out of service as a result of a network failure.

2.2 Use Requirements

The system is designed to be on-line 24 hours a day, seven days a week. The customer and the contractor have estimated that 520 one-hour meetings are conducted each year between the three sites. This amounts to two one-hour meetings per day over a year which is comprised of 260 operational days. The meetings are held primarily between 6 AM and 6 PM EST Monday through Friday. Occasionally, situations will arise where an emergency meeting will have to be called to address an operational anomaly. Both parties desire to have the capability of conducting a teleconferencing meeting at any time of the day or night.

The program plan and milestones for the teleconferencing network are reflected in Figure 2.2. The milestones indicate that the teleconferencing network will be acquired, installed, tested, and initialized within the first year of the life cycle. The network is designed to have a five-year operational life. This time frame was agreed upon by the network supplier

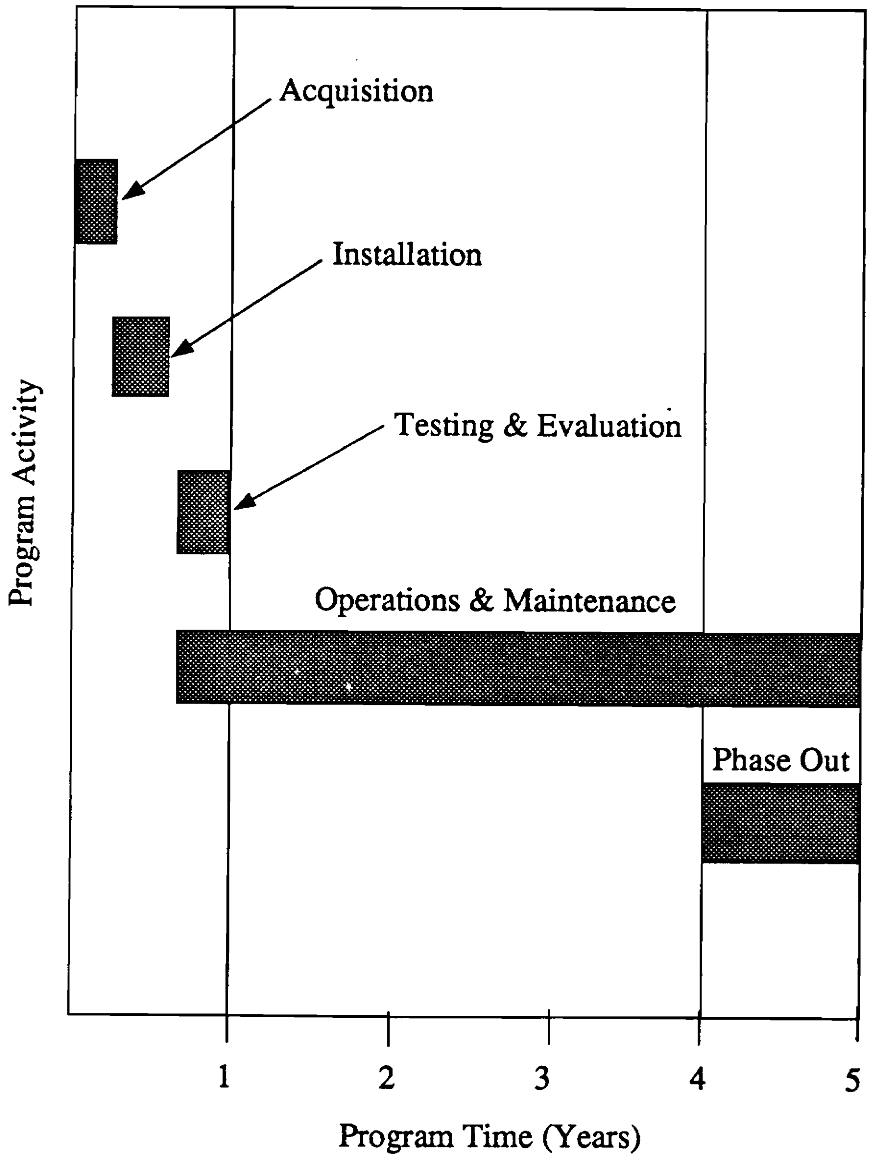

Figure 2.2 - Project Planning and Milestones

and the customer/contractor party so as to allow a sufficient time period to assess the investment. At the end of five years, the customer/ contractor party will determine if the network has indeed reduced travelling costs. Also, the customer/contractor party is concerned about technological advances in the field of teleconferencing. They feel that the network may be outdated at the end of five years and an upgrade may be in order.

2.3 Operational Deployment

The teleconferencing network will be assembled in one of three supplier factory locations. The factory sites are located in the Washington, D.C. area, Texas, and California. The equipment needed to install the system will be delivered by van to the three sites. The Washington, D.C. supplier site is responsible for supporting the Washington D.C. and Philadelphia, PA customer and contractor sites. The California supplier site is responsible for the Los Angeles, CA contractor site. The Texas supplier site will be used for additional electrical components during the maintenance effort. The Texas supplier site will enter the maintenance arena in the event that one of the other two supplier locations do not have a specific component in stock. The deployment time from supplier factory to site will vary depending on the distance between the two. Maximum deployment time will not exceed three days.

Once the system is delivered to the site, supplier technicians will integrate the network equipment into the site specific teleconferencing environment. The maximum integration time will not exceed seven days. Upon installation and integration of the network, the supplier technicians will conduct a two to three day training class on basic system functions and operations. These classes are aimed at minimizing down time by reducing the number of calls to the supplier factories for maintenance questions related to system operation.

2.4 Operational Functional Flow

Functional analysis is a logical and systematic approach to system design and development. It constitutes the process of translating system operational and support requirements into specific qualitative and quantitative design requirements. This process is iterative and is accomplished through the development of functional flow diagrams.

Functional flow diagrams are developed for the primary purpose of structuring system requirements into functional terms. They are developed to indicate basic system organization and to identify system interfaces. The functional flow diagrams for the operational and support analysis for the teleconferencing network is shown in Figures 2.3 and 2.4, respectively. Figure 2.3 represents an overall portrayal of the way that the network will be used by the customer/contractor party at the three sites. Figure 2.4 represents an overall portrayal of the way that data will flow within the teleconferencing network.

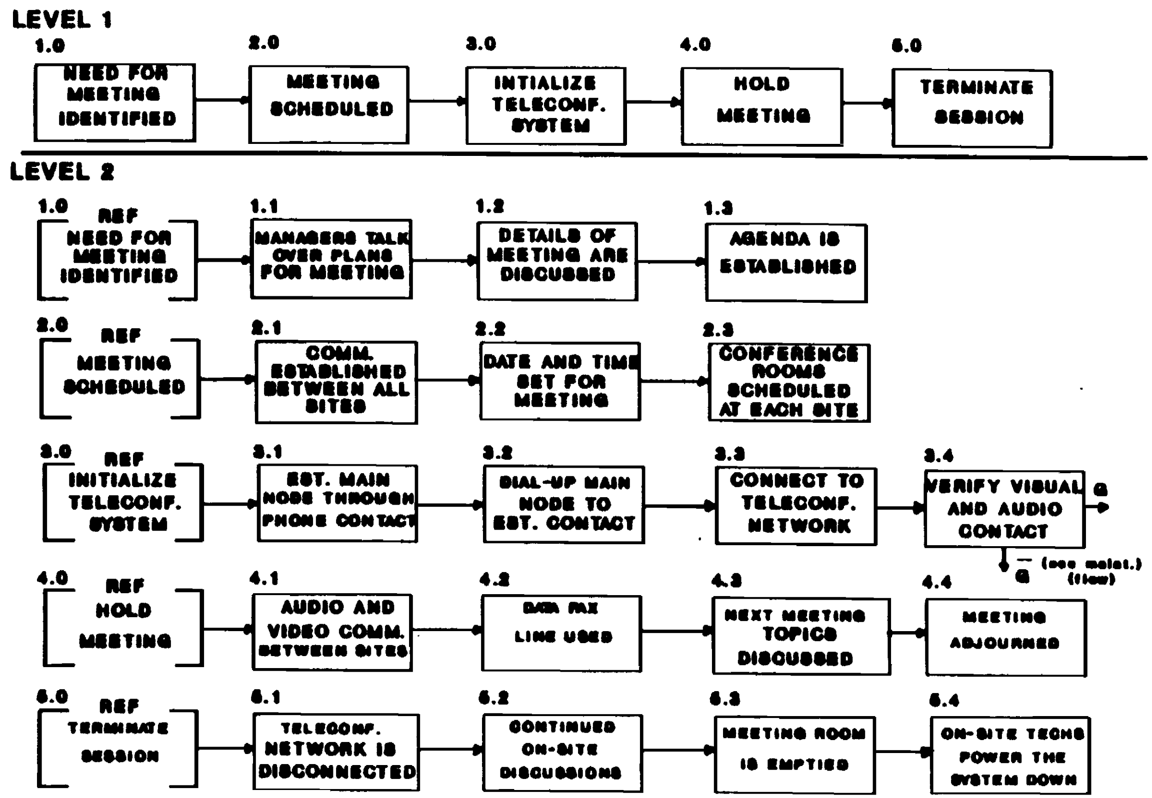

Figure 2.3 - Operational Functional Flow

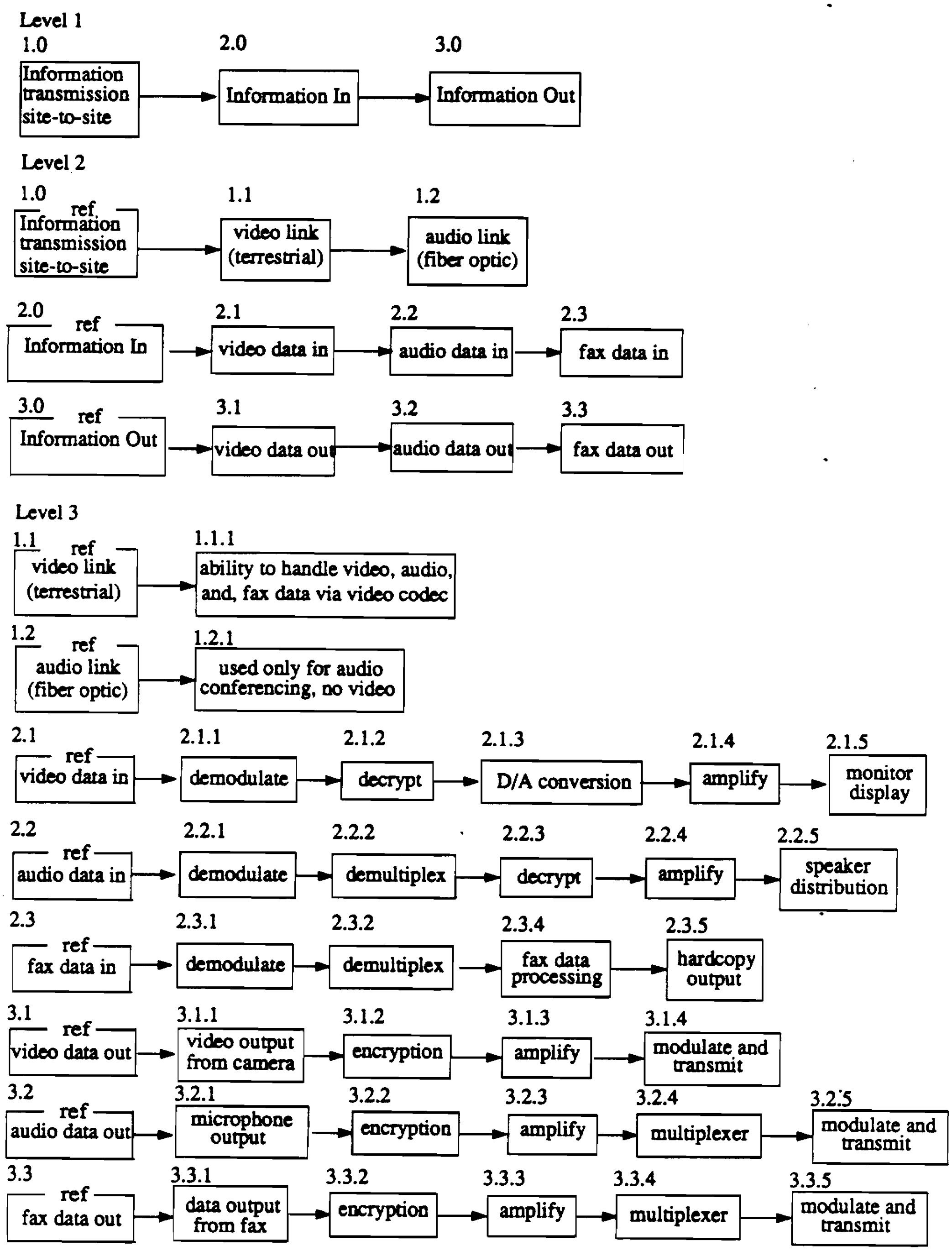

Figure 2.4 - System Functional Flow

3.0 Teleconferencing Network Design

3.1 Conceptual Design

The network is designed to transmit video, audio, and fax data over an existing satellite link with the use of a video codec. Sending the combination of data over the satellite link eliminates the lip-synchronization problem commonly encountered with videoconferencing. The network is also capable of performing stand-alone audio conferencing using the existing fiber optic phone lines.

The proposed teleconferencing network will be comprised of various electronic components (monitor, camera, power supply, etc.) housed in a console cabinet. The unit will be delivered and installed at the three requested sites and integrated directly into the teleconferencing environment of the site.

Each console cabinet will be built at a supplier factory location. The units will then be delivered and integrated into the teleconferencing environment at the three sites. Each unit will contain the following components:

- two color monitors (one for each of the other sites)
- a mounted camera for video capabilities
- a removable rack that contains the power module

- a removable rack that contains the subsystem components of the teleconferencing network
- a mounted loudspeaker.

Other equipment that will be delivered with the teleconferencing network includes:

- network controller and associated electronics
- a data fax unit
- cabling and conduit
- microphones.

See Figure 3.1 for details on the typical operational setup and unit configuration within the teleconferencing environment.

3.2 Subsystem Component Analysis

The teleconferencing network is comprised of four subsystems: 1) the networking electronics, 2) the audio electronics, 3) the video and fax electronics, and 4) peripherals. The networking and audio electronics are supplied by Shure Teleconferencing Systems of Evanston, IL. The video camera is supplied by Toshiba, Inc. of San Francisco, CA. The television monitors are supplied by Sony, Inc. of Dallas, TX. The data fax units are supplied by Data Beam Inc. of Baltimore, MD. The video codec is provided by Compression Labs, Inc. of San Jose, CA.

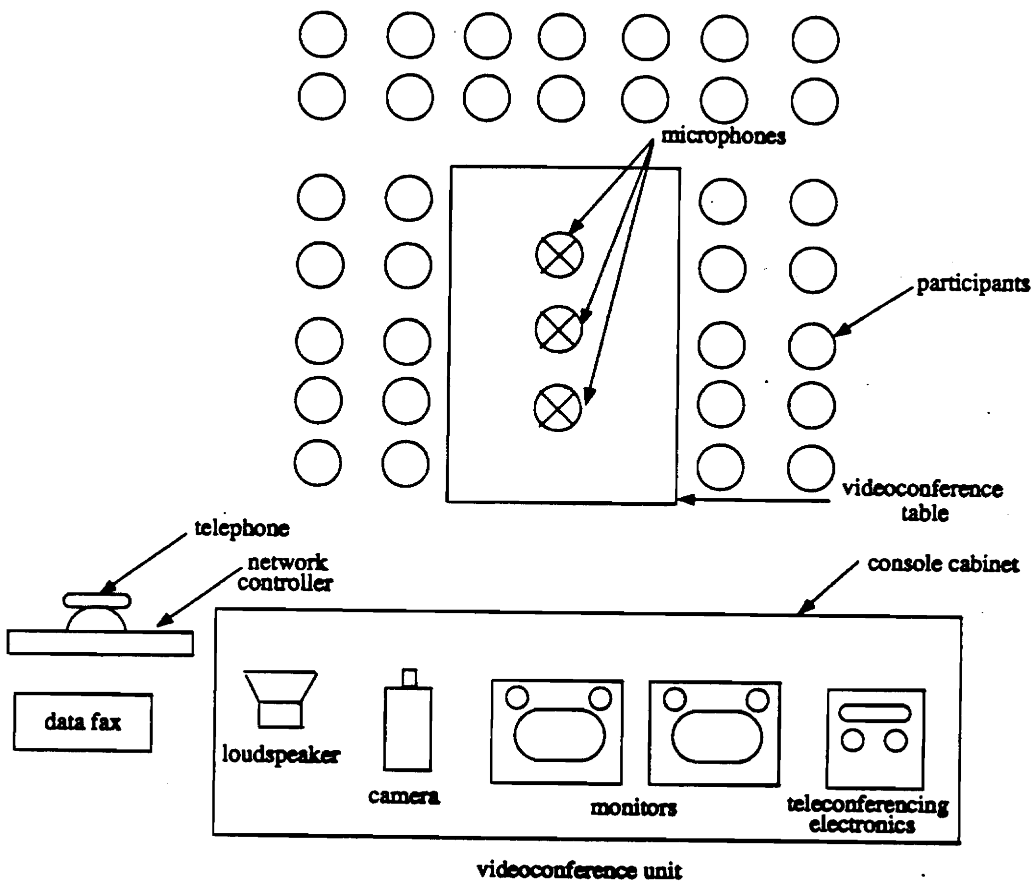

Figure 3.1 - Typical Operational Setup/Unit Configuration

The following section includes technical data on the key components of the teleconferencing network:

1. **Shure ST6000 Type 2A Teleconferencing System**

   The ST6000 provides full-duplex, echo-free satellite and compressed video conferencing without distortion, noise, or restricted bandwidth. The ST6000 uses integrated echo reduction circuitry to eliminate residual echo as well as providing 4-wire loopback modes for ease in setup and error checking. This component incorporates the necessary bridging circuitry to establish, using the Shure STC64 Controller and the Shure ST2AC Canceller, a fully interactive teleconferencing site communicating with a 4-wire videoconference link and a 2-wire public telephone network.

2. **The Shure STB624 Videoconference Network Interface**

   The STB624 enables the user to convert a video uplink site into a downlink site in a Direct Broadcast Network. When combined with the Shure STC64 Controller, the STB624 links a 2-wire phone line to a 4-wire satellite link for echo-free full audio interactivity.

3. **The Shure ST2AC Canceller**

   The ST2AC uses a split-type adapter echo canceller module and digital signal processing to eliminate returned echo signals. The ST2AC cancels both signal-transit and time-delay echoes generated by long terrestrial circuitry.

4. **The Shure ST6008 Expansion Mixer**

   The ST6008 provides power amplification to the mounted loudspeaker and the ability to add up to 200 microphones.

5. **The Shure STM33 Tri-Mic**

   The STM33 provides uniform 360 degree coverage from a single unit. The STM33 is designed to eliminate dead spots in the room.

6. **The Shure STL78 Loudspeaker**

   The STL78 provides 2 watts of power and a frequency response from 200 to 5000 Hz with a 4 ohm impedance.

7. **The CLI Rembrandt II/06 Video Codec**

   The CLI Codec provides superior picture quality compared with other video codecs on the market at bandwidths from 56 Kbps to 384 Kbps using Discrete Cosine Transformed-based CTX (Cosine Transform Extended) mode. The CLI Codec allows for faster, simpler troubleshooting with comprehensive, on-board diagnostics, error log stored in non-volatile memory, and test-signal generation. Diagnostics are accessible remotely by service personnel through an RS-232 port. The CLI Codec has a BNC connector, 1 V p-p, 75 ohm video connection interface and a 600 ohm balanced, 0 dBm, 9-pin DB connector audio connection interface.

Figure 3.2 shows the typical hardware connections of the network. The elements in Figure 3.2 are basically represented by the teleconferencing electronics element in Figure 3.1.

3.3 Performance Specifications

The teleconferencing network is designed to have a five year operational life. The system requirements state that the mean time between failure must exceed 3120 hours (calculation of the system MTBF is provided in section 6.3). The system is rated as having a power requirement of 92 to 132 VAC, 47 to 63 Hz, and 750 W maximum. The operating temperature of the system is intended to range from 10 to 40 ^{o}C. The operating environment should be such that the humidity in the room should range from 15 to 95 percent. The heat dissipation of the system is rated at 2900 BTUs. This consideration is handled through cooling fans integrated into the console cabinet delivered from the supplier factory.

3.4 Operating Conditions

The specified operating conditions of the system define the conditions under which the system is intended to operate. These conditions include environmental factors, transportation, handling, and storage. The system is intended to be operated in an environmentally controlled environment suitable for humans. An operating temperature range of 65-75 ^{o}F is recommended for system operation. The console cabinet is equipped with cooling fans to compensate for thermal heating of the electrical components.

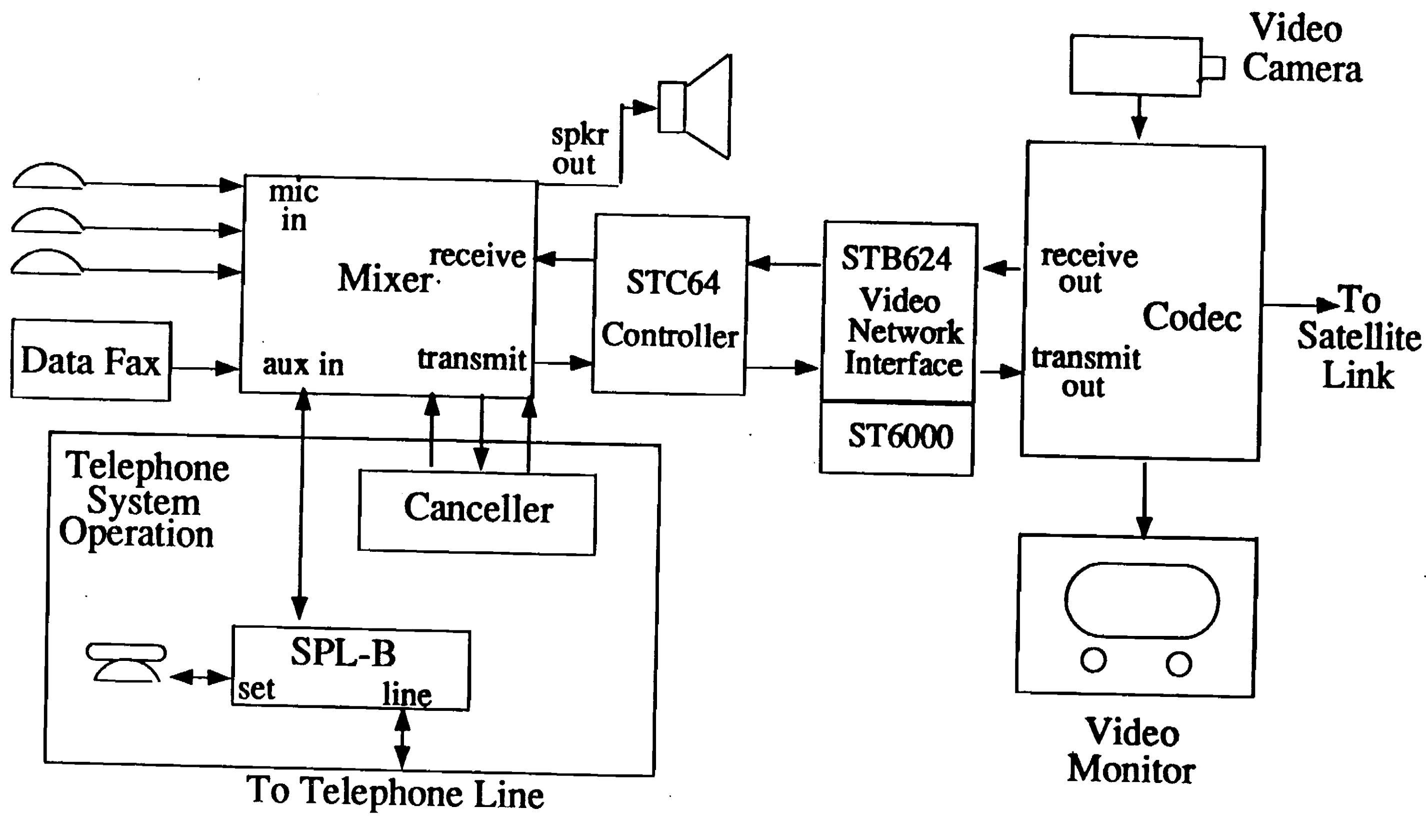

Figure 3.2 - Typical Connections for the Teleconferencing Network

Transportation and handling during installation is the responsibility of the network supplier. Any subsequent transportation and handling of the network components (i.e., moving the network to another room or the return of damaged components to the supplier) must be performed with extreme care to avoid additional damage due to humidity, vibration, and/or shock.

3.5 Security Techniques

Protecting the integrity of the data transmitted across the teleconferencing network is of utmost priority. The integrity of the data will be protected by encryption/decryption techniques using the Data Encryption Standard (DES) of the National Bureau of Standards.

3.6 System Initialization

The system is activated by using the conference system telephone in the usual manner to dial and establish a good telephone connection between the sites. Once the telephone connection is established, the network controller is activated to bring either the telephone line (for audio conferencing) or satellite link (for full video conferencing) into the conference. The video codec is used to interface the teleconferencing network with the satellite link and establish the video portion of the conference.

3.7 System T&E/Quality Assurance

All subsystem components are delivered from the various manufacturers to one of the supplier factory locations. Each teleconferencing network is assembled at the supplier factory location before it is shipped to the various sites. The network is tested through a full range of operational capabilities. The tests are to ensure component compatibility and operability. If a component is inoperable, it will be replaced before network distribution.

4.0 **Maintenance Concept**

The maintenance concept for the teleconferencing network will provide guidelines, from a support perspective, for aiding the design process. The key areas covered in this section are:

a. levels of maintenance support

b. maintenance responsibilities

c. repair policies and maintenance constraints

d. logistics impacts

e. maintenance effectiveness

f. maintenance environment.

Each of these topics will be discussed in detail to describe the basic goals and constraints for system maintenance.

4.1 **Level of Maintenance Support**

Maintenance for the teleconferencing network will be provided by the network supplier. All maintenance actions will be handled through the supplier factory sites which are located in the Washington, D.C. area, Texas, and California. Technicians at the supplier factory sites are responsible for providing service actions to failed electrical components, answering any technical questions, and providing technical training to the customer and contractor technicians. Supplier technicians will provide telephone support for maintenance actions from 8 AM to 5 PM EST. Supplier technicians will respond to maintenance actions as they are reported from the customer and contractor locations. Supplier technicians will only be dispatched from the supplier factory locations to the site which requires maintenance actions in the event of a catastrophic failure. A catastrophic failure would be defined as a loss of network functionality where the problem cannot be identified or corrected through phone support. When phone support is adequate to identify the problem with the network, replacement components will be shipped via overnight mail from the supplier factory locations to the effected site so as to keep the mean corrective maintenance time to under 24 hours.

4.2 Maintenance Responsibilities

Fault isolation down to the electrical subcomponent level will be carried out by customer/contractor party personnel which have been trained by supplier technicians. The electric subcomponents of the network are equipped with internal test circuitry to facilitate fault isolation. Once the source of the problem has been determined, the customer/contractor party technician will contact the supplier technicians, remove the damaged component, and ship it to the nearest supplier factory location for repair. A new component will be sent via overnight mail from the supplier factory location to the affected site. Mean corrective repair time during maintenance periods will not exceed 24 hours.

The network supplier is responsible for providing telephone support to the customer/contractor sites and delivering replacement components to the effected site(s) within 24 hours. The network supplier is also responsible for maintaining a proper stockpile of electrical components to ensure that a replacement component is available when needed. Figure 4.1 details the system maintenance responsibilities.

4.3 Repair Policies and Constraints

4.3.1 The Supplier as a Maintenance Liaison

The supplier is acting as a maintenance liaison on behalf of the customer/contractor party for all subsystem component repair. This service is provided so that the customer/contractor party will only have to deal with the supplier for maintenance issues. Otherwise, it would be the responsibility of the customer/contractor party to contact each of the subsystem component manufacturers for warranteed repair. Due to the fact that the supplier stockpiles additional subsystem components, the customer/contractor party is guaranteed that the mean corrective repair time will not exceed 24 hours.

4.3.2 Repair of the Transmission Medium

Repair of the transmission medium (i.e., the fiber optic phone and satellite networks) is strictly the responsibility of the customer/contractor party. The network supplier merely provides an interface to the various transmission mediums. A maintenance agreement between the customer/contractor party and the transmission medium suppliers will have to be made regarding repair of the networks.

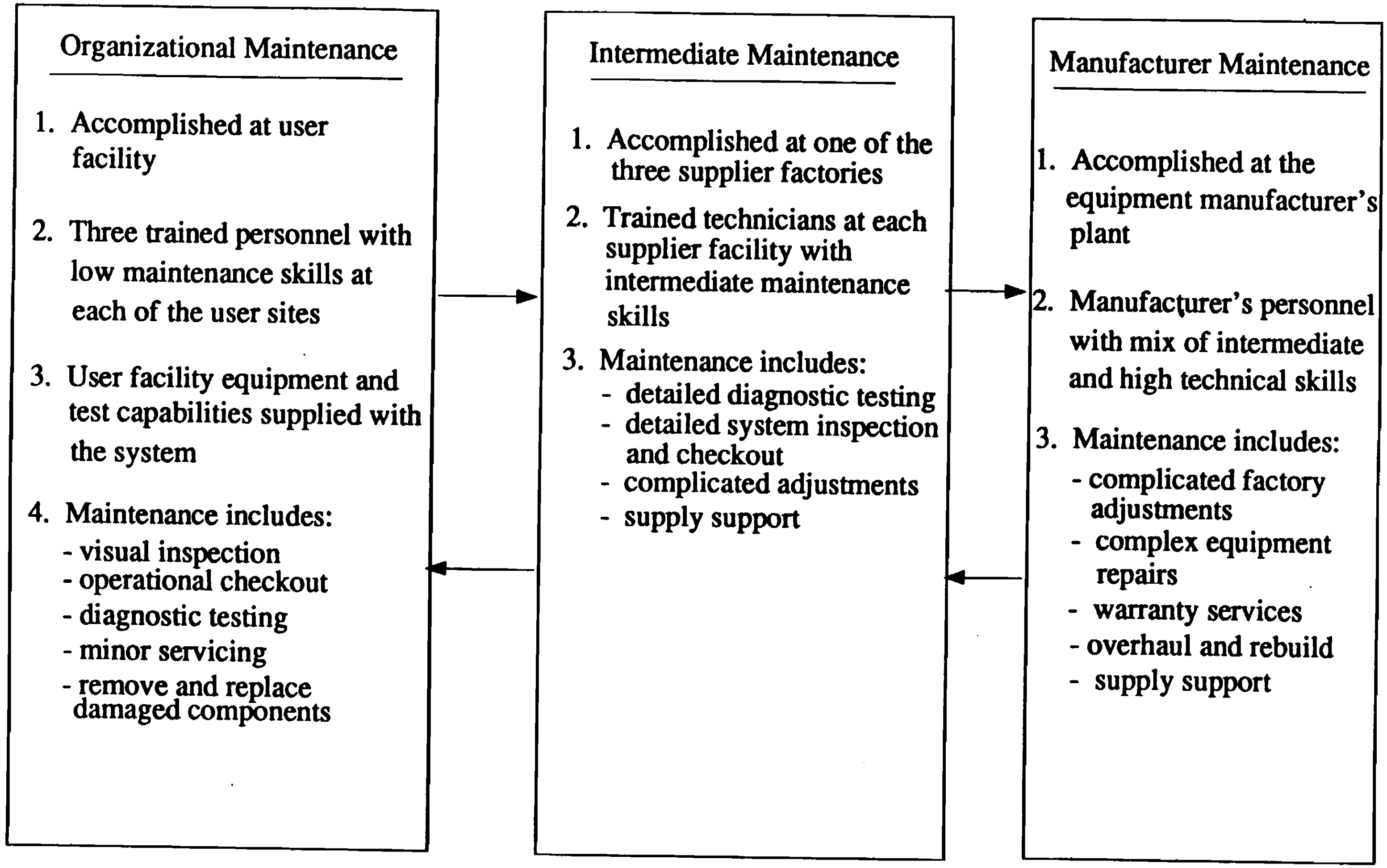

Figure 4.1 - System Maintenance Responsibilities Overview

4.4 Logistics Impacts

4.4.1 Maintenance and Logistics at the Supplier Factory Locations

Three supplier factory sites are located in the Washington, D.C. area, Texas, and California. Each site will contain at least the following functional items:

- one room for assembly of the console cabinets with associated networking electronics and peripherals
- one room dedicated to maintenance functions for all returned equipment
- one stock room and equipment room
- one administrative and clerical office.

Each supplier factory location will be staffed with three technicians highly trained on the network equipment. Each location will have the following set of diagnostic equipment for repairing failed components:

- oscilloscopes
- precision multimeters
- logic probes
- power supplies
- required set of hand tools.

4.4.2 Spare Components at the Supplier Factory Locations

Each supplier factory location will maintain at least five of each assembly (i.e., electrical subcomponents, monitors, data faxes, etc.) as spares. An even larger stock of components which are found to be unreliable in advanced design life stages will be kept in supply at each supplier factory location.

4.4.3 Maintenance and Logistics for the Customer and Contractor Sites

To provide local fault isolation, each customer site should have at least three personnel trained by the supplier in network equipment operation, basic troubleshooting, and the use of a precision multimeter.

4.5 Maintenance Effectiveness

The expected mean corrective maintenance time for each unit as a result of failure in the networking electronics, power modules, etc. will not exceed 24 hours. New components will be sent via overnight mail from the supplier factory location to the affected site as soon as the problem is reported. The mean time between failure (MTBF) for the teleconferencing network must exceed 3120 hours.

4.6 Maintenance Environment

System maintenance at the customer and contractor sites will occur where the teleconferencing network is located. It is the responsibility of the customer and the contractor to provide an environmentally controlled facility so as to not put the network under extreme conditions. The operating specifications of the network include a 10 to 40 $^{\circ}$C operating temperature, a

15 to 95 percent humidity range, and an absence of standing water.

Although maintenance at the supplier factory locations will be performed in an environmentally controlled facility, the replacement components will be transferred to the three sites via overnight mail. This method of transportation leaves the replacement components susceptible to a wide range of environmental conditions. The components have been designed to handle the vibration, shock, and thermal changes that accompany such a delivery.

4.7 Maintenance Functional Flow

Maintenance functions identified up to this point reflect consideration for the effectiveness and supportability factors specified at the system level as well as available logistic resources. Maintenance functional flow is prepared for corrective maintenance, transportation and handling factors, support equipment maintenance, etc. The maintenance functional flow diagram for the teleconferencing network is shown in Figure 4.2.

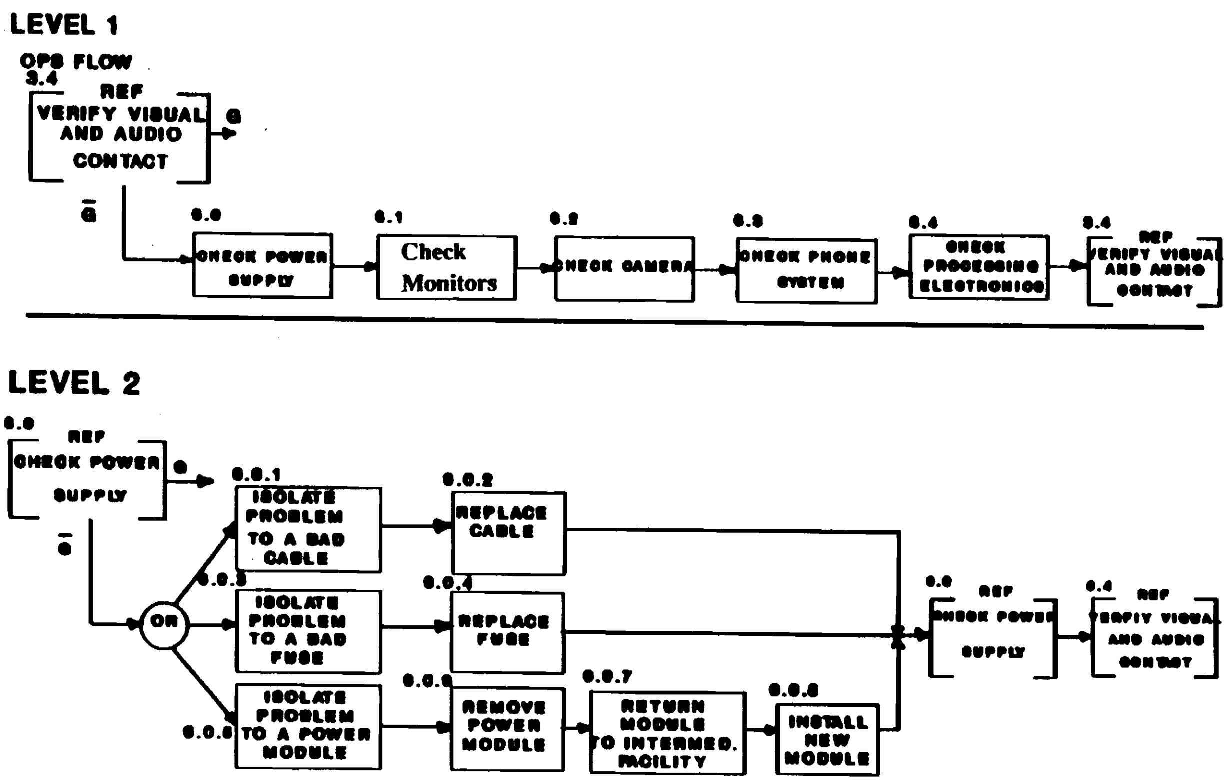

Figure 4.2 - Maintenance Functional Flow

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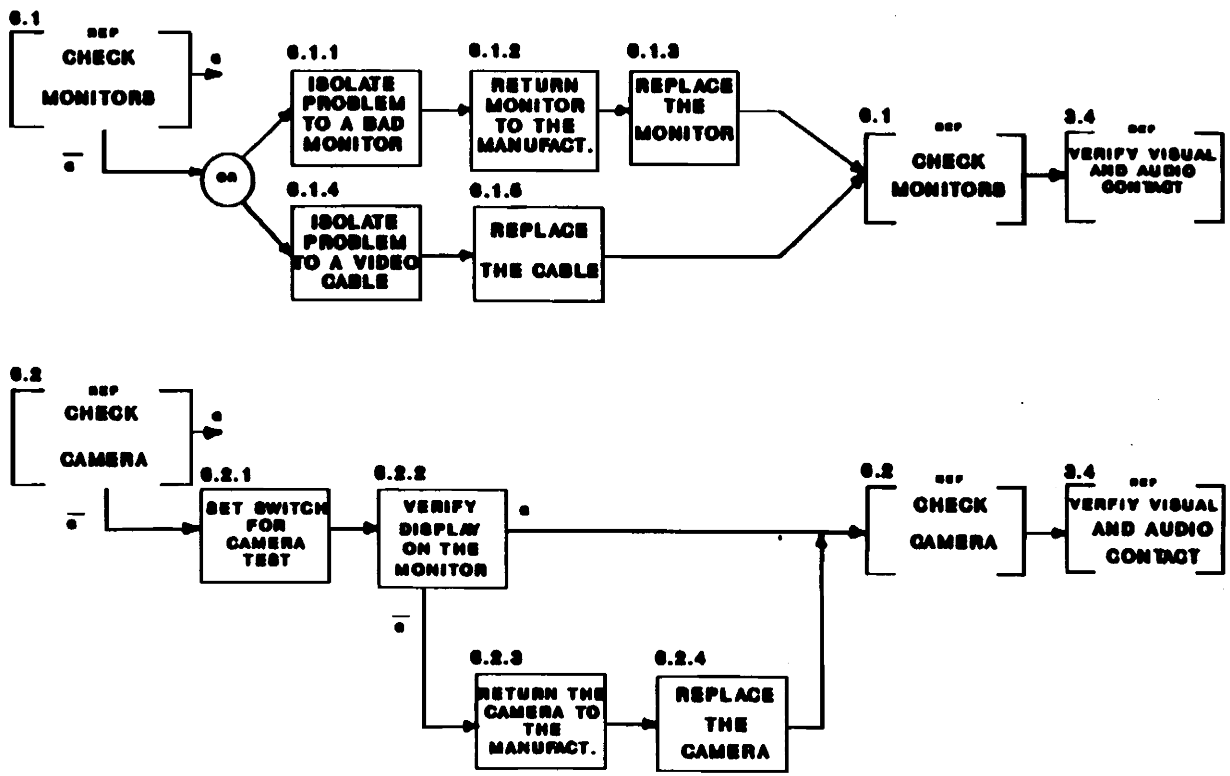

Figure 4.2 - Maintenance Functional Flow (cont.)

LEVEL 2 cont.

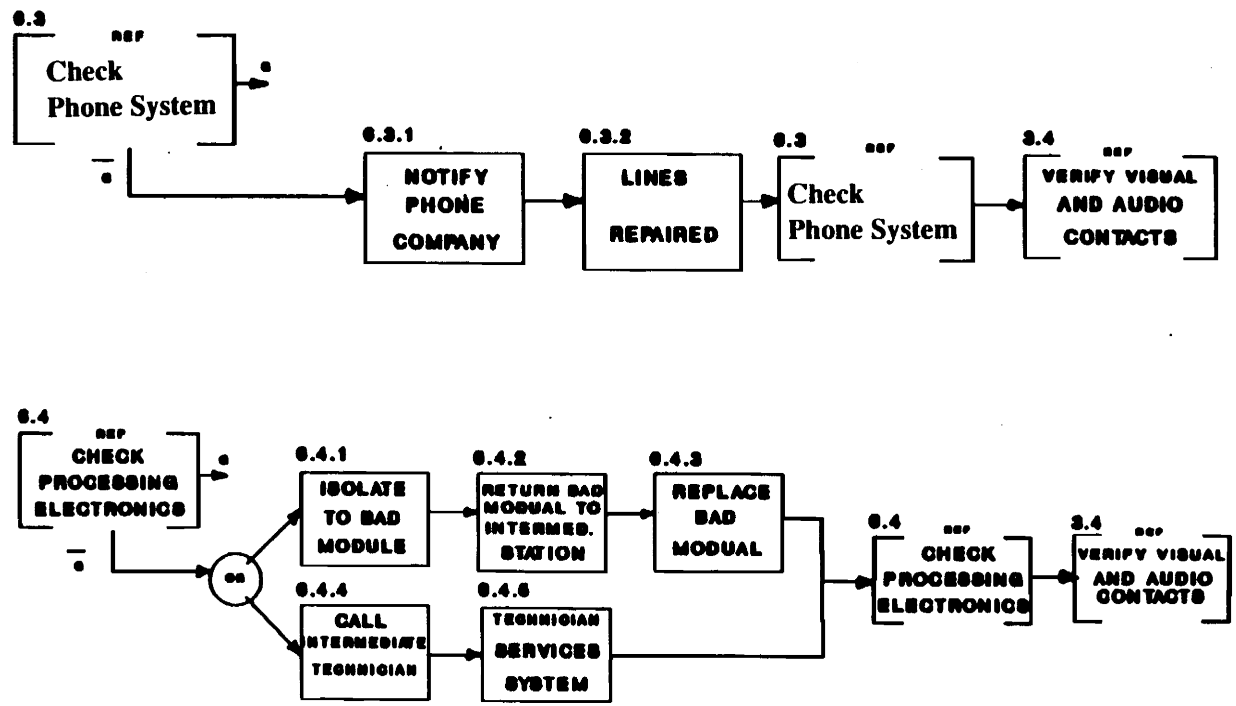

Figure 4.2 - Maintenance Functional Flow (cont.)

5.0 Human Factors Engineering

The human factors analysis constitutes a composite of individual program activities directed toward (1) the initial establishment of human factors requirements for system design, (2) the evaluation of system design to ensure that the optimum interface exists between human and other elements of the system, and (3) the assessment of personnel number and skill level requirements for a given system design configuration.

5.1 Human Factors Console Configuration Limits

In order to accommodate the three site configuration, two video monitors are included in every console cabinet; one monitor for each of the other two sites. This configuration allows for a meeting size of approximately 25 individuals. The network electronics allow for up to 200 microphones and 75 loudspeakers to be added to the controller. The only consideration that needs to be addressed here is the positioning of the participants of the meeting. It is recommended that the viewers remain at least 60 inches (5 feet) from the monitors to reduce eye strain and to allow for the best possible viewing angle. The optimum eye rotation angle has been found to be 15 degrees off center. Placing a person 60 inches from the monitors easily allows for the optimum eye rotation angle to be achieved with only the slightest of head rotation.[2]

5.2 Human Factors Criteria for Console Cabinet Development

Use of internal circuitry and slide out electronic component racks are incorporated into the console cabinet design to reduce the level of training and maintenance effort required for system operation.

5.3 Human Factors Criteria for Audio Considerations

Manufacturers specifications rate the maximum audio speech intensity of the network at 65 dB. Therefore, the network is capable of accommodating a dynamic range of speaker volumes up to 65 dB. Also, talkers need to be positioned 2 to 4 feet in front of their microphones to eliminate distortion and feedback. The system cannot be used by the deaf because there is no closed captioned capability.

5.4 Human Factor Criteria for Video Considerations

Figure 3.1 shows the recommended configuration of the teleconferencing network components. This configuration can accommodate a meeting of approximately 25 participants. The camera will be situated so as to place the fifteen participants located around the table into the viewing area. Anyone outside of that sphere will have to approach the table in order to be placed into the viewing area. The camera lens can be adjusted to reduce the viewing area but a table surrounded by fifteen participants is the approximate maximum. Although the teleconferencing network does provide additional graphics capability (i.e., graphical display on the monitor, interactive computer CRT display, etc.), only participant display capability is provided per customer/contractor requirements.

6.0 Reliability Analysis

Reliability is a characteristic inherent in design. Reliability can be defined as the probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified conditions. This definition stresses the elements of probability, satisfactory performance, time, and specified operating conditions. Each of these elements plays a significant role in determining the reliability of the teleconferencing network.

6.1 Breakdown of Reliability Parameters

6.1.1 Probabilistic Concerns

Probabilistic concerns deal with the expected number of failures which will occur at different points in time when there are supposedly identical items operating under similar conditions. This is typically measured with a quantitative expression representing a fraction specifying the number of times that one can expect a failure to occur in a specified period of time. The teleconferencing network is comprised of several subsystems each with a large number of components possessing their own set of reliability probabilities. To identify all of these probabilities is beyond the scope of this document. Instead, defining reliability will be approached from a system perspective. The emphasis will be placed on the performance of the entire network under a specified set of operating conditions as opposed to each subsystem or the components thereof.

6.1.2 **Definition of Satisfactory System Performance**

The phrase "satisfactory system performance" indicates the specific criteria that must be established which describe what is considered to be satisfactory. This will prove to be nothing more than an extension to the concepts developed in Section 3. In essence, satisfactory system performance is defined as the ability to successfully conduct a meeting amongst any combination of the three sites through the use of the teleconferencing network. A corollary involves the ability to perform the meeting 7 days a week, 24 hours a day. Anything short of this measure is deemed unsatisfactory system performance.

6.1.3 **Reliability as a Function of Time**

The time element is extremely important because it represents a measure against which the degree of system performance can be related. Of particular interest is the ability to predict the probability of the network surviving for a designated period of time. The network reliability is rated in terms of the Mean Time Between Failure (MTBF). The requirements state that the MTBF for the network must exceed 3120 hours. Reliability prediction techniques will be applied to determine if the proposed teleconferencing network actually meets the specified requirements for MTBF. Reliability of the fiber optic and satellite networks is the responsibility of the phone system contractor and the satellite link contractor, respectively.

6.2 Reliability Component Relationships

The teleconferencing network is basically a series relationship amongst the components. There are many single points of failure that may cause the system to experience unsatisfactory system performance. Single points of failure include the network controller, the microphones, the fiber optic phone network, the mixer, the power source, etc. Subsystem failure involving the video or fax capabilities would not necessarily indicate total system failure. If these subsystems fail, the audio portion of the meeting can continue without interruption. It is assumed that if the audio portion of the network becomes disfunctional, the network has achieved unsatisfactory system performance. The reliability block diagram for the teleconferencing network is shown in Figure 6.1.

6.3 Reliability Prediction Analysis

Reliability prediction is important in determining the overall system reliability. Prediction is accomplished at different times during the design phase of the system as is updated as better input data becomes available. The prediction analysis culminates in a determination of the MTBF value for the system.

Several basic prediction techniques can be applied to determine the system MTBF. The reliability prediction technique best suited for the teleconferencing network is an equipment parts count. Basically, an equipment list list is

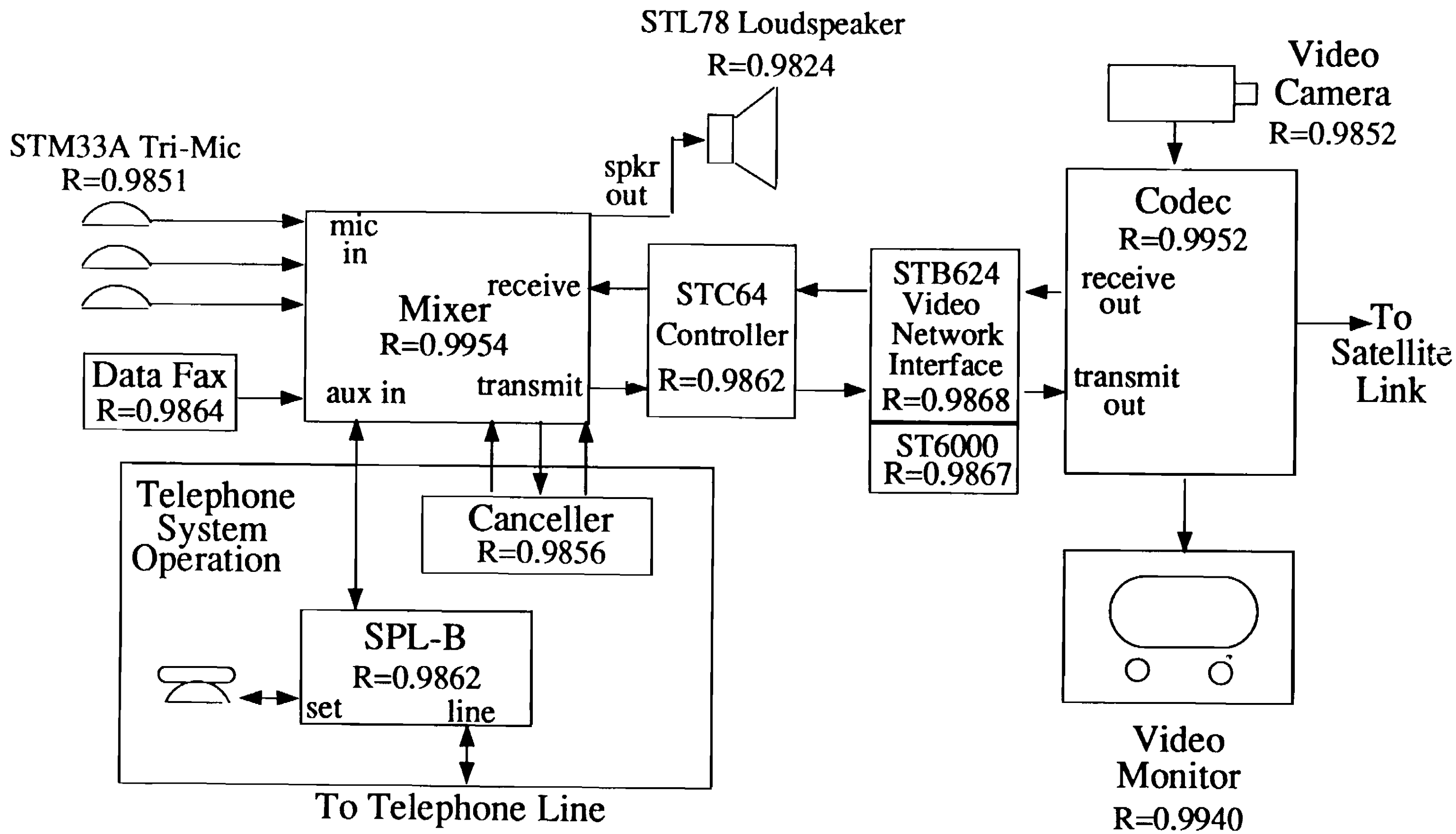

Figure 6.1 - Reliabilty Block Diagram for the Teleconferencing Network

generated and parts are classified in certain designated categories. Failure rates are assigned and combined to provide a predicted MTBF at the system level. These figures are based on operational experience and component manufacturer data. The reliability prediction analysis for the teleconferencing network is shown in Figure 6.2. The analysis is based on a five year useful life with 260 operational days in each year with two hours of operational use per day for a total of 2600 operational hours. The overall system MTBF is determined to be 3864 hours. Therefore, the network does exceed the MTBF requirement of 3120 hours.

The system availability is a reliability figure-of-merit which is based on the system MTBF. The availability of the teleconferencing network will be determined by calculating the inherent availability. Inherent availability is "the probability that the network, when used under stated conditions in an ideal support environment, will operate satisfactorily at any point in time as required." Inherent availability excludes preventive or scheduled maintenance actions, logistics delay time, and administrative delay time, and is expressed as

$$A_i = MTBF/(MTBF+M_{ct}) \qquad (6.1)$$

$$= 3864/(3864+24) = 0.9938.$$

Therefore, the inherent availability for the teleconferencing network is approximately 99.4 percent. Reworking Equation 6.1 for the initial MTBF

Component	Quantity	Failure rate (%/2600hrs)	(Failure rate) (quantity)
ST6000 Type 2A Console with Remote	1	4.322	4.322
STM33A Tri-Mic (3)	3	4.204	12.612
STL78 Loudspeaker	1	4.042	4.042
STB624 Videoconference Network Interface	1	4.326	4.326
A624PS Power Supply	1	4.304	4.304
STC64A-SPLB Controller	1	4.282	4.282
ST2AC Canceller	1	4.244	4.244
ST6008 Type 2 Mixer	1	5.386	5.386
Rembrandt Codec	1	5.348	5.348
Video Monitor	2	5.114	10.228
Video Camera	1	4.210	4.210
Data Fax	1	4.298	4.298

Total = 67.60 %

System Failure Rate = 67.60%/2600 hours

MTBF = 2600/0.676 = 3846 hours.

Figure 6.2 - Reliability Prediction Analysis[6]

requirement of 3120 hours yields an inherent availability of approximately 99.2 percent. Therefore, the network does exceed the requirements for inherent availability specified by the customer/contractor party.

Some interpretation is required to match the inherent availability quantity to the availability of the system. Section 2.2 indicates that the teleconferencing network must be available 24 hours per day, seven days a week even though actual usage of the network will be two hours per day, 260 days per year. The percentage of total time that the network must actually be available per year is calculated as follows:

$$\text{Total Percent Available} = ((2x260)/(24x365))x100 = 5.94\%. \qquad (6.2)$$

The inherent availability is a measure of the percent of the total operational time that the teleconferencing network will be available. Therefore, the network will be available 99.4 percent of the 520 operational hours per year per site.

6.4 Operational Reliability Assessment

Once the network is on-line, it is important to assess the operational reliability of the network. This assessment of system reliability in an operational environment is best accomplished through the establishment of an effective data collection, analysis, and system evaluation capability. The purpose of this endeavor is to provide ongoing data that can be analyzed to determine the true reliability of the system while performing its intended mission as well as providing historical data that can be used in the design of new systems.

The mechanism by which operational reliability assessment will be implemented is via maintenance event reports and failure analysis report. For every system failure encountered which requires a maintenance action by the supplier factory, a maintenance event report must be filed to the supplier. The maintenance event report will contain the operational status and condition of the network at the time of the failure, the maintenance requirements necessary to restore the system to full operational status, and the details associated with the actual cause of the failure and the effects on the other elements of the network. The supplier will submit a failure analysis report to discuss the specific failure mode and the corrective action. This data will be collected throughout the operational life of the network and analyzed to determine trends and inherent weaknesses in the system.

7.0 Life-Cycle Cost Analysis

Life-cycle cost refers to all costs associated with the teleconferencing network which are required to achieve the defined system objective. In general, life-cycle cost for the teleconferencing network includes the following four aspects:

1. **Research and development cost -** initial planning; feasibility studies; product research; engineering design; design documentation; testing and evaluation; and associated management functions.
2. **Production and construction cost -** industrial engineering and operational analysis; process development; production operations; quality control; and initial logistic support requirements.
3. **Operations and maintenance cost -** customer/contractor operations of the network at the three sites; product distribution; and sustaining logistic support throughout the system during the network life cycle.
4. **Retirement and disposal cost -** disposal of nonrepairable items throughout the life cycle; system/product retirement; material recycling; and applicable logistic support requirements.

Life-cycle cost is determined by identifying the applicable functions in each phase of these four aspects, costing these functions, applying the appropriate costs by function on a year-to-year schedule, and ultimately accumulating the costs for the entire span of the useful life. Life-cycle cost includes all network supplier and customer/contractor costs.

7.1 Guidelines, Constraints, and Objectives of the Analysis

The logical flow of the life-cycle cost analysis will include: 1) definition of the need for analysis, 2) establishment of the analysis approach, 3) selection of a model to facilitate the evaluation process, 4) generation of the appropriate data for each alternative being considered, 5) evaluation of the alternatives, and 6) recommendation of a proposed solution.

The objective of the life-cycle cost analysis is to show the customer/contractor party that the network supplier has incorporated cost emphasis in every aspect of the system. The analysis will show that the supplier has incorporated a design-to-cost concept as a system design parameter along with performance, effectiveness, reliability, maintainability, supportability, and manability.

The need for the life-cycle analysis is to determine the total cost of integrating the teleconferencing network into the customer/contractor three-site configuration. The life-cycle analysis will identify and break out all applicable costs relating to the integration of the teleconferencing network. This will allow the customer/contractor party to verify that the network supplier has established quantitative cost factors as requirements during network development.

The network supplier has recommended to the customer/contractor party to evaluate buy versus lease as a means of acquiring the network. The life-cycle analysis will be used to supply total system cost figures for the buy versus lease analysis. An engineering economic analysis will be performed to determine the present equivalent cost of the after-tax cash flow or the saving realized if the teleconferencing network is installed at the three sites. The specifications for the lease option will be outlined so that they can be compared to the purchase option. The alternative (either buying or leasing the network) which provides the highest present worth of the after-tax cash flow or the greatest savings realized will be recommended as the best alternative.

7.2 Development of the Cost Breakdown Structure (CBS)

The supplier defines a cost breakdown structure for the development and installation of the teleconferencing network. The CBS links objectives and activities with resources, and constitutes a logical subdivision of cost by major elements of the system. The CBS provides a mechanism for initial cost allocation, cost categorization, and cost monitoring and control. The CBS for the teleconferencing network is shown in Figure 7.1.

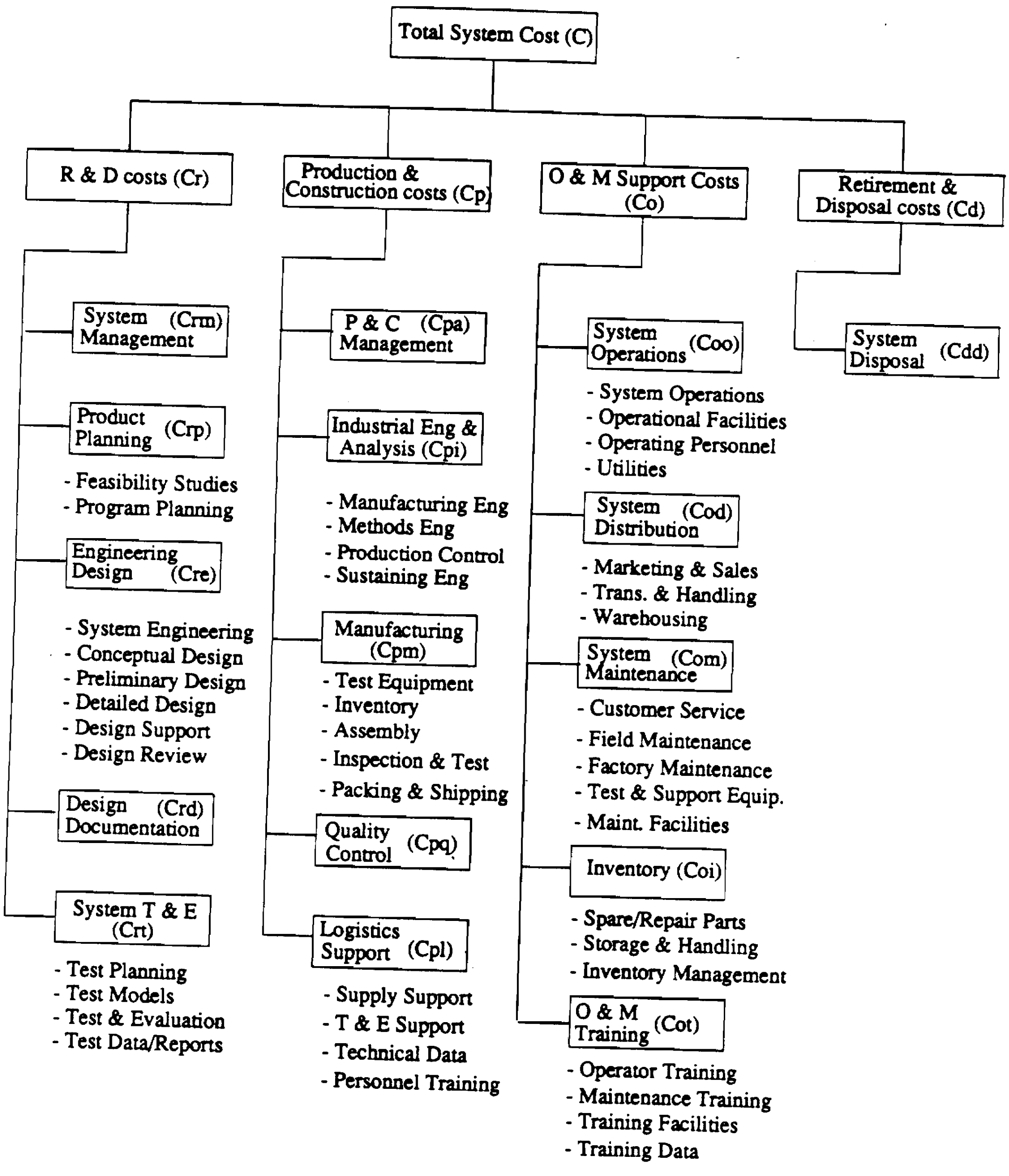

Figure 7.1 - Cost Breakdown Structure[1]

The CBS is divided into four major components: 1) research and development costs, 2) production and construction costs, 3) operations and maintenance costs, and 4) retirement and disposal costs. The CBS for the teleconferencing network is such that heavy emphasis is placed on research and development and operations and maintenance while little emphasis is placed on production and construction and retirement and disposal. The driver for these criteria is total system cost. The teleconferencing network is designed to maximize performance while providing the greatest possible savings to the customer/contractor party in Travel and Living expenses.

7.3 Life-Cycle Costing of Major System Elements

The following section will map the costing of the major system elements to the operational requirements, conceptual design, maintenance concept, reliability analysis, and the cost breakdown structure.

7.3.1 Research and Development Costs

Research and development costs are incurred through ongoing research into teleconferencing networking and electrical component technology. Costs related to research and development are also generated from initial program planning, the accomplishment of feasibility studies, the development of operational requirements and the maintenance concept, the preparation of top-level specifications, and general management activities. The components chosen for the network are state of the art electrical components that offer the very latest in teleconferencing technology. This is an ongoing process that will allow the supplier to offer the very best technology available.

Research and development costs are only generated during the first year of the project (refer to Figure 2.2). Costs are determined by a combination of customer/contractor cost projections and historical data submitted by the supplier. Direct costs, indirect costs, inflation factors for both labor and material, general and administrative expenses, and projected network supplier profits are included. A summary of the generated research and development costs are shown in Figure 7.2.

7.3.2 Production and Construction Costs

Production and construction costs are kept to a minimum because the supplier does not manufacture any of the electrical components. The manufacturing of the electrical components is subcontracted out to various companies which manufacture such equipment. (Section 3.2 contains a complete list of the electrical subcomponents of the teleconferencing network and their manufacturers.) The only expenses incurred in this area involve the networking of the electrical components when they are received from the manufacturer. Expenses incurred in this area are due to testing and evaluation of the components once they are assembled.

Program Activity	Cost by Program Year ($)	
	Year 1	Total
A. Customer costs		
1. System Management	35,000	35,000
2. Product planning	14,780	14,780
B. Supplier costs		
1. System management	35,000	35,000
2. Product planning	28,794	28,794
3. Engineering design	26,851	26,851
4. Design documentation	8,632	8,632
5. System T&E	9,466	9,466
TOTAL	158,523	158,523

Figure 7.2 - Research and Development Cost Summary

A description of the production and construction costs are as follows:

1. **System or product management** - addresses any ongoing management issues generated during the production phase.
2. **Industrial engineering and operations analysis cost** - addresses activities related to production planning and the methods necessary to assemble the teleconferencing network once the electrical components are acquired.
3. **Manufacturing costs** - nonrecurring costs associated with the acquisition of the electrical subcomponents and initial assembly of the teleconferencing network. Figure 7.3 has a complete breakdown of all the electrical subcomponents and their cost. The total cost shown in Figure 7.3 is for only one of the teleconferencing networks. A total of three networks are required for the customer/ contractor configuration. Therefore, the total cost of the electrical subcomponents for the three sites is approximately $100,000.
4. **Quality control costs** - typically this category addresses issues related to quality assurance. These costs are non-applicable to this teleconferencing network because quality assurance is the responsibility of the electrical component subcontractor. These costs have already been accounted for in the price of the electrical subcomponent.
5. **Supply support costs** - addresses the costs associated with the

Component	Manufacturer	Price ($)
ST6000 Type 2A Console with Remote	Shure	8200
A6000A Console Cabinet	Shure	250
STM33A Tri-Mic (3)	Shure	1980
STL78 Loudspeaker	Shure	1650
STB624 Videoconference Network Interface	Shure	2750
A624PS Power Supply	Shure	140
STC64A-SPLB Controller	Shure	3430
ST2AC Canceller	Shure	1640
ST6008 Type 2 Mixer	Shure	4000
Rembrandt Codec	CLI	4000
Video Monitor (2)	Sony	700
Video Camera	Toshiba	1000
Data Fax	Panasonic	3500
Total		33240

Figure 7.3 - Electrical Subsystem Component Analysis

acquisition of major electrical subcomponents to support the maintenance effort. These costs are incurred from the stocking of additional inventory of electrical subcomponents.

6. **Testing and evaluation support costs -** addresses the costs associated with testing the assembled teleconferencing network before distribution to a customer site.
7. **Technical data costs -** addresses costs associated with the preparation and publication of system installation and test instructions, operating procedures, and maintenance procedures.
8. **Personnel training costs -** addresses costs associated with the training of supplier and customer personnel on basic system operation and maintenance. The cost of training is approximately $1,000 per technician. Section 4.0 indicates that there will be three technicians at each of the supplier, customer, and contractor sites.

As was the case with the research and development costs, production and construction costs are only incurred during the first year of the life cycle. Costs are determined by customer/contractor cost projections and historical data submitted by the network supplier. A summary of the production and construction costs are shown in Figure 7.4.

Program Activity	Cost by Program Year ($)	
	Year 1	Total
A. Customer Costs		
1. System Management	35,000	35,000
B. Supplier Costs		
1. Industrial engineering and operating analysis	9,500	9,500
2. Manufacturing	100,000	100,000
3. Quality Control	-	-
4. Initial Logistics Support		
a. Supply support	5,000	5,000
b. T & E support	5,000	5,000
c. Technical data	5,100	5,100
d. Personnel training	18,000	18,000
Total	177,600	177,600

Figure 7.4 - Production and Construction Cost Summary

7.3.3 Operations and Maintenance Costs

Operation and support cost includes those individual costs associated with system operation, distribution, and logistic support. Operations and maintenance costs are incurred through operational support and training. A large amount of expense and man effort is generated at each supplier factory location to support the operational demands of the customer. The expense and effort culminates from the 24-hour turnaround on deficient components, the amount of training offered at the customer locations, and the on-line telephone support. A brief synopsis of the relevant costs for operations and maintenance are included below.

1. **Operating personnel cost** - addresses the costs associated with operating the teleconferencing network. This is primarily a customer cost because the customer is responsible for the operation of the network. No operating personnel costs are generated during the first year of the life cycle (refer to Figure 2.2). Operating personnel cost (OPC) is determined from Equation 7.1 as

   OPC = (cost of operator labor)x(quantity of operators)
   x(quantity of systems)x(hours of system operation) (7.1)

   Estimates for operator labor costs are $10.25 per hour. Section 4.0 indicates that there will be three technicians per site and that the network will be operational two hours per day, 260 days per year.

The estimates allow for a ten percent wage increase each year for operator performance.

2. **System distribution cost** - addresses all costs associated with the initial transportation and installation of the teleconferencing network from the supplier factory locations to the three customer sites. (Operational deployment of the network is outlined in detail in Section 2.3.) System distribution cost is calculated as the sum of the cost of transportation, the cost of packing, and the cost of system installation. Estimates of these costs are based on moving 48 electrical components a total of 610 miles between the supplier factory locations and the customer/contractor sies. Per diem rates for travel and living for the supplier technicians during network installation periods is set at $100 per night. The pay scale for the supplier technicians is estimated at $10.25 per hour for an eight hour work day during network installation periods. Estimates of travel distances and packaging costs are identified under transportation and handling costs.

3. **Maintenance cost** - addresses the personnel activity costs associated with the performance of maintenance actions on the teleconferencing network. Specifically, this includes the operations of isolating the problem, contacting the supplier factory for a new component, removing the faulty component from the network,

sending the faulty component to the supplier factory, replacing the component once received from the supplier, and documenting the problem. The frequency of such maintenance actions, and the costs associated with these actions, are based on the reliability prediction analysis presented in Section 6.0. Maintenance costs will decrease during the useful life of the network as a direct result of learning. After providing several years of operational support, the supplier technicians will have gained enough experience at network maintenance to reduce overall maintenance costs by 25 percent per year.

4. **Transportation and handling cost -** addresses costs associated with moving electrical components either from one supplier factory location to another or from a supplier factory location to a customer or contractor site. Electrical components may have to be moved from one supplier location to another for inventory and spare purposes. Any movement in electrical equipment from the supplier location to a customer or contractor site would be the direct result of a maintenance action. (Section 4.2 outlines, in detail, the maintenance responsibilities of the network supplier.) Transportation and handling costs are determined from the Equation 7.2 as

$$THC = [(\text{cost of transportation}) + (\text{cost of packing})] \times (\text{number of one-way shipments}) \quad (7.2)$$

Transportation and handling costs are directly dependent upon the reliability of the network. In order to determine the transportation and handling costs, an estimate as to the number of maintenance actions required must be provided. The number of maintenance actions required (MAR), assuming that the network is in the steady state and that all failures are independent, is calculated from Equation 7.3 as

$$\begin{aligned} MAR &= (1/MTBF)x(\#\text{ of operation hours})x(\#\text{ of sites}) \\ &= (1/3864)x(2600)x(3) = 2.019. \end{aligned} \quad (7.3)$$

Supplier estimates for similar networks indicate that under extreme conditions as many as four maintenance actions have been required over a five-year useful life. For planning and calculation purposes, the worst case scenario of four required maintenance actions over the useful life will be used as an estimate.

Representative one-way mileage figures between the supplier factory locations and the customer/contractor sites are as follows:

Washington, D.C. to Washington, D.C. = 25 miles

Washington, D.C. to Philadelphia, PA = 180 miles

California to Los Angeles,CA = 100 miles.

The mileage charge to distribute a replacement part by van from the supplier factory locations to the customer/contractor sites is 27 cents per mile. The mileage charges are assessed on a round-trip basis. The transportation cost to deliver a replacement part via overnight mail is $50 per component. The packing cost is estimated at $25 per component. Supplier estimates of transportation and handling costs due to maintenance actions were based on the information provided above.

5. **Maintenance facilities cost** - addresses occupancy, utilities and facility maintenance costs of the supplier factory locations. Section 4.4.1 discusses the maintenance logistics at the supplier factory locations.

6. **Supply support cost** - addresses costs associated with supplying spare electrical components for the teleconferencing network to the three supplier factory locations. Supply support costs are a result of requiring spare components to accomplish a 24-hour turnaround in the event of a maintenance action. Supply support logistics at the supplier factory locations are defined in Section 4.4.2 and are depicted in the intermediate maintenance section of Figure 4.1.

7. **Maintenance personnel training** - addresses costs associated with training supplier and customer operators and technicians on system

operation and maintenance. The network supplier provides training on network operations and maintenance. The details on network training are offered in Section 2.3. Initially, when the network is first introduced, there is a requirement to train operators and maintenance personnel. The cost for this initial training is included under Production and Construction costs. These costs for training relate to personnel attrition and the addition of new operators and maintenance technicians.

Training costs will be higher during the first year of the system life cycle to compensate for customer/contractor technician training during network integration. Training costs will also decrease over the system useful life as a result of technician familiarity with the teleconferencing network.

8. **Testing and evaluation equipment** - addresses costs associated with the acquisition of equipment and tools necessary to perform diagnostic testing and maintenance on the teleconferencing network both at the supplier factory and the customer site. The type of tools and equipment necessary to provide adequate network maintenance are described in Section 4.4.

The bulk of the operations and maintenance costs are incurred during years two through five of the life cycle. All aspects of operations and maintenance costs can be mapped directly back to the information provided in the operational requirements, conceptual design, maintenance concept, and reliability analysis sections. Consideration has been provided for rises in labor costs, overhead costs, and material costs due to general inflation. The only costs generated for this category in year one is the cost of the initial transportation and installation of the teleconferencing network as well as technician training at the three customer sites. (Details on operational deployment of the teleconferencing network are described in Section 2.3.) A summary of the operations and maintenance costs are shown in Figure 7.5.

7.3.4 Retirement and Disposal Costs

Retirement and disposal costs for the teleconferencing network are negligible. When the electrical components reach the end of their operational life, they are discarded. Whether the system is leased or purchased, the customer receives no credit for returned components.

7.4 Summary

The cost breakdown for the five-year useful life of the teleconferencing network is shown in Figure 7.6. The effective cost for the network over the span of the useful life is calculated as $781,345. The cost allocation by program year for the network is given in Figure 7.7. This data will be used as input to the buy versus lease analysis, the break-even analysis, and the sensitivity analysis.

Program Activity	Cost by Program Year ($)					
	Year 1	Year 2	Year 3	Year 4	Year 5	Total
A. Customer Costs						
1. Operating personnel	12,000	52,767	58,043	63,848	70,232	256,890
B. Supplier Costs						
1. Distribution	12,830	-	-	-	-	12,830
2. Maintenance actions	1,333	4,000	3,000	2,250	1,687	12,270
3. Transportation & handling	750	1,500	1,500	1,500	3,000	8,250
4. Maintenance facilities	5,000	20,000	22,500	25,000	27,500	100,000
5. Supply support	1,250	4,500	4,000	3,500	5,000	18,250
6. Maintenance personnel training	9,000	6,000	5,000	4,000	3,000	27,000
7. Testing & evaluation equipment	450	2,000	2,200	2,420	2,662	9,732
Total	42,613	90,767	96,243	102,518	113,081	445,222

Figure 7.5 - Operations and Maintenance Cost Summary

Program Activity	Cost ($)	% of Total
1. Research & Development Costs		
a. System Management	70,000	8.96
b. Product Planning	43,574	5.58
c. Engineering Design	26,851	3.44
d. Design Data	8,632	1.10
e. System T&E	9,466	1.21
Subtotal	158,523	20.29
2. Production & Construction Costs		
a. System Management	35,000	4.48
b. Industrial Engineering and Operating Analysis	9,500	1.22
c. Manufacturing	100,000	12.80
d. Initial Logistics Support		
1. Supply Support	5,000	0.64
2. T&E Support	5,000	0.64
3. Technical Data	5,100	0.65
4. Personnel Training	18,000	2.30
Subtotal	177,600	22.73
3. Operations & Maintenance Costs		
a. Operating Personnel	256,890	32.88
b. Distribution	12,830	1.64
c. Maintenance Actions	12,270	1.57
d. Transportation & Handling	8,250	1.06
e. Maintenance Facilities	100,000	12.80
f. Supply Support	18,250	2.34
g. Maintenance Personnel Training	27,000	3.46
h. T&E Equipment	9,732	1.25
Subtotal	445,222	56.98
Grand Total	781,345	100.00

Figure 7.6 - Total Life-Cycle Cost Breakdown

Program Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Total
1. Research & Development Costs	158,523	-	-	-	-	158,523
2. Production & Construction Costs	177,600	-	-	-	-	177,600
3. Operations & Maintenance Costs	42,613	90,767	96,243	102,518	113,081	445,222
Total	378,733	90,767	96,243	102,518	113,081	781,345
% of Total	48.47	11.62	12.32	13.12	14.47	100.00

Figure 7.7 - Life-Cycle Cost Allocation By Year

8.0 Buy Versus Lease Analysis

The buy versus lease analysis will determine the present equivalent cost of the after-tax cash flows for both network acquisition alternatives. The alternative which offers the highest benefit or savings to the customer/contractor party will be recommended. The input to the analysis will be the data generated in the life-cycle cost analysis presented in Section 7.0.

8.1 Determination of the Pre-Tax and After-Tax Cash Flows for Purchasing the Network

From the information provided in Figure 7.7, based on an interest rate of 10 percent and applying present cost factors, the present equivalent cost of the pre-tax cash flow for the teleconferencing network is calculated as

$$P = \$378{,}733\underset{(P/F,10,1)}{(0.9091)} + \$90{,}767\underset{(P/F,10,2)}{(0.8265)} + \$96{,}243\underset{(P/F,10,3)}{(0.7513)} + \$102{,}518\underset{(P/F,10,4)}{(0.6830)} + \$113{,}081\underset{(P/F,10,5)}{(0.6209)} = \$631{,}936 \tag{8.1}$$

Therefore, the present equivalent cost of the pre-tax cash flow of the teleconferencing network is approximately $632,000.

The pre-tax analysis of the present equivalent cost cash flow does not yield a true representation of the savings that the teleconferencing network can offer. Many other factors must be considered to determine the true system savings. An after tax cash flow analysis must be performed to account for such contributing factors as reduction in operating expenses, income taxes, and interest.

8.2 Effect of Depreciation on System Cost

The effect of depreciation on the teleconferencing network needs to be addressed in the lease versus buy analysis. The cash flow analysis performed in Section 8.1 will be reworked taking depreciation into account. Depreciation represents any reduction in value of the teleconferencing network through wear. Depreciation allowances are determined through the purchase price, the salvage value, and the useful life of the network. The purchase price of the network is set at \$336,123. This figure is a culmination of the research and development costs and the production and construction costs shown in Figure 7.6. The straight line depreciation method will be used to determine the depreciation allowance at the end of each year. The equation used to determine the straight line depreciation allowance is

$$D = (P - F)/n = (\$336{,}123 - 0)/5 = \$67{,}225 \qquad (8.2)$$

where P is the purchase price, F is the salvage value, and n is the useful life of the network.

The after tax cash flow analysis for purchasing the teleconferencing network with depreciation taken into account is shown in Figure 8.1. The analysis assumes a tax rate of 33 percent and a reduction in operating expenses of \$500,000 per year. All costs associated with operations and maintenace will

A End Of Year	B Reduced Expenses ($)	C Depreciation ($)	D = B - C Taxable Income ($)	E = D x .33 Tax ($)	F = B - E After Tax Cash Flow ($)
0	-336,123				-336,123
1	82,387	16,806	65,581	21,642	60,745
2	409,233	67,225	342,008	112,863	296,370
3	403,757	67,225	336,532	111,056	292,701
4	397,482	67,225	330,257	108,985	288,497
5	386,919	67,225	319,694	105,499	281,420

Figure 8.1 - After-Tax Cost Calculations With Depreciation

be deducted from the reduction in operating expenses estimate on a yearly basis. The operations and maintenance costs for the network are shown in Figure 7.5. An assumption is made that the network will be on-line during the ninth month of the first year of the life cycle. Therefore, the depreciation allowance and the reduction in operating expenses have been prorated by 75 percent during the first year. Based on an interest rate of 10 percent with a 33 percent tax rate and applying present cost factors, the present equivalent cost of the after-tax cash flow for the network is calculated as

$$\begin{aligned} P &= -\$336{,}123 + (\$60{,}745)\overset{(P/F,10,1)}{(0.9091)} + (\$296{,}370)\overset{(P/F,10,2)}{(0.8265)} + \\ &\quad (\$292{,}701)\overset{(P/F,10,3)}{(0.7513)} + (\$288{,}497)\overset{(P/F,10,4)}{(0.6830)} + (\$281{,}420)\overset{(P/F,10,5)}{(0.6209)} \\ &= \$555{,}733. \end{aligned} \tag{8.3}$$

Therefore, the present equivalent cost of the after-tax cash flow or savings that the customer/contractor party can expect by purchasing and installing the teleconferencing network at the three sites taking depreciation into account is approximately \$555,740.

When the network is leased, a schedule of payments over time is agreed on. Lease charges, being expenses, apply directly against taxable income during the year in which they occur. Thus, each dollar spent on a leased item can be discounted by the amount of the applicable tax rate (33 percent, in this case). Another benefit of leasing is that less capital is necessary up-front to acquire the network.

When a network is purchased, depreciation expense is deducted each year from taxable income during the estimated useful life of the network. A benefit is realized if the system is purchased because the depreciation expense incurred offsets net income thus lowering the effective tax paid.

8.3 Evaluation of Lease Options

The price to lease the system, including installation, for all three sites during year t is given as

$$\text{Lease Price} = \$150{,}000 - \$1000(t - 1) \tag{8.4}$$

during year t. There is a stipulation that the lease must run for at least two years. There are no annual maintenance costs incurred whether the system is bought or leased. Maintenance charges have been calculated into the buying and/or leasing price.

The after tax cash flow analysis for leasing the teleconferencing network is shown in Figure 8.2. The analysis assumes a tax rate of 33 percent and a reduction in operating expenses of $500,000 per year (refer to Section 1.0). The operations and maintenance costs shown in Figure 7.5 will be deducted from the reduction in operating expenses estimate on a yearly basis. An assumption is made that the network will be on-line during the ninth month

A End Of Year	B Reduced Expenses ($)	C Lease Cost ($)	D = B - C Taxable Income ($)	E = D x .33 Tax ($)	F = B - C - E After Tax Cash Flow ($)
0					
1	82,387	37,500	49,887	14,813	30,074
2	409,233	149,000	260,233	85,877	174,356
3	403,757	148,000	255,757	84,400	171,357
4	397,482	147,000	250,482	82,659	167,823
5	386,919	146,000	240,919	79,503	161,416

Figure 8.2 - After-Tax Lease Cost Calculations

of the first year of the life cycle. Therefore, the reduction in operating expenses and the lease cost have been prorated by 75 percent during the first year. Based on an interest rate of 10 percent with a 33 percent tax rate and applying present worth factors, the present equivalent cost of the after-tax cash flow for the network is calculated as

$$
\begin{aligned}
P &= (\$30{,}075)\overset{(P/F,10,1)}{(0.9091)} + (\$174{,}356)\overset{(P/F,10,2)}{(0.8265)} + (\$171{,}357)\overset{(P/F,10,3)}{(0.7513)} + \\
&\quad (\$167{,}823)\overset{(P/F,10,4)}{(0.6830)} + (\$161{,}416)\overset{(P/F,10,5)}{(0.6209)} \\
&= \$515{,}033. \qquad (8.5)
\end{aligned}
$$

Therefore, the present equivalent cost of the after-tax cash flow or savings that the customer/contractor party can expect by leasing and installing the teleconferencing network at the three sites is approximately $515,000.

9.0 **Break-Even Analysis**

Before a final decision can be made as to which alternative to select as a means of acquiring the network (buy or lease), a break-even analysis should be performed to determine the point in time where one acquisition alternative becomes more economical than the other. The break-even analysis plots present equivalent cost, or annual savings, for both network acquisition alternatives over the network useful life. The break-even analysis for the buy and lease options is shown in Figure 9.1.

The present equivalent cost of the after-tax cash flow calculations presented in Sections 8.2 and 8.3 show that purchasing the network would yield approximately an $40,700 savings over leasing. The break-even analysis indicates that the crossover point is not reached until approximately four years and five and one half months. This point is quite late in the networks estimated useful life of five years. Therefore, if the network expired at any time prior to four years and five and one half months after the start of the useful life, leasing the network would be a better means of acquisition.

However, extending the buy and lease present equivalent cost of the after-tax cash flow analysis into the sixth year indicate that purchasing the network would save the customer/contractor party significantly more money than leasing. Therefore, if the network outlasts the estimated useful life of

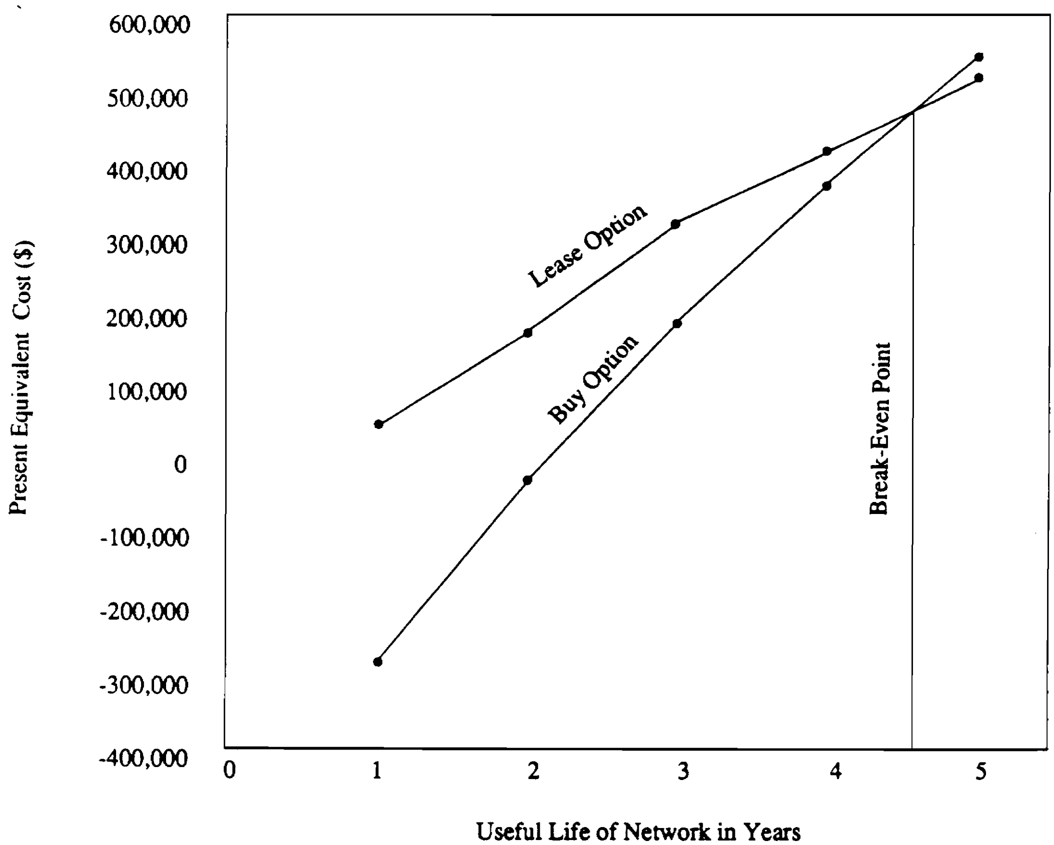

Figure 9.1 - Break-Even Analysis

five years, purchasing the network is a more attractive means of acquisition than leasing.

10.0 Sensitivity Analysis

A sensitivity analysis is performed to determine the effects of input parameter variations on the network cost. The sensitivity analysis will address any possible inaccuracies associated with the input data as well as such factors as questionable prediction techniques. Two input parameters have been considered in reference to the teleconferencing network which may cause a decision reversal: 1) the estimated reduction in operating expenses as a result of decreased T&L expenses, and 2) the impact of the interest rate.

10.1 Effect of Reduced Operating Costs on System Cost

An overall reduction in operating costs of $500,000 per year is expected as a result of reduced T&L expenses. That amounts to a one-third reduction in the yearly T&L expenses estimate of 1.5 million dollars. This estimate makes purchasing the teleconferencing network look quite attractive. Suppose the estimate is incorrect. Suppose that after three years, historical data has revealed that installing the teleconferencing network has only reduced T&L expenses by a quarter instead of the estimated third. If this is the case, purchasing the teleconferencing network (instead of leasing) may prove to be a financial disaster. The customer/contractor engineering team in charge of acquiring the network must be very careful when estimating the reduction in operating expenses.

Reworking the analyses provided in Sections 8.2 and 8.3 for a range of estimated percentage reduction in operating expenses indicates that diminishing returns can be expected at approximately 16 percent for purchasing the network and 21.5 percent for leasing. In either situation, acquisition of the network at conditions below these percentage reduction estimates will result in operating at a loss. When the estimated percentage reduction in operating expenses is below these figures, the amount of money saved by acquiring the network is not large enough to overcome the operations and maintenace costs, the depreciation allowance, and the lease cost.

10.2 Effect of the Interest Rate on System Cost

The rate at which money can be borrowed to acquire the teleconferencing network can have an enormous impact on the total cost. What appears to be the best acquisition method at one interest rate would be the incorrect choice at another. A sensitivity analysis is performed to determine the impact of varying the percentage reduction in operating expenses and the interest rate over a range of values. The analysis will determine the optimum interest rate at which the best acquisition method (buy or lease) can be selected for any given situation.

The analysis involves reworking the calculations performed in Sections 8.2 and 8.3. The present equivalent cost of the after-tax cash flow is calculated at a set percentage reduction in operating expenses estimate while the interest rate is varied. The interest rate where the present equivalent cost of the after-tax cash flow for purchasing and leasing the network is equal is recorded. This calculation is repeated incrementing the percentage reduction in operating expenses estimate over a range of twenty-five percent to fifty percent. The interest rate is incremented over a range of ten percent to twenty percent. The applicable tax rate is held constant at 33 percent.

Based on the data presented above, the optimum interest rate is calculated as approximately 14.25 percent. Regardless of the percentage reduction in operating expenses estimate, the two acquisition alternatives were approximately equal at an interest rate of 14.25 percent. When the interest rate was below 14.25 percent, purchasing the network was the better acquisition alternative. When the interest rate was greater than 14.25 percent, leasing the network was the better acquisition alternative.

The graphical representation of the relationship between the percentage reduction in operating expenses estimate and the interest rate is shown in Figure 10.1. Figure 10.1 will allow the customer/contractor party to make a better assessment as to which acquisition method to pursue based on their estimates.

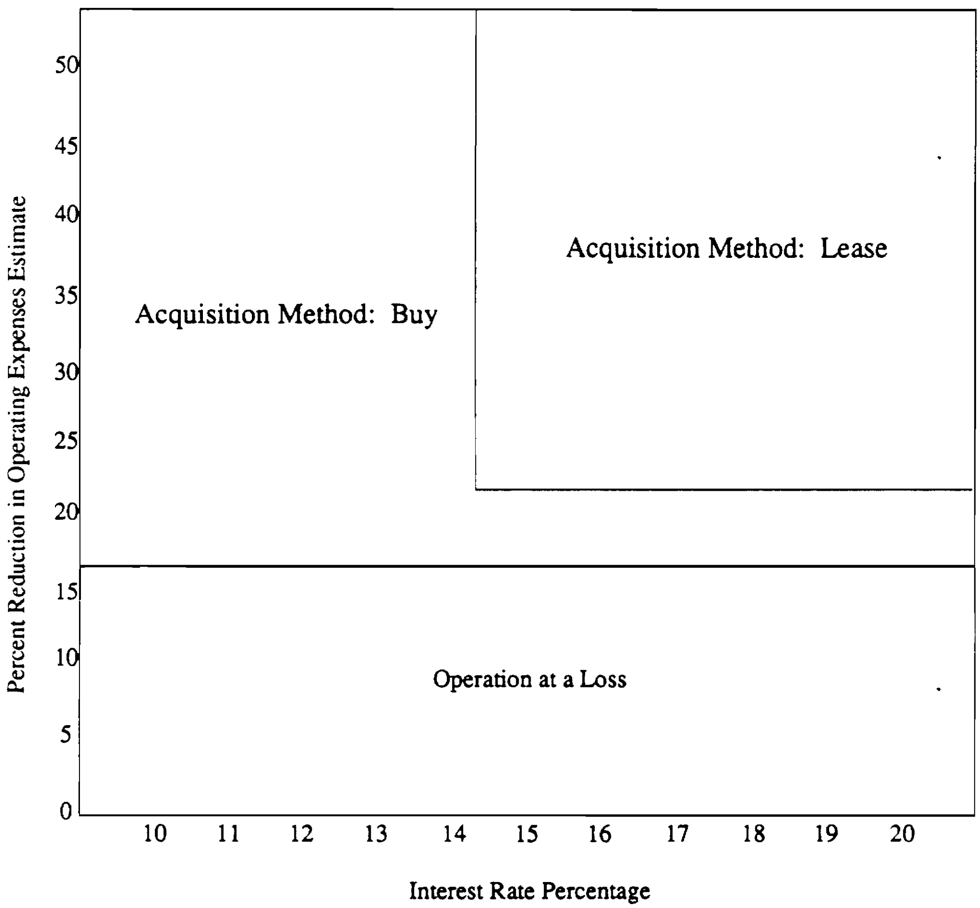

Figure 10.1 - Sensitivity Analysis

11.0 Conclusion

Several conclusions can be made concerning the teleconferencing network as a direct outcome of the analyses provided in Sections 3.0 and 6.0. The first conclusion is that the teleconferencing network meets or exceeds the communication needs of the customer/contractor party. The network is capable of transmitting video, voice, and fax data between the three sites. Also, the teleconferencing network exceeds the reliability requirement of a MTBF of 3120 hours while providing an inherent availability of approximately 99.4 percent. The network is also able to perform these functions in a cost effective manner. Initial estimates indicate that implementation of the teleconferencing network into the three-site configuration would result in a $500,000 annual savings on T&L expenses.

A buy versus lease analysis is provided in Sections 8.2 and 8.3 to determine the best acquisition method for the network. The analysis indicated that purchasing the teleconferencing network would result in more after-tax savings than leasing the network. This determination was based on the present equivalent cost of the after-tax cash flow of each acquisition method. The present equivalent cost of the after-tax cash flow calculations show that purchasing the network would yield approximately an $40,700 savings over leasing.

A break-even analysis is provided in Section 9.0 to determine the point in time where one acquisition alternative becomes more economical than the other. The break-even analysis plotted present equivalent annual cost, or annual savings, for both network acquisition alternatives over the network useful life. The break-even analysis indicated that the crossover point was reached at approximately four years and five and one half months. This point is quite late in the networks estimated useful life of five years. Therefore, if the network expired at any time prior to four years and five and one half months after the start of the useful life, leasing the network would be a better means of acquisition.

A sensitivity analysis is provided in Section 10.0 to determine the effects of input parameter variations on the network cost. The sensitivity analysis addressed possible inaccuracies associated with the input data as well as questionable prediction techniques. The analysis developed a relationship between the estimate of reduced operating expenses as a result of decreased T&L expenses and the interest rate. Figure 10.1 was developed to allow the customer/contractor party determine the best acquisition method based on their estimates.

In summary, the life-cycle analysis has shown that the teleconferencing network meets the communication needs of the customer/contractor party and, if implemented, can potentially result in a $500,000 annual savings in T&L expenses. Under the conditions presented in Sections 8.2 and 8.3 (one-third reduction in operating expenses, ten percent interest rate), purchasing the network would be the best method of acquisition. If estimates as to the reduction in operating expenses or the interest rate are different, Figure 10.1 can be used to determine the best acquisition method.

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