

**CONCEPTUAL DESIGN OF A
NETWORK ARCHITECTURE
FOR A TYPICAL
MANUFACTURING INFORMATION SYSTEM
USING OPEN SYSTEMS INTEGRATION**

by

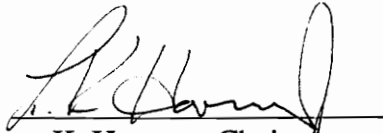
Robert J. Winig

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in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

in

System Engineering

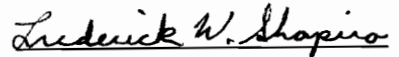
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Committee Chairman: Ken Harmon
Systems Engineering

(ABSTRACT)

This project demonstrates an understanding of how a manufacturing organization can use the methodology of open systems integration to upgrade the design of the network architecture for their manufacturing information system. In upgrading the design of their manufacturing information system's network architecture, a limited application of the system engineering process is used to produce an initial conceptual design. As technology grows, many manufacturing organizations are taking the necessary steps to upgrade their operations to remain competitive in these changing times. This project explores this problem which many manufacturing organizations are experiencing as technology continues to leap frog past its current limitations. Many of the manufacturing organizations which have been in operation for years are having difficulties competing with many of the new manufacturing organizations with their current technologies.

The technologies which are researched in this project to produce an open systems architecture include Local Area Networking, Wide Area Networking, Multiplexing, and Transmission Media. The Local Area Networking involves the latest in PC's and workstations and the connectivity across diverse platforms. The Wide Area Networking includes connectivity between all the locations in the manufacturing organization, the Multiplexing of all the data links at each of the locations, and the Transmission Media which is used to connect each of the locations to one another.

The results of the research from this project provides an initial conceptual design of a network architecture for a manufacturing information system that is driven by needs analysis and feasibility studies, meets both physical and functional requirements, and also reflects current technology. The initial conceptual design identifies the definition of need for the manufacturing information system's network architecture and produces feasibility studies for each of the areas in the open systems architecture. This project also provides an understanding of open systems integration. In addition, this project supplies recommendations on how best to implement the manufacturing information system's network architecture, including pricing of vendor's products and vendor comparisons in such areas as Local Area Networking, Wide Area Networking, Multiplexing, and Transmission Media.

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1. INTRODUCTION

This project accomplishes a partial fulfillment of the requirements for a Systems Engineering degree from Virginia Polytechnic Institute and State University. This project deals with enhancement of a manufacturing information system through the integration of Commercial Off-The-Shelf (COTS) technologies in an open systems environment. This topic was chosen because of its relevance to my current work at Hughes Aircraft Company and its timely nature in the rapidly evolving field of information technology.

1.1 Project Objectives

The primary purpose of this effort is to provide an initial conceptual design for the network architecture required to enhance a typical manufacturing information system. While this involves the application of some systems engineering principles and techniques, it is not intended to demonstrate the total systems engineering process. The design which will be recommended by this project is intended to be a common approach which can be used as the basis for developing design alternatives in any systems engineering project to enhance manufacturing information systems. While it is not the purpose of this project to develop a specific solution to a real-world problem in a particular company or government agency, my recommendations for a network architecture are rationalized in the environment of a hypothetical but realistic company, FONEX Inc., which is constructed for this purpose.

The following include the secondary objectives of this project:

1. To identify the definition of need for the manufacturing information system and produce feasibility studies for each of the areas in the open systems architecture,
2. To develop an initial conceptual design which is driven by needs analysis and feasibility studies,
3. To provide an understanding of open systems integration,
4. To produce an initial conceptual design which meets both functional and physical requirements of a network architecture for a manufacturing information system,
5. To recommend a set of vendor's products for a manufacturing information system's network architecture that conforms to the open systems architecture and industry standards.

A manufacturing organization should be able to use this initial conceptual design to upgrade the network architecture of their existing manufacturing information system to conform with the standards of an open systems architecture. In addition, a manufacturing organization could benefit from this project by understanding the methodology of open systems integration.

1.2 Project Methodology

The approach followed in conducting this project is based on a limited application of the systems engineering process. This approach consists of developing an initial conceptual design for the network architecture in an advanced manufacturing information system, using open system integration. This systems engineering project is understood to consist of the following process and techniques.

In this approach, the system engineering process involves the technical application of engineering and scientific efforts to transform an operational need into a description of system performance parameters and desirable system configuration through the process of functional analysis, synthesis, optimization, definition, design, test, and evaluation. In this approach the system engineering process also combines technical parameters and assures compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design, and integrates performance producibility, reliability, maintainability, supportability and other specialties in the entire engineering effort. Systems engineering requires that all engineering disciplines combine experience to ensure all elements of the system are considered in a proper and timely manner.¹

This project methodology will only use part of the design evolution of the systems engineering process methodology. The portion of the design evolution which is contained within this project includes the identification of the need for the manufacturing

¹ Blanchard, Benjamin S. and Wolter J. Fabrycky, Systems Engineering and Analysis, Second Edition, Prentice Hall, Englewood Cliffs, New Jersey, 1981.

information system's network architecture through the conceptual design phase of the system life cycle process, as shown in Figure 1.1.

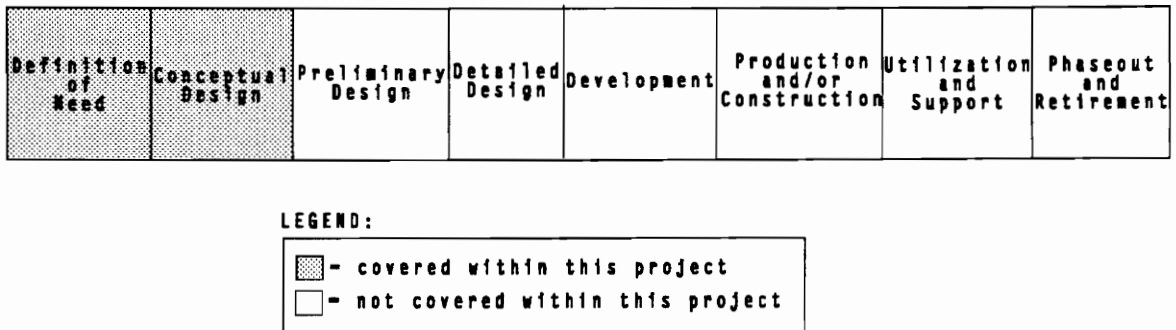


Figure 1.1: Phases of the System Life Cycle

The process of organizing a diverse collection of different processors and peripherals that goes to make up a contemporary computer installation could be referred to as system integration. The principle goals of open systems (interoperability, connectivity, and applications portability) are fundamental to systems integration, since open systems includes the interfaces that allow the building of a heterogeneous environment. The need to ensure that communication of different systems and system components is consistent and effective throughout the network architecture of a manufacturing information system is the essence of open systems integration.

Open systems integration focuses on the following three issues:

1. Network/Distributed Processing - open system integrators need to look in three different directions, conventional operating systems, Graphical User Interfaces (GUI) developers, and network operating systems;
2. Applications portability - is possible at a basic level by relying on systems using the same central processor;
3. User Interfaces - operating systems of the future will all include a GUI and networking software.

Open systems integration encompasses the adoption of industry wide standards. Conformance to these standards offers a form of guarantee that systems and components will be open. Neither testing nor conformance can guarantee that systems or components will actually work with each other, or that the software is completely portable between systems. However, there are three important sets of standards for conformance of open systems: IEEE's (Institute of Electrical and Electronic Engineering) Portable Operating System Interface for Computer Environments (POSIX), X/Open Portability Guide 3 (XPG3), and International Standards Organization's (ISO) Open Systems Interconnect (OSI). These three sets of standards cover everything relevant to open systems integration.

In summary, COTS components which are produced in accordance with these standards can be more easily integrate into an overall system solution. The specifications for this system are of course designed from operational needs and functional analysis developed from applying the system engineering approach.

1.3 Project Scope

The scope of this project is to develop, by way of open systems integration, an initial conceptual design of an enhanced network architecture for FONEX's manufacturing information system which incorporates current computer hardware and software, and telecommunications technology in a distributed computing environment. The scope of this project is to design a network architecture for a typical manufacturing information system and not to design an entire manufacturing information system for a particular organization. The development of an initial conceptual design of the entire manufacturing information system would include additional areas such as Database Management Systems (DBMS), Graphical User Interfaces (GUI), and software engineering applications (for example, Computer Aided Design, CAD, and Computer Aided Manufacturing, CAM).

The scope of this project is to develop an initial conceptual design that addresses network architecture technology in each of the following areas:

1. A Local Area Network (LAN) at each location which includes the latest in PC's (Personal Computers) and workstations and the connectivity across diverse platforms,
2. A Wide Area Network (WAN) which includes connectivity between all the locations in the company and the five supplier's locations,
3. The Multiplexing of all of the data links at each location,

4. The Transmission Media which is used to connect each of the locations to one another.

Each of these areas include a feasibility study, an extensive description of the design, the system operational requirements for the design, the protocols used within the design, a vendor comparison and a recommendation of an equipment choice of the products used within the design, and the costs for purchasing the equipment to implement the design.

The proposed design will conform to technical requirements which will be derived from operational needs that are explained in a description of FONEX. This manufacturing information system's network architecture will provide FONEX with an open systems environment which captures the organizations manufacturing strategies. This environment will supply FONEX with communication by linking the headquarters, the research and development facility, the two manufacturing facilities, the two marketing offices, and the two shipping and receiving facilities along with five suppliers with the latest in information technology.

2. THE MANUFACTURING ORGANIZATION

This section provides a description of the manufacturing organization. Also included in this section is an insight of the new manufacturing strategies which the manufacturing organization intends to practice brought on with the addition of the new network architecture for the manufacturing information system.

2.1 Description of the Manufacturing Organization

FONEX is a phone manufacturing company headquartered in Washington, DC. They currently manufacture analog and digital phones for a number of companies in the U.S. and overseas. In addition, FONEX also consists of two Manufacturing plants which are located in San Diego, CA (which manufactures the FONEX analog models) and New York, NY (which manufactures the FONEX digital models), a Research and Development (R&D) facility located at Raleigh, NC, two Shipping and Receiving offices which are split up with one on the west coast in Los Angeles, CA (for the FONEX analog models) and one on the east coast in Greenbelt, MD (for the FONEX digital models), and two Marketing offices which are also split up with one on the west coast in San Francisco, CA and one on the east coast in Fairfax, VA.

Headquarters (HQ) consists of personnel from the following areas: executives; upper management of each area of the organization; personnel; finance and support; marketing and new business; publishing; and administrative support. At the research and development facility there are three divisions (Mechanical Division, Electrical Division,

and Research and Development Division) and ten administration personnel for support. Each of the Shipping and Receiving facilities consists of approximately thirty five people. Each of the Manufacturing facilities consists of a small group of engineers, managers, and administrative personnel, and a larger group of production line workers. The marketing offices consist of a small group of managers, salesmen, and administrative personnel.

2.2 The Manufacturing Organization's Strategies

FONEX has decided to take on new manufacturing strategies in order to remain competitive and successful. FONEX has incorporated integrated manufacturing strategies to be practiced throughout the organization, in which manufacturing must work with finance, marketing, engineering, research & development, personnel, and purchasing.

2.3.1 Manufacturing Management Strategies

FONEX's new manufacturing management strategies consists of nine decision categories:

1. Facilities - determining the size, location, and capabilities of each facility,
2. Capacity - determining whether to add capacity in anticipation of future demand or in response to existing demand,
3. Vertical Integration - determining whether to design and produce internally will be better than the market is producing,

4. Processes and Technologies - determining which process type is best (automated versus assembly line),
5. Scope and New Products - determining the number of products and the frequency of new products,
6. Human Resources - determining the best method to motivate employees,
7. Quality Management - determining which decision tools and measurement systems are best,
8. Manufacturing Infrastructure - determining how to manufacture and how to manage materials (Manufacturing Requirements Planning, Just-In-Time),
9. Vendor Relations - determining whether to employ the competitive approach or the cooperative approach (multiple sources versus long term relationships).²

2.2.2 Manufacturing Engineering Strategies

FONEX's new manufacturing engineering strategies consists of seven categories. These seven categories and some of their contributing variables are as follows:

1. Cost - the unit cost, inventory costs, total cost, life cycle cost, and Just-In-Time (JIT);
2. Quality - return rate, product reliability, the rate of field repairs, Mean Time Between Failure (MTBF), JIT, and Total Quality Control (TQC);

² Fine, Charles H., and Hax, Arnoldo C., "Manufacturing Strategy: A Methodology and an Illustration," *Interfaces*, November/December 1985, pp. 28-46.

3. Flexibility - product mix, lead time, volume changes, Flexible Manufacturing Systems (FMS), JIT, and information systems;
4. Dependability - planning, scheduling, inventory, vendor, and Manufacturing Requirements Planning (MRP),
5. Uncertainty - economic, environmental, scheduling, and technology;
6. Delivery - on time shipments, predictability of delivery dates, average delays, expediting response time, and JIT;
7. Performance - the combination of the cost, quality, flexibility, dependability, uncertainty, and delivery.³

FONEX is committed to a successful manufacturing engineering strategy which uses the JIT philosophy to eliminate or shorten their material moves between their suppliers. This will be done by developing a long term partnership with their suppliers which will reduce the product's unit cost, increase the product's quality, increase the product's competitiveness, and determine the proper scheduling of product's delivery dates.

2.2.3 Just-In-Time

Just-In-Time is the philosophy according to which every stage in the manufacturing operation from receipt of materials to assembly and dispatch occurs precisely when it needs to - not before and never later. It does not matter what the size of the plant is or the uniquenesses of each facility and the products manufactured, the Just-In-Time philosophy still remains the same. It is however common for the manufacturing

³ Swamidass, Paul M., and Newell, William T., "Manufacturing, Strategy, Environmental Uncertainty and Performance: A Path Analytic Model," *Management Science*, April 4, 1987, pp.509-524.

management to think of Just-In-Time as a production control technique, rather than the corporate strategic philosophy that it really is - "the elimination of waste".⁴

The following factors summarize FONEX's Just-In-Time concept and provides a guideline to implementing Just-In-Time: Design for Production; Change plant layouts to eliminate or shorten material moves; Institute worker-involvement programs (Quality Circles); Improve data accuracy; Use on-line real-time data update and retrieval and interactive decision making; Reduce scrap; Reduce inventories; and Strive for continuous improvement in all areas. Hence, Just-In-Time is an approach to achieving manufacturing excellence through the continuing elimination of waste and the reduction of lead time.

Just-In-Time can increase FONEX's TQC by seeking to reduce inventory levels at all stages in the supplier/receiver process. This provides the suppliers for purchased parts based on their willingness and ability to form a long term partnership. When this partnership is established, the TQC will increase due to the suppliers dedication to delivering parts which exactly meet FONEX's product requirements and specifications.

2.2.4 Computer Integrated Manufacturing (CIM)

Computer Integrated Manufacturing is the process of using computers and communication networks to transform the islands of automation into a highly interconnected manufacturing organization. With CIM, FONEX will be capable of executing any task within the factory. CIM can be accomplished in the following stages:

⁴ Bowman, D. Jerry, "If You Don't Understand JIT How Can You Implement It?," *Industrial Engineering*, February 1991, pp. 38-39.

1. Islands of Automation - the automation of individual work centers as single manufacturing components,
2. Automated Cells - the integration of selected islands of automation,
3. Flexible Manufacturing System - the integration of several automated work cells capable of producing a variety of parts.⁵

For CIM to be executed properly it must involve all layers of FONEX's management, supervisors, and the factory employees.⁶ Hence, to fully apply CIM, FONEX's CIM and MRPII systems will have to be tightly integrated.

CIM can provide FONEX the means of producing products more efficiently, with greater quality control and larger profit margins. Therefore, CIM can generate the following benefits for FONEX:

- Increase productivity,
- Increase future growth,
- Reduce product cost,
- Increase market share,
- Improve product quality.

⁵ Badiru, Adedeji B., P.E., "A Systems Approach To Total Quality Management," *Industrial Engineering*, March 1990, pp. 33-36.

⁶ Aletan, Samuel, Ph.D., "The Components Of A Successful CIM Implementation," *Industrial Engineering*, November 1991, pp. 20-22.

2.2.5 Manufacturing Automation Protocol (MAP)

The Manufacturing Automation Protocol was developed by the General Motors MAP task force in 1980. There were many international standards organizations which were consulted to determine the most widely accepted methods of networking. Some of these organizations included the IEEE, the International Standards Organization (ISO), and the American National Standards Institute (ANSI).⁷

FONEX's plan is to incorporate more automated equipment and computers within their factories in an effort to employ CIM. When FONEX establishes MAP within their network, the tools required to build the bridges between island of automation, the factory cells, will be available to help FONEX implement CIM. The MAP network enables any device in the FONEX's factory to communicate with any other device. MAP has proven over the years of have the capability of reducing a manufacturing organization's networking costs.⁸ These reductions can be attributed to the cabling costs and the software development. Hence, having one communication standard for all devices eliminates the work of developing unique communications software.

FONEX's main benefit from implementing MAP is the freedom to choose equipment from any vendor that best fits the requirements for each task. MAP will provide FONEX with a flexible and powerful communications network with greater freedom in selecting automation products with which to implement their CIM strategies.

⁷ Larson, Gaylan I., "MAP Fills the Gap Between Islands of Automation," *Industrial Engineering*, November 1987, pp. 50-51.

⁸ Larson, Gaylan I., "MAP Fills the Gap Between Islands of Automation," *Industrial Engineering*, November 1987, pp. 50-51.

3. NEEDS ANALYSIS

This section addresses the first stage of the system life-cycle, the identification of need. The identification of need is developed as a result of a deficiency in the current network architecture of the information system and the desire to improve this system.

3.1 Product Need

Due to the recent passing of legislation by Congress allowing foreign companies access to the U.S. telephone market and coupled with the increased interest in digital phones and cellular phones FONEX sought to take the necessary steps to upgrade its operations to remain competitive and retain their market share well into the nineties.

Because of the deficiencies in the network architecture of FONEX's manufacturing information system the following needs have been identified:

1. The current information system is not capable of directly accessing the company database to provide information sharing,
2. The current information system lacks the means to transfer data between locations without the use of Federal Express or the United States Postal Services,
3. The current information system lacks communication among geographically dispersed team members can be overcome by enabling members to share applications and engineering tools to enhance integration of common products,

4. There is a desire to increase vendor relations by providing suppliers with access to exactly when parts are needed for delivery and the requirements and specifications of each part,
5. With a new network architecture for the information system there is a capability of developing new products by breaking into the mobile phone market, and increasing vendor relationships by providing communication links to supplier's facilities.

3.2 FONEX's Needs Analysis

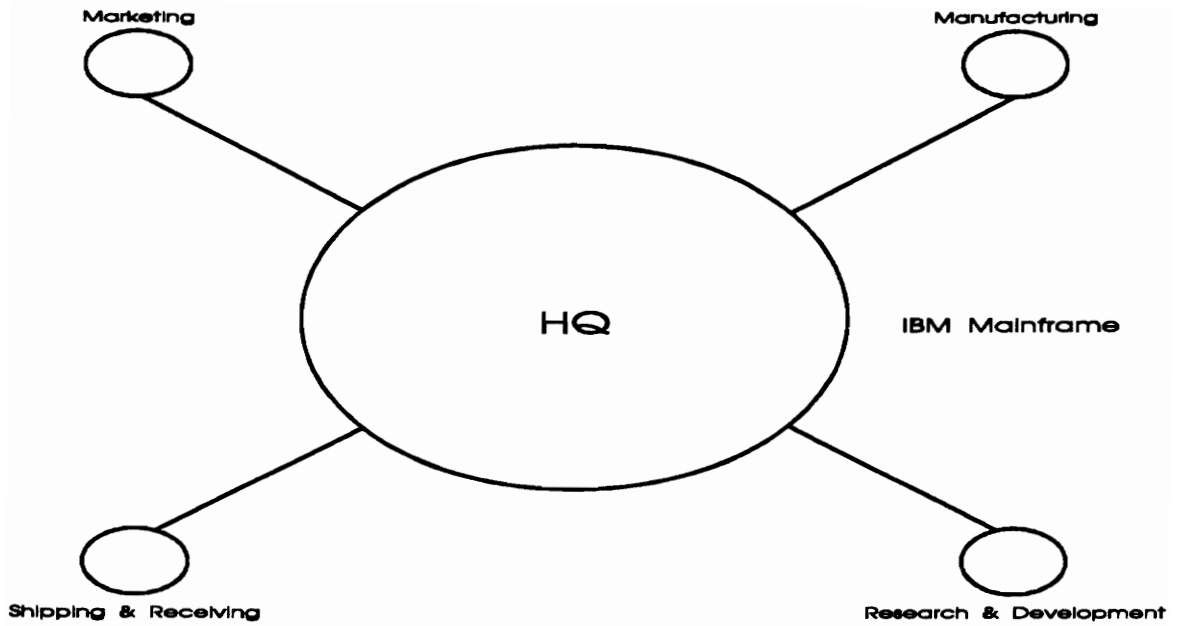
To accomplish the goal of satisfying all the deficiencies outlined in section 3.1, FONEX is looking to update the network architecture of its information systems into a fully integrated network to facilitate the use of an information management system and a CAD/CAM system.

FONEX's management would be capable of improving the manufacturing management strategies outlined in section 2.3.1 with a new network architecture for its information system. The two immediate advantages which FONEX would be able experience are: to increase their Scope and New Products by breaking into the mobile phone market, and to increase their Vendor Relations by implementing JIT.

Currently, FONEX's computer resources consists of a Headquarters, two Shipping and Receiving offices connected by dedicated phone lines to a mainframe, a Research and Development facility, two Manufacturing plants, and two Marketing offices. Each location has an array of computer systems, where only some computer systems are integrated (for example, Figure 3.1 shows how the headquarters is integrated used an

SNA, Systems Network Architecture, Network). Table 3.1 provides a listing of the existing equipment at each site and their functional purpose found at each site.

FONEX not only has a need to upgrade their communications capability, but also to upgrade their computing capability and their interaction with their suppliers. To increase its computing power, FONEX's R&D facility located at Raleigh, NC wishes to upgrade to include new computer hardware/software and a new state-of-the-art CAD/CAM system for product design and development. In addition, FONEX wishes to expand their network to include five parts suppliers equipped with Personal Computers (PC) and WAN interfacing hardware/software. The suppliers are to be directly linked with Headquarters in Washington, DC. Three of the five suppliers are located in Washington, DC, and the two other suppliers are located in Chicago and in Dallas. At the supplier facilities there are a number of PC's and WAN interface hardware and software. FONEX's two manufacturing plants wish to upgrade to include a new state-of-the-art CAD/CAM system. At the two Marketing offices there are a number of PC's equipped with modems. FONEX's would like to keep the costs of its information system's network architecture as low as possible by trying to use as much of this existing equipment identified in Table 3.1. FONEX is also interested in lowering the turn around time of the network architecture for this manufacturing information system by designing and developing by the methodology of open systems integration and the use of COTS technologies.



Centralized SNA Network Using
3270 Terminals and Standalone PCs

Figure 3.1: Headquarter's Current SNA Network

Table 3.1: Existing Equipment

LOCATION	TYPE	QUANTITY	FUNCTION
HEADQUARTERS	MACINTOSH	20	DESKTOP PUBLISHING
	IBM 3090 MAINFRAME	1	DATABASE, E-MAIL, AND BUSINESS APPLICATIONS
	PC's	50	OFFICE AUTOMATION, MARKETING, AND BUSINESS APPLICATIONS
RESEARCH AND DEVELOPMENT	SUN SPARC SERVER	6	CAD/CAM AND ENGINEERING
	SPARC STATIONS	12	CAD/CAM AND ENGINEERING
	PC's	10	ADMINISTRATION
SHIPPING AND RECEIVING	3270 IBM TERMINALS	25	MAINFRAME ACCESS
MARKETING	PC's	5	MARKETING, AND BUSINESS APPLICATIONS

3.3 Functional Requirements

This section details the functional requirements of the network architecture for a manufacturing information system. These requirements point out the functional relationships amongst the different components of the manufacturing information system's network architecture. In addition, these requirements analyze the principles of what a manufacturing organization needs. These needs include such items as portability, connectivity, availability, interoperability, accessibility, reliability, maintainability, supportability, and performance.

3.3.1 Portability

1. All software shall be designed to provide the capability of using the same application source code on more than one platform.
2. All software shall be designed to be portable into any site environment which requires that softwares functionality.

3.3.2 Connectivity

3.3.2.1 Local Area Network

1. Intra-site connectivity between hardware platforms shall be provided via a Local Area Network.
2. The Local Area Network shall provide the capability to share printer resources by providing print spooling via the Local Area Network transmission media.

3. The Local Area Network shall provide the capability to simultaneously access multiple software applications from a single hardware platform.

3.3.2.2 Wide Area Network

1. Inter-site connectivity between sites shall be provided via a Wide Area Network.
2. The Wide Area Network shall provide the capability to interface with a transmission line with the following characteristics:
 - with a data rate of either 256 Kbps or 56 Kbps,
 - with continuous availability,
 - synchronous data transmission.
3. The Wide Area Network shall be capable of bi-directional transfers, via the transmission lines, between any of the sites.
4. The Wide Area Network hardware shall be configured to provide complete transmission of files in the event that one and only one of the transmission lines between any of the manufacturing organization's sites becomes inoperable.
5. The Wide Area Network shall provide the capability for locally controlled remote site accesses via password logons.
6. The Wide Area Network shall provide the following capabilities between any two sites:
 - transfer data,
 - transfer user's data files,
 - transfer electronic mail (E-Mail),
 - transfer software source code,
 - transfer databases,

- allow users at one site to remotely log onto computers at other sites.

3.3.2.3 Interoperability

1. The heterogeneous computer systems on the network shall have the capability to electronically transfer data with other computer systems on the network.
2. Software applications shall have the capability to electronically transfer data between software applications.

3.3.2.4 Access

1. All computer systems on the network shall provide user logons and passwords in order to protect the manufacturing information system from unauthorized users.
2. All computer systems on the network shall deny access to unauthorized users.
3. All computer systems on the network shall provide access to databases only to authorized users.

3.3.2.5 Back-up

Back-up shall be provided via distribution of redundant resources of the software applications.

3.3.3 Remote Access

At each of the sites the network shall be capable of handling multiple simultaneous remote user logons at any time.

3.3.4 Interfaces

1. The CAD software application shall interface with CAM software application as defined in section 3.3.2.3.
2. The manufacturing information system shall provide all sites the following interface capabilities:
 - to send or receive electronic mail for any user,
 - to access any database, both locally or remotely, with the proper authorization as defined in section 3.3.2.4.

3.3.5 Quality Factors

3.3.5.1 Reliability

3.3.5.1.1 Intra-site Reliability

The failure of a single component within a site's Local Area Network shall not cause the failure of the entire site's Local Area Network.

3.3.5.1.2 Inter-site Reliability

The failure of a single site's Local Area Network shall not cause the failure of any other site's Local Area Network.

3.3.5.2 Maintainability

1. Maintenance support shall be identified to each of the sites in order to provide the following capabilities:
 - define actions to be performed to ensure that required computer equipment maintenance resources are available whenever needed,
 - define maintenance procedures,
 - define procedures to ensure the operational hardware and software is not impacted when approved hardware and software changes are verified and tested.
2. Maintenance support shall provide the capability to maintain the hardware components and software applications and provide upgrades when needed.

3.3.6 Design and Construction

1. The design and construction of the manufacturing information system's network shall provide an open systems architecture.
2. The design and construction of the manufacturing information system's network architecture shall conform to industry wide standards to include:
 - ISO's OSI standard,

- Open Software Foundation's standards,
- IEEE's POSIX standard.

3.3.7 Logistics

Logistics support shall be identified to each of the sites in order to provide the following capabilities:

- logistic support procedures for all hardware and software;
- the identification and management of spare parts, repair parts, consumables, telecommunications equipment, test and support equipment, and computer equipment;
- technical data and a listing of all documents necessary for personnel to operate and maintain the hardware and software.

3.3.8 Configuration Control

3.3.8.1 Hardware Configuration Control

A plan shall be provided for managing the configuration of all of the hardware in the entire network.

3.3.8.2 Software Configuration Control

A plan shall be provided for managing the configuration of all of the software in the entire network.

3.3.9 Performance

3.3.9.1 Back-up Performance

Back-up performance shall be provided via software portability, as defined in section 3.3.1, to allow any software application to be run at a minimum of two sites.

3.3.9.2 User Interface Performance

1. The manufacturing information system shall provide the capability to run multiple software applications simultaneously from a single hardware platform.
2. At each of the sites the manufacturing information system shall provide multiple user access to hardware platforms and software applications limited only by the number of computer systems available at the site.

3.3.10 Personnel Training

Training aids shall be provided for all of the personnel utilizing any of the software applications and/or any of the hardware components.

4. LOCAL AREA NETWORK

This section addresses the following: a feasibility study for FONEX's Local Area Network (LAN), the system operational requirements of the LAN, the protocols used with the design of their LAN, the LAN design, how the LAN will be implemented, vendor comparisons, the equipment choices, and the total cost for implementing the LAN. The design and implementation of the LAN is provided as both diagrams and descriptions for each location in the network.

4.1 LAN Feasibility Study

There is a trend today toward distributed computing environments with resources shared over networks. It is generally accepted that industry standards are required in order to govern the physical, electrical, and procedural characteristics of these shared resources.⁹ Communication between heterogeneous machines (either different vendors or different models of same vendors) would be a major problem without any established standards. Different data formats and data exchange conventions are used by each communication product. In order to define industry standards for communication services and protocols, the International Standards Organization (ISO), a worldwide organization, established the Open Systems Interconnection (OSI) standards for integrated networks in 1983.¹⁰ The Open Software Foundation (OSF) was established to set standards specifically for

⁹ Stallings, William, Handbook of Computer - Communications Standards, Volume 1, Macmillian Publishing Company, New York, New York, 1987.

¹⁰ Stallings, William, Data and Computer Communications, Third Edition, Macmillian Publishing Company, New York, New York, 1991.

the UNIX community. In addition to these two standard setting organizations, the IEEE has established an interface standard for operating systems, known as POSIX.

In recent years, there has been increasing activity in the design of standards for computer communications protocols and the implementation of these protocols. All of the standards work, since the introduction of the OSI reference model, and most of the development of protocols has been in the context of the hierarchical, seven-layers, communications architecture. Table 4.1 briefly defines the functions performed at each of the layers, where the functions each of layer is with the two adjacent layers. Each layer insulates its upper and lower layer, therefore there are no direct communications between the upper and the lower layers. Services on the same level do not interact with one another. The intent of the OSI model is that protocols and services be developed to perform the functions of each layer.

Figure 4.1 illustrates the seven layers of the OSI model with the right side symbolizing three parts. The lower part represents the network service for a computer to interact with a network. The middle section represents the end-to-end service for users to interact with the communication facility, and the top section represents the transport service for the exchange of data between users. The left side also symbolizes three parts with the lower section representing the link between a host and the network. The middle section represents the transferring of data from one host to another, and the top section represents user's concerns, for example the considerations of the application to be performed. Adherence to the OSI model provides a foundation for different vendors' products to interoperate.

Table 4.1: The OSI Layers¹¹

1. Physical Layer	Concerned with the transmission of unstructured bit stream over physical medium; deals with the Mechanical, Electrical, Functional, and Procedural Characteristics to access the physical medium
2. Data Link Layer	Provides the reliable transfer of information across the physical link; sends blocks of data (frames) with the necessary synchronization, error control, and flow control
3. Network Layer	Provides upper layers with independence from the data transmission and switching technologies used to connect systems; responsible for establishing, maintaining, and terminating connections
4. Transport Layer	Provides reliable, transparent transfer of data between end points; provides end-to-end error recovery and flow control
5. Session Layer	Provides control structure for communication between applications; establishes, manages, and terminates connections (sessions) between cooperating applications
6. Presentation Layer	Provides independence to the application processes from differences in data representation (syntax)
7. Application Layer	Provides access to the OSI environment for users and also provides distributed information services

¹¹ Stallings, William, Data and Computer Communications, Third Edition, Macmillan Publishing Company, New York, New York, 1991.

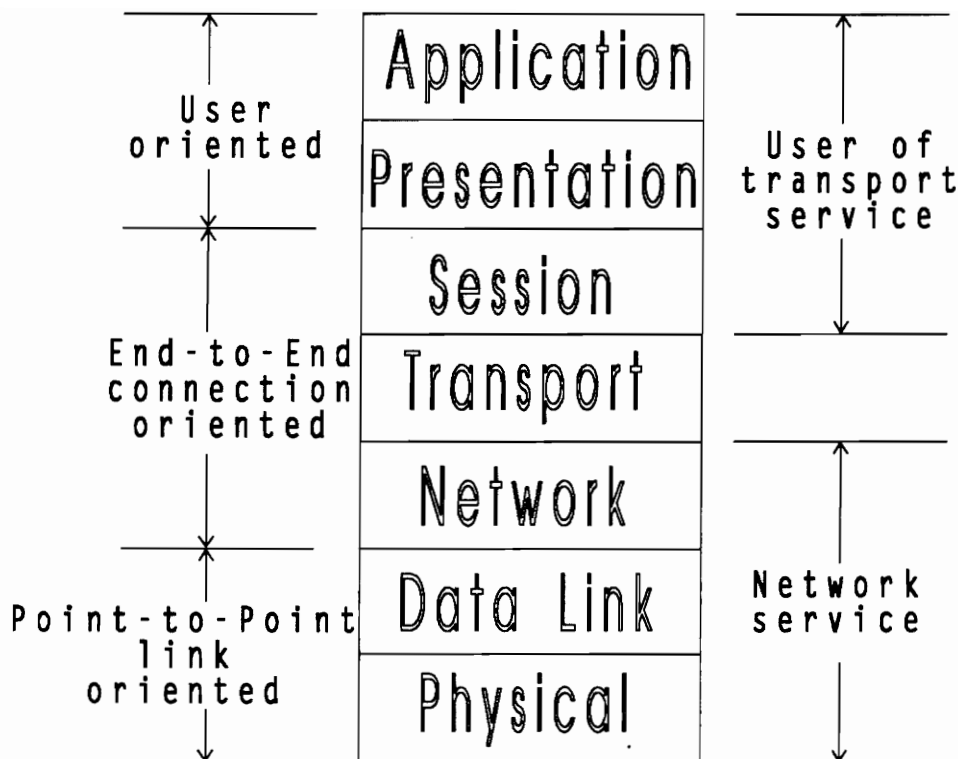


Figure 4.1: The OSI Architecture

OSI is only one example of a communication architecture, the others include TCP/IP (Transmission Control Protocol/Internet Protocol) protocol suite and International Business Corporation's (IBM) SNA. The TCP/IP architecture was developed as a result of ARPANET (Advanced Research Projects Agency computer network) and the Defense Data Network (DDN) research.¹² The SNA architecture was developed by IBM to protect its customer base and allow its customers to take advantage of the new IBM offerings. Table 4.2 compares the OSI architecture with the other two communication architectures.

¹²Stallings, William, Data and Computer Communications, Third Edition, Macmillian Publishing Company, New York, New York, 1991.

Table 4.2: Comparison of Communications Architectures

OSI		TCP/IP	SNA
7	Application	Process/ application	Transaction services
6	Presentation		Presentation services
5	Session		Data Flow control
4	Transport	Host-to-Host	Transmission control
3	Network	Internet	Path control
2	Data Link	Network access	Data Link control
1	Physical		Physical control

The intent of the OSI model is that protocols be developed to perform the functions of each layer. Each of the major LAN and WAN components will examine protocols which will make use of the OSI model. The major LAN components are analyzed and evaluated which demonstrates an initial conceptual design and integration of the network.

In 1988 the OSF was founded by seven prominent computer vendors, IBM, Digital Equipment Corporation (DEC), Groupe Bull, Hewlett Parkard (HP), Apollo Computer, Nixdorf Computer, and Siemens.¹³ This group aimed to develop an open systems alternative to the AT&T and Sun Microsystems (SUN) collaboration in producing UNIX System V Release 4 (SVR4). This goal was in order to establish industry wide standards for UNIX systems and layers five through seven of the OSI model (OSF standards are built upon the ISO standards). OSF's main objective is to focus on the networked information processing environment by providing users with maximum portability, interoperability, and scalability of applications. The portability provides users the use of applications software on computers from multiple vendors. The interoperability provides users with a successful cooperation of computers from different vendors. The scalability provides users the use of the same software environment on computers ranging form desktop devices to supercomputers.

All the major vendors (IBM, DEC, SUN, and HP) belong to the OSF and abide by OSF standards. The elements of OSF conform to the OSI model and open system architecture standards. By selecting systems that are OSF compatible, developers can increase the likelihood that the system being developed will be supported for years to come by a wide variety of vendors. OSF standards for open systems include OSF/Motif, Distributed Computing Environment (DCE), Distributed Management Environment (DME), OSF/1 Operating System, and Architecture Neutral Distribution Format (ANDF).

¹³Datapro Information Services Group, Datapro Reports on UNIX Systems & Software, McGraw Hill Inc., Delran, New Jersey, January 1992.

OSF/Motif, a GUI, introduced in August 1989 was the first standard offered by OSF. OSF/Motif GUI has become a standard GUI for the UNIX systems. Motif is a three-dimensional environment that reduces complex commands to easily recognizable pictures and icons on the computer screen. Motif provides a consistent interface between users and machines in a heterogeneous computing environment.¹⁴ There are over 85 hardware vendors that have licensed the product on over 145 platforms, and it currently supports over 1000 applications and 47 operating systems.¹⁵

DCE, introduced in September 1991, allows for interoperability and distributed computing between LAN's, on heterogeneous platforms and different operating systems. DCE provides the services needed for the development, use, and maintenance of distributed applications. DCE enables users to share resources such as processing power, data, and peripherals over a network.¹⁶

DME, developed in 1992, offers a method to manage the architecture provided by DCE. DME provides a consistent approach for managing networks made up of PC's, Workstations, and Mainframes running a variety of operating systems. Therefore, DME allows administrators to develop and use management applications across these various platforms and operating systems.¹⁷

¹⁴ Accelerating Open Systems Technology, Open Systems Foundation Inc., Cambridge, Massachusetts, 1990.

¹⁵ Datapro Information Services Group, Datapro Reports on UNIX Systems & Software, McGraw Hill Inc., Delran, New Jersey, January 1992.

¹⁶ Datapro Information Services Group, Datapro Reports on UNIX Systems & Software, McGraw Hill Inc., Delran, New Jersey, January 1992.

¹⁷ OSF Distributed Management Environment (DME) Architecture, Open Systems Foundation Inc., Cambridge, Massachusetts, May 1992.

OSF/1 Operating System, introduced in October 1990, provides an alternative to the traditional UNIX operating system. OSF/1 is fully compliant with industry standards and specifications. OSF/1 provides users with an operating system that is capable of such features as symmetric multiprocessing, logical volume management, disk mirroring, and dynamic system configuration.¹⁸

ANDF solves the problem facing the open systems industry by allowing users to run a single version of a software application on different hardware architectures, without having to port to the software application onto each platform. This permits developers to support all platforms by creating source code, converting it to ANDF, package it once, and distribute it in as an off-the shelf form or on a network server.¹⁹

There are various standards efforts included under the IEEE's POSIX, a family of standards development projects. The POSIX family includes examples of a group of related standards for delivering interoperable systems. These projects consist of such components as programming languages, network interfaces, user interfaces, systems security, and a variety of systems utilities and administrative features. However, POSIX 1003.1 or POSIX.1, the primary POSIX component, is the main standard in the POSIX family, and it is this standard which defines interfaces for the POSIX compliant operating systems.²⁰

¹⁸Datapro Information Services Group, Datapro Reports on UNIX Systems & Software, McGraw Hill Inc., Delran, New Jersey, January 1992.

¹⁹ANDF, Application, Portability, and Open Systems, A White Paper, Open Systems Foundation Inc., Cambridge, Massachusetts, December 1991.

²⁰Datapro Information Services Group, Datapro Reports on UNIX Systems & Software, McGraw Hill Inc., Delran, New Jersey, November 1992.

All of the major hardware and operating systems vendors either currently supply the POSIX standard or have promised to conform with the POSIX standard. POSIX benefits users by providing a vendor neutral basis for building interoperable applications. POSIX accomplishes this by delivering the following advantages:

1. **Better Connectivity** - POSIX allows UNIX to serve as a true enterprise operating system, and allows for a convergence of features across different operating systems,
2. **Vendor Independence** - POSIX frees users from being bound to a single vendor by providing portability among applications,
3. **Commercially Available Applications** - POSIX enables users to buy applications that run on a variety of operating systems with the process of recompiling using a POSIX compliant translator,
4. **Protection from Obsolescence** - POSIX compliant software will have a longer life span than proprietary applications since vendors will not have support multiple environments.

Hence, the new types of applications which deliver the promise of workgroup computing, such as, document sharing, E-Mail, and distributed databases, will benefit from the easier cross platform interoperability that is available with the POSIX standard.

The POSIX.1 compliance represents one of the most important developments in the industries' campaign for open systems. However, POSIX compliance and the open systems environment that it guarantees are still in the earliest stages of development.

4.1.1 LAN System Operational Requirements

The following system operational requirements were established to be used in the evaluation of an appropriate vendor. These requirements are fundamental to the correct implementation of a network.

The LAN must support five heterogeneous computer systems, and some of the systems which are needed to intercommunicate. For example, the DOS (Disk Operating System) and Macintosh computers have to communicate with the mainframe to access the centralized mail system. The following systems are supported within the LAN:

1. IBM Mainframe,
2. UNIX Workstations,
3. DOS Based Personal Computers,
4. Apple Macintosh Computers,
5. DEC VAX systems.

As mentioned earlier, the administration PC's must be able to communicate with the IBM mainframe. Additionally, the headquarters building is cabled using Type-I cable. This cable is specified by IBM and is used primarily to support Token Ring LAN's. The Type-I cable is also known as Shielded Twisted Pair. All of the other locations have been cabled using Unshielded Twisted Pair (UTP). 10BaseT is an Ethernet topology that operates over UTP. Therefore, 10BaseT is required for many of the LAN segments in this design.

The UNIX workstations should have the capability to operate with more than one LAN interface card. One to connect to the Ethernet backbone and at least one to connect to a subnetwork operating over 10BaseT, 10Base5, or 10Base2.

4.1.2 LAN Protocols

The LAN architectures that are available today that meet the requirements, listed in section 4.1.1, are Ethernet, Token Ring, and Appletalk. These three LAN topologies are used to connect all of the computer systems. Ethernet is used to connect the Unix, DOS, Apple, and VAX systems. Token Ring is used to connect the DOS PC's to the Novell File Servers. Appletalk is used to connect the Apple Macintosh computers in the Publishing department. Novell File Servers are used to provide DOS and Macintosh computers file and print services.

Ethernet was developed in the late 1970's by a consortium of DEC, Intel, and Xerox (DIX) that could provide a uniform wiring approach using coaxial cable.²¹ Additionally, it provides a connection architecture that creates a high speed backbone link shared by diverse and incompatible terminals and computers. The DIX Ethernet is commonly called Ethernet Type II. The DIX Ethernet was then modified by the IEEE which produced the IEEE 802.3 standard. Both types of Ethernet are in wide use today and operate at 10 Megabits per second.²² Most VAX and Unix systems communicate with DIX Ethernet, whereas Novell and Open Systems Interconnection (OSI) compatible devices communicate with 802.3 Ethernet. It is important to note that the two types of

²¹ Kessler, Gary C., "IEEE 802.6 MAN; An Overview of this Metropolitan Area Network Standard," *LAN Magazine*, April 1990, pp.102-116.

²² Derfler, Frank Jr., "Connectivity Simplified: An Introduction to the Ways of Networking," *PC Magazine*, March 31, 1992, pp. 251-287.

Ethernet differ in the packet header formats, and therefore devices communicating with Ethernet Type II cannot directly communicate with devices communicating IEEE 802.3 Ethernet.

IEEE 802.3 is the Carrier Sense Multiple Access/Collision Detection (CSMA/CD) protocol which is referred to as Ethernet. In CSMA/CD stations listen to the bus and only transmit when the bus is free. If a collision occurs, the packet is retransmitted after a random time out.²³

Token ring is an outgrowth of the designs created at IBM. Token ring is in wide use throughout the network industry. It is a ring topology that uses a hub concept. Each device is connected to a switch port on a token ring hub. This makes for a reliable LAN architecture. The IBM developed token ring was adopted by the IEEE, and was made into the 802.5 standard. Token ring runs at both 4 and 16 Megabits per second.²⁴

IEEE 802.5 uses the token ring protocol which is a ring topology where a token circulates around the ring, a station may transmit by seizing the token, inserting a packet onto the ring and then retransmitting the token.²⁵

Appletalk was designed by Apple Computer, and is the network operating system of all Apple computers. The networking software is built into the operating system which makes it easy to install and operate. Appletalk closely follows the OSI communications model. There is a file services layer that runs on top of Appletalk which is named Apple

²³Fetterolf, Peter, "Connectivity: The Sum of its Parts," *BYTE*, November 1991, pp.197-208.

²⁴Nance, Barry, "Interoperability Today," *BYTE*, November 1991, pp. 187-196.

²⁵Stallings, William, Local Networks, Third Edition, Macmillian Publishing Company, New York, New York, 1990.

File Protocol (AFP). Appletalk consists of three implementations: Ethertalk, Appletalk Phase I, and Appletalk Phase II. Ethertalk operates at 10 Mbps and Appletalk operates at 256 Kbps.²⁶

4.1.3 LAN Vendor Comparison

Vendor comparisons for SNA gateways, 10BaseT concentrators, token ring hubs, workstations, and personal computers are explained in this section. Each vendor is compared by their functionality and their price.

4.1.3.1 SNA Gateways

The following three vendors, that sell SNA gateway products, were compared:

1. DCA Communications IRMALAN Gateway,
2. Novell SNA Gateway,
3. Rabbit Software Corporation RabbitGate.

A gateway provides an interface at all protocol layers that allows the interconnection of the network to another system. The most common application of a gateway is to allow a workstation on a network to connect to another system as a terminal. Gateways are most often utilized on a WAN. These networks, unlike LAN's, are not bound by physical size. They provide a timely communication link between geographically separated nodes or networks. Most WAN's consist of either a packet-switching network or a direct

²⁶Derfler, Frank Jr., "LAN Fundamentals, Part 2: Low-Cost LANs Grow in Features and Performance," *PC Magazine*, April 14, 1992, pp. 299-350.

communication link between two nodes. SNA gateways provide Logical Units (LU) on the IBM front end. Generally, these LU's map to physical workstations.

4.1.3.1.1 DCA Communications Inc.²⁷

DCA Communications Inc. manufactures many SNA gateway products including the Intelligent Synchronous Communications Adapters (ISCA). The DCA software allows the user to access an SNA network from stand-alone workstations and from PC's on your LAN. The DCA Intelligent Synchronous Communications Adapter provides high-speed throughput for both Synchronous Data Link Control (SDLC) and X.25 Qualified Logical Link Control (QLLC) connectivity. The following are the description of ISCA key features:

- Micro Channel Architecture (MCA) and Industry Standard Architecture (ISA),
- Point-to-point or multi-point connection can be implemented, depending on the communications software,
- A data rate of up to 19.2 Kbps (Kilobits per second) is achieved, with an RS-232 connected to a modem,
- A data rate of up to 72 Kbps through a V.35 interface can be achieved,
- ISCA includes an on-board 80186 microprocessor running at 10 MHz (MegaHertz) and 512 Kilobits of parity-protected, zero-wait-state memory.

DCA's gateway software is called IRMALAN/EP. DCA IRMALAN Extended Platform SNA Gateway (IRMALAN/EP) provides flexible, resources-efficient access from

²⁷Specification data listings acquired from sales personnel from DCA Communications Inc.

personal computers on a LAN to an IBM SNA mainframe. A single gateway can support PC's running DOS and Microsoft Windows on IBM NETBIOS-compatible or Novell NetWare IPX/SPX (Internet Packet Exchange/Sequenced Packet Exchange) LAN's plus Apple Macintosh computers on Apple Talk LAN's.

The IRMALAN gateway gives each client access to the IBM host. The gateway software supports 802.2, and SDLC connections in NETBIOS, IPX/SPX, and AppleTalk LAN environment. Each IRMALAN 802.2 and SDLC gateway provides concurrent access for 8 to 128 users, depending on the gateway package purchased.

A single gateway can support client connections from NETBIOS and AppleTalk LAN's or from NetWare IPX/SPX and AppleTalk LAN's. The gateway handles dual protocol stacks for either of those combinations, routing data between them as necessary. DOS, Windows, and Macintosh clients provide host access through a single gateway in a variety of LAN environments.

4.1.3.1.2 Novell Inc.²⁸

Novell sells many types of gateways. The one that is used on the network is the SDLC gateway. The Novell Token-Ring gateway supports 97 users and up to 128 sessions. The SDLC gateway connects a LAN to the mainframe 37xx communications controller.

²⁸ Specification data listings acquired from sales personnel from Novell Inc.

4.1.3.1.3 Rabbit Software Corporation²⁹

Rabbit Software products let PC's communicate with minicomputers and mainframes, supporting SNA and bisync protocols and the SNA and OSI connectivity architecture. A Rabbit product allows a single user at a PC or many users in a workgroup-communication with one or more mainframes or minicomputers.

Rabbit Software's DOS based products allow PC's to connect to IBM mainframes by emulating IBM 3278 and 3279 terminals. Its 3270 line comprises local, remote, stand alone, and gateway connectivity products. The devices are interfaced to the host directly through coaxial cable or twisted-pair wire, or remotely through an RS-232 connection.

The DOS based line of products can be divided into two categories: stand alone (RabbitSTATION) and gateway (RabbitGATE). Within these two categories, products are available for both local and remote connections, which include either the bisync or SNA protocols.

Rabbit's DOS products operate on IBM PC/XT/AT, PS/2 computers, and compatibles, and requires a diskette drive or a hard disk. Bisync products operate at an aggregate rate of 19.2 Kbps.

The strength of the Rabbit products is with the use of the UNIX product family which is called Open Advantage. The products allow a 386-based computer operating under the UNIX, Xenix, or AIX operating system to communicate with a mainframe over dial-up

²⁹Specification data listings acquired from sales personnel from Rabbit Software Corporation.

or leased lines, as well as over X.25 packet switched networks. Like the DOS product line, the Open Advantage products offer bisync and SNA protocol compatibility. In addition, the Open Advantage products support standard Remote Job Entry (RJE) features, such as compression/decompression, point-to-point and multi-point communications, and unattended operation.

4.1.3.2 Token Ring Hubs

This section briefly describes vendors that manufacture Token Ring Hubs. There are well over 45 Token Ring Hub vendors.³⁰ The three vendors investigated are:

1. IBM,
2. Proteon Inc.,
3. Madge Networks Inc.

4.1.3.2.1 IBM³¹

The token ring hubs manufactured by IBM are the standard by which the other hubs are compared. The IBM token ring hub provides no network management capability. The token ring topology utilizes a hub architecture which is comprised of Multi-Station Access Units (MAU's) and have the following characteristics:

³⁰*Data Communications*, "1993 Product Selection Guide Issue," October 15, 1992, Volume 21, Number 15.

³¹Specification data listings acquired from sales personnel from IBM.

1. Used for Token passing access method developed by IBM that adheres to the IEEE 802.5 standards,
2. Supports baseband transmission at 4 Mbps (Megabits per second),
3. Ring failure is prevented by bypass switching in the MAU to which each PC connects,
4. Allows up to 8 PC's to be connected to each MAU.

4.1.3.2.2 Proteon Inc.³²

Proteon Series 70 token ring hubs are IBM-compatible, multi-station access units offering high reliability and excellent network management capabilities. However, the network management must be performed out-of-band which requires additional cabling.

4.1.3.2.3 Madge Networks Inc.³³

Madge Networks Madge 8 station Ringhub is IBM compatible and allows 8 computers to connect to an 802.5 network. The Ringhub is identical in functionality as the IBM token ring hub and provides no network management capability.

4.1.3.3 10BASE-T Concentrators

There are well over 60 vendors that manufacture 10BaseT hubs.³⁴ 10BASE-T allows organizations to reduce costs by using the same twisted-pair type of cabling for both

³² Specification data listings acquired from sales personnel from Proteon Inc.

³³ Specification data listings acquired from sales personnel from Madge Networks Inc.

³⁴ *Data Communications*, "1993 Product Selection Guide Issue," October 15, 1992, Volume 21, Number 15.

telephone and computer communications. Furthermore, users can communicate over most previously installed wires, saving the time, expense, and inconvenience of installing additional cable. The three 10BASE-T vendors which were investigated are:

1. 3COM LinkBuilder,
2. Cabletron,
3. Synoptics Lattisnet.

4.1.3.3.1 3COM Corporation³⁵

The 3COM LinkBuilder product line provides comprehensive management of coaxial, twisted pair and fiber Ethernet wiring installations. LinkBuilder can use the star topology cabling systems that are already installed in most office buildings as an economical platform for running managed 10-Mbps Ethernet local area networks.

The LinkBuilder offers modularity and flexibility, allowing the network administrator to plan efficiently for current and future user requirements and network configurations. Additionally, it reduces material and installation costs through easy integration into most existing cabling systems. It also simplifies management by allowing easy modifications to the network, which eliminates the disruptive and expensive cable reconfiguration.

The LinkBuilder provides a single-source cabling solution from a recognized leader in data networking. It can be managed centrally along with a range of other networking components and environments using 3COM's planned network management system

³⁵Specification data listings acquired from sales personnel from 3COM Corporation.

(based on Open Management Architecture) or other Simple Network Management Protocol (SNMP) based hub management system.

This hub is comprised of modules that perform different functions. The 10BASE-T Host Module provides communication channels over unshielded twisted pair link segments. It is equipped with 12 RJ-45 modular receptacles to support host device connections to compatible transceivers and network interface cards. The module incorporates a sophisticated link integrity scheme that protects the network from failed equipment and maintains performance in case of broken link segments.

4.1.3.3.2 Cabletron Systems Inc.³⁶

Cabletron Systems provides a family of IEEE 802.3 10BASE-T twisted pair products. These products include four different types of media modules for 10BASE-T, offering users a variety of ways to connect to unshielded or shielded twisted pair wiring. Each module contains twelve or twenty four connections and can be plugged directly into any of the chassis. Different modules integrate into Cabletron's management technologies, allowing users to track usage, display errors, set alarms, and route data.

4.1.3.3.3 Synoptics Communications Inc.³⁷

Synoptics Communications Inc., the market leader, manufactures many 10BaseT hubs. The Synoptics LattisNet model 2800 10BASE-T Workgroup Concentrator is used for small low-density Ethernet networking environments. The model 2800 is compatible

³⁶ Specification data listings acquired from sales personnel from Cabletron Systems Inc.

³⁷ Specification data listings acquired from sales personnel from Synoptics Communications Inc.

with IEEE 802.3 Type 10BASE-T which specifies the operation of the Ethernet at 10 megabits per second over unshielded twisted pair wire. The concentrator resides in a wiring closet, where it implements networks in an active hierarchical star configuration over a building's structured cabling system.

Each Model 2800 features 12 RJ-45 modular receptacle host ports for unshielded twisted pair wire connections. An Attachment Unit Interface (AUI) interconnect port allows the Model 2800 to connect to a variety of other cabling and backbones, such as thick and thin coaxial cabling or fiber optic cable, via an external transceiver. Front panel LED indicators reports incoming and out going data, collision and AUI port auto-partitioning status. Per-port LED's indicated partition and link status on an individual port basis.

The Model 2800 can be configured alone to support single networks of 12 users, or they can be linked via the AUI interconnect port to create larger networks supporting 100 or more nodes. A convenient MDI-X/MDI switch on the front panel enables concentrators to be interconnected using straight-through unshielded twisted pair cable.

4.1.3.4 Workstations

The following workstations vendors were considered:

1. DEC,
2. Hewlett Parkard,
3. IBM,
4. Silicon Graphics Inc. (SGI),

5. Sun Microsystems.

With the rise of engineering workstations to new heights of power and popularity, each of the major computer vendors has added to the market their version of a UNIX RISC workstation. The expression "Reduced Instruction Set Computer" (RISC) refers to the processing Central Processing Unit (CPU) architecture of the workstation. Improved performance is obtained by either reducing the number of machine instructions or reducing the complexity of the instructions. Both methods allow the processor to be designed to execute the majority of the instructions in one CPU clock cycle. This allows the workstation to execute certain instructions at much greater speeds than is otherwise possible.³⁸

Technology is advancing so rapidly and competition between vendors is so intense that UNIX product standings change every few months. A workstation that appears to be at the bottom of today's competition could be at the top within weeks. A comparison table of UNIX workstation platforms is shown in Table 4.3.

³⁸Datapro Information Services Group, Datapro Reports on UNIX Systems & Software, McGraw Hill Inc., Delran, New Jersey, October 1991.

Table 4.3: Workstation Comparison Table

	DEC ³⁹	HP ⁴⁰	IBM ⁴¹	SGI ⁴²	SUN ⁴³
Model	DEC3000 500AXP	HP Model 735	RS/6000 POWER Station 580	IRIS Crimson Elan	SPARC Station 10/41
SPECint92 *	71.3	80	59	58.3	52.6
SPECfp92 +	121.8	150.6	125	61.5	64.7
Microprocessor	DEC chip 21064 (Alpha)	PA-RISC 7100	POWER RISC	MIPS R4000SC RISC	Super SPARC
Memory max capacity	1 GB	400 MB	1 GB	256 MB	512 MB
Disk Storage max. capacity	125 GB	125 GB	133 GB	74 GB	26 GB
CPU Cycle Time	150 MHz	99 MHz	63 MHz	50 MHz	40 MHz
Operating System	Open VMS or OSF/1	HP-UX	AIX	IRIX	Solaris
Purchase Price (basic configuration)	\$39K	\$37.4K	\$72K	\$75K	\$25K

* SPECint92 measures the performance of a single processor's integer units generated by running multiple copies of integer tests simultaneously and reflect the increased throughput of a multiprocessor system.

+ SPECfp92 measures the performance of a single processor's floating point units generated by running multiple copies of floating point tests simultaneously and reflect the increased throughput of a multiprocessor system.

SPEC is a trademark of the Standard Performance Evaluation Corporation, Fairfax, VA.⁴⁴

³⁹ Specification data listings acquired from sales personnel from Digital Equipment Corporation.

⁴⁰ Krill, Paul, "HP Adds Faster Boxes, Retains Its Speed Lead," *Open Systems Today*, November 16, 1992, pp. 1-5.

⁴¹ Krill, Paul, pp. 1-5.

⁴² Specification data listings acquired from sales personnel from Silicon Graphics Inc..

⁴³ Specification data listings acquired from sales personnel from Sun Microsystems Computer Corporation.

⁴⁴ Krill, Paul, "HP Adds Faster Boxes, Retains Its Speed Lead," *Open Systems Today*, November 16, 1992, pp. 1-5.

4.1.3.5 Personal Computers

The following PC/File Server vendors were considered:

1. Compaq,
2. Dell Systems,
3. Gateway 2000,
4. IBM,
5. Zeos International Ltd.

The term "Server" is often used for many different types of servers on a LAN. There are three classic roles of a network server:

1. Print Server,
2. Communications Server,
3. File Server.

However, the print, communications, and file server functions are often combined into one PC referred to as a "File Server". The file servers available today do much more than just provide networked PC's with access to shared files and subdirectories. They have become hosts for database engines that provide responses to application programs' complex queries; they communicate with uninterruptable power supplies and take the appropriate actions when the power goes out; they run network management and monitoring programs; and they even hold hubs for 10BaseT UTP systems. All the tasks

of the file server rely on fast disk storage, a large amount of memory for cache, and a fast internal bus architecture.

Twenty two of the leading manufacturers of file servers believe that their file servers should be used on a Novell Netware network, a Network Operating System (NOS).⁴⁵ Novell's Netware is often considered the File Server standard in industry since Novell is an open systems company dedicated to standards.⁴⁶ Novell supports products which coexist with and connect to DOS, Macintosh, UNIX and DEC environments.

The advantages of the 32 bit Extended Industry Standard Architecture (EISA) and MCA buses over the 16 bit ISA bus are not obvious in typical DOS applications. However, when selecting a PC or File Server it is important to consider how much data traffic the computer will need to direct. When selecting a file server it is important to review an EISA bus, capable of a 33 Mbps transfer rate, or an MCA bus, capable of a 20 Mbps transfer rate.⁴⁷ A comparison table of File Servers, which may differ in their configurations, is shown in Table 4.4. In addition, when selecting a PC to be used for desktop applications it is important to review an ISA bus which is only capable of a 4 Mbps transfer rate.⁴⁸ A comparison table of PC's, which may differ in their configurations, is shown in Table 4.5.

⁴⁵Derfler, Frank Jr., "File Servers," *PC Magazine*, March 17, 1992, pp. 187-281.

⁴⁶Netware Buyer's Guide, Novell Inc., Provo, Utah, October 1991.

⁴⁷Quain, John R., "Power Gets Cheaper," *PC Magazine*, February 11, 1992, pp. 113-205.

⁴⁸Quain, John R., "Power Gets Cheaper," *PC Magazine*, February 11, 1992, pp. 113-205.

Table 4.4: File Server Comparison Table⁴⁹

	Compaq	Dell	Gateway	IBM	Zeos
Model	Systempro/LT 486/33-510	PowerLine 433DE	4DX2-33E	PS/2 Model 95 XP 486	486-33E
Bus Architecture *	EISA	EISA	EISA	MCA	EISA
RAM (standard)	8 MB	32 MB	16 MB	16 MB	16 MB
min capacity	8 MB	4 MB	8 MB	4 MB	1 MB
max capacity	64 MB	96 MB	64 MB	64 MB	32 MB
Cache RAM	N/A	128K	256K	256K	128K
Disk Storage (standard)	510 MB	660 MB	1 GB	1.6 GB	660 MB
min. capacity	120 MB	80 MB	40 MB	80 MB	42 MB
max. capacity	4.08 GB	1.4 GB	1.2 GB	1.6 GB	1.16 GB
Floppy Disk Drive Configuration	1.2 MB or 1.44 MB	1.2 MB	1.2 MB & 1.44 MB	1.2 MB & 1.44 MB	1.2 MB & 1.44 MB
Expansion 32-bit slots	8 (6 open)	6 (5 open)	8 (4 open)	8 (5 open)	8 (4 open)
Standard Display Mode	800 x 600 pixels	1024 x 768 pixels	1024 x 768 pixels	800 x 600 pixels	1024 x 768 pixels
Display RAM	512K	512 KB	1 MB	256 KB	1 MB
Display Size	14" inch	14" inch	14" inch	14" inch	14" inch
Power Supply (watts)	355	224	200	329	450
Operating System	MS-DOS 5.0	MS-DOS 5.0	MS-DOS 5.0	MS-DOS 5.0	MS-DOS 5.0
Purchase Price (basic configuration)	\$8,171	\$6,388	\$2,895	\$14,455	\$3,395

* EISA and MCA are based on a 32 bit bus architecture.

⁴⁹Table compiled from various *PC Magazines* and from various *PC Week* publications.

Table 4.5: PC Comparison Table⁵⁰

	Compaq	Dell	Gateway	IBM	Zeos
Model	ProLinea 4/33	486-25SX	4DX-33	PS/1 2155-G44	486-33
Bus Architecture *	ISA	ISA	ISA	ISA	ISA
CPU Cycle Time	33 MHz	25 MHz	33 MHz	20MHz	33 MHz
RAM (standard)	4 MB	4 MB	8 MB	4 MB	4 MB
min capacity	4 MB	4 MB	4 MB	4 MB	4 MB
max capacity	32 MB	64 MB	64 MB	32 MB	64 MB
Cache RAM	256K	32K	64K	32K	32K
Disk Storage (standard)	240 MB	170 MB	250 MB	170 MB	130 MB
min capacity	120 MB	80 MB	80 MB	85 MB	42 MB
max capacity	240 MB	500 MB	500 MB	211 MB	1.16 GB
Floppy Disk Drive Configuration	1.2 MB & 1.44 MB	1.44 MB	1.2 MB & 1.44 MB	1.2 MB & 1.44 MB	1.2 MB & 1.44 MB
Expansion slots					
8-bit, 16-bit, 32-bit	0, 3, 0	0, 3, 0	0, 5, 0	0, 5, 0	1, 7, 0
Standard Display Mode					
	800 x 600 pixels	800 x 600 pixels	1024 x 768 pixels	800 x 600 pixels	1024 x 768 pixels
Display RAM	1 MB	1 MB	1 MB	512KB	1 MB
Display Size	14" inch	14" inch	14" inch	13" inch	14" inch
Power Supply (watts)	146	146	200	95	200
Operating System	MS-DOS 5.0	MS-DOS 5.0	MS-DOS 5.0	MS-DOS 5.0	MS-DOS 5.0
Desktop Manager	Windows 3.1	Windows 3.1	Windows 3.1	Windows 3.1	Windows 3.1
Purchase Price (basic configuration)	\$2,250	\$1,948	\$1,995	\$1,999	\$2,095

* ISA is based on a 16 bit bus architecture.

⁵⁰Table compiled from various *PC Magazines* and from various *PC Week* publications.

4.1.4 LAN Equipment Choices

The following products were chosen to implement the SNA gateway, Token Ring Hubs, 10BaseT concentrators, Personal Computers, and Workstations. The IRMALAN EP product line was chosen to implement the SNA gateway because it is the only product evaluated that has Macintosh and DOS support. Madge Networks token ring hubs were chosen due to cost and compatibility with IBM hubs. The Synoptics 10BaseT hubs were chosen due to their market leadership, cost, and network management capability.

Silicon Graphics Workstations were chosen to implement the CAD/CAM operations since Silicon Graphics specializes in high-end graphic workstations, commonly referred to as visualization or visual processing systems. These workstations provide the extreme high graphics and computational performance required by applications such as CAD, CAM, animation, and visual simulation. In addition to the highly priced Silicon Graphics Workstations, the HP and DEC Workstations were chosen for engineering and CAD/CAM operations. These two vendor's workstations were chosen based on speed, performance, and price since most of the workstations available on the market today will be outdated in approximately 5 years.

The Novell Netware NOS was selected as the type of File Server since Novell is an open systems company dedicated to standards. The Gateway 2000 personal computers were chosen since they manufacture a File Server and a PC which provides the most performance and features and quickest speed for the dollar. In addition, the cost for the Gateway 2000 File Server was the least among the vendors reviewed. The actual PC or File Server (a 25, 33, 50, or 66 MHz with a 286, 386, or 486 chip) which will be

purchased will be based on the application which requires the PC. For example, a PC which will be used solely as a word processor would require only a 286 based PC. Table 4.6 lists the new computer equipment and their associated functions which FONEX could incorporate in their design.

Table 4.6 (a): New Equipment

LOCATION	TYPE	QUANTITY	FUNCTION
HEADQUARTERS	NOVELL File Server	5	LAN applications and office automation
	DEC / VAX	2	Engineering and Test
	SGI W/S	2	Engineering and Prototyping
	DEC W/S	2	Engineering and Prototyping
	PC's	50	LAN applications, office automation, and business applications
RESEARCH AND DEVELOPMENT	HP W/S	12	CAD/CAM and Engineering
	DEC W/S	12	CAD/CAM and Engineering
	SGI W/S	12	CAD/CAM and Engineering
	NOVELL File Server	1	LAN applications and office automation
SHIPPING AND RECEIVING	PC's	25	Business applications, database, and quality assurance
	Gateway	1	WAN/LAN access
	NOVELL File Server	1	LAN applications and office automation

Table 4.6 (b): New Equipment

LOCATION	TYPE	QUANTITY	FUNCTION
SUPPLIERS	PC's	10	Business applications, database, and quality assurance
	Gateway	1	WAN/LAN access
	NOVELL File Server	1	LAN applications and office automation
MANUFACTURER	DEC/VAX	2	Manufacturing Automation Protocol (MAP)
	TERMINALS	200	Production Line
	NOVELL File Server	1	LAN applications and office automation
	Gateway	1	WAN/LAN access
	PC's	6	Business applications, database, and quality assurance
	SUN SPARC Server	2	CAD/CAM and Engineering
	HP W/S	12	CAD/CAM and Engineering
SGI W/S	12	CAD/CAM and Engineering	
MARKETING	PC's	10	Marketing, business applications, and database
	Gateway	1	WAN/LAN access
	NOVELL File Server	1	LAN applications and office automation

4.2 LAN Design / Implementation

Headquarters

Headquarters is the most complicated LAN. There are a number of LAN's connected through the use of an Ethernet Backbone. The Ethernet is comprised of a Thin-Net and 10Base2 Ethernet segments. It is important to note that this backbone is housed in a single room and is very reliable. Thin-Net Ethernet can be an unreliable topology if the segments are not kept intact and stable. The mainframe is accessed via SNA gateways connected to the Front End Processor (FEP) and backbone. Workstations operate software that provides an interface to the mainframe as a 3270 terminal. Novell file servers are used to route traffic onto the backbone and allow workstations to have access to large disks and printers. A Network Interface Unit (NIU) provides access to the Wide Area Network and ties together remote LAN's. The following drawings, Figures 4.2, 4.3, 4.4, depict the LAN architecture of the Headquarters.

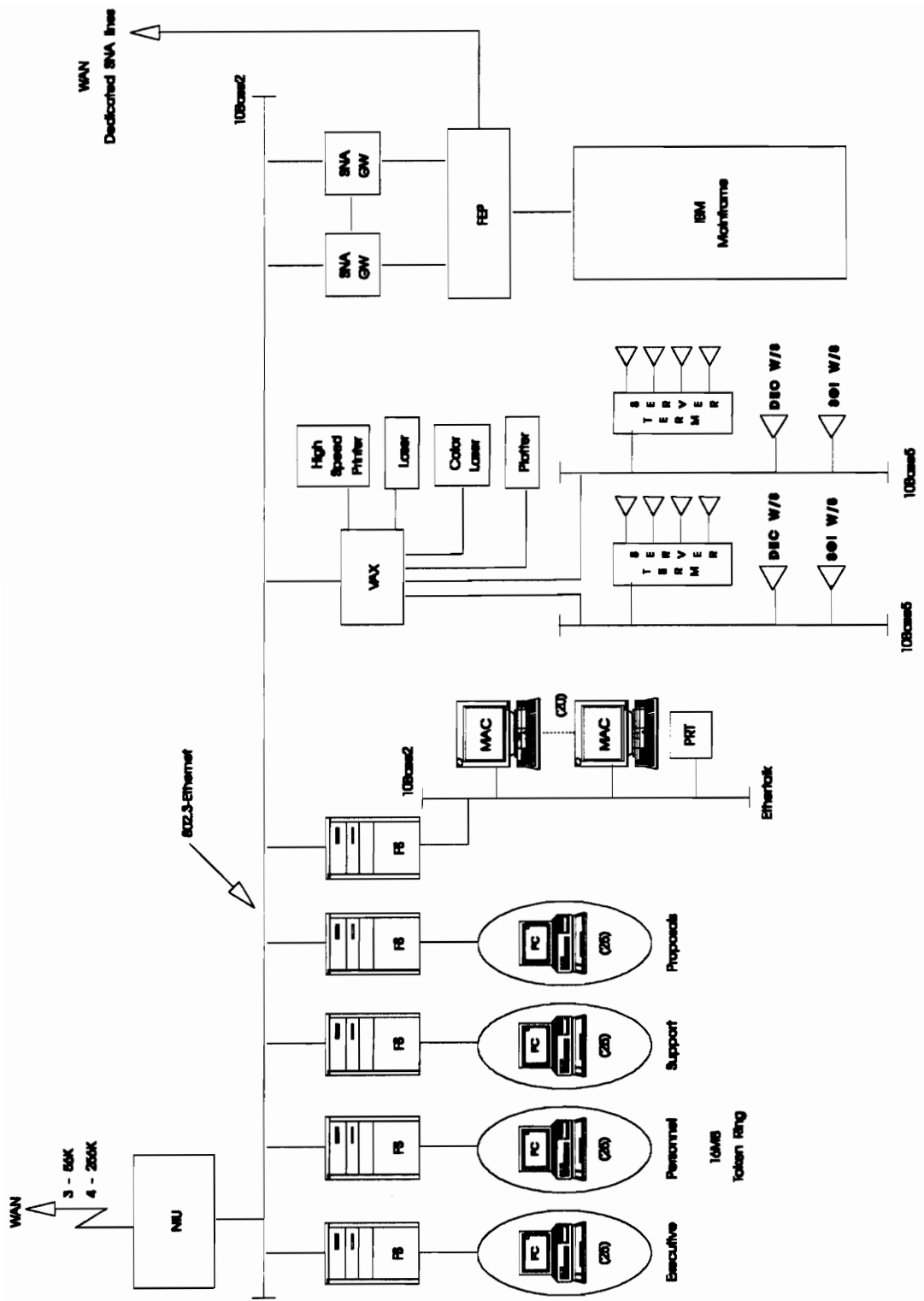


Figure 4.2: The LAN Configuration at Headquarters

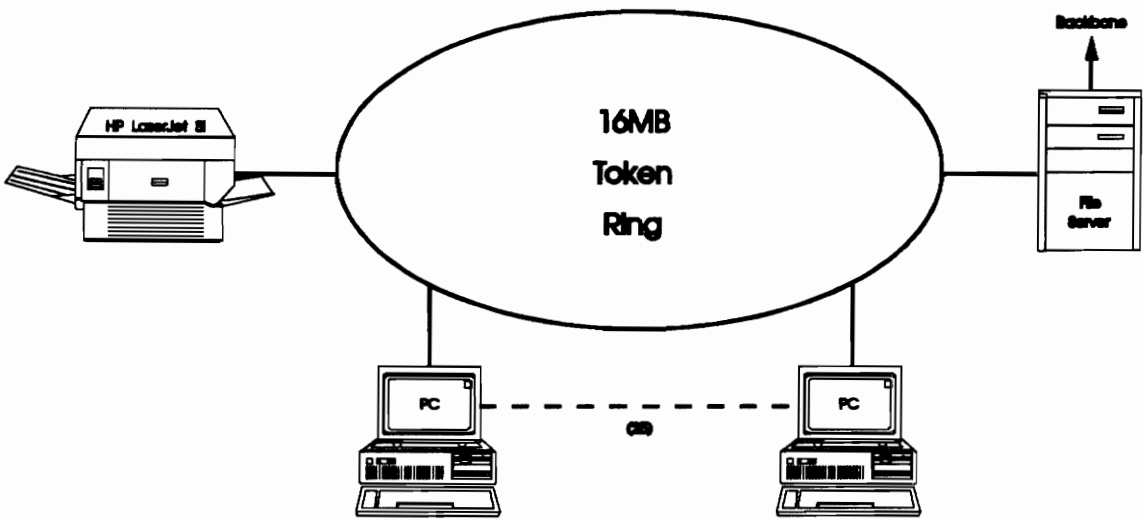


Figure 4.3: The Execute, Personnel, Administrative, and Support Configuration at Headquarters

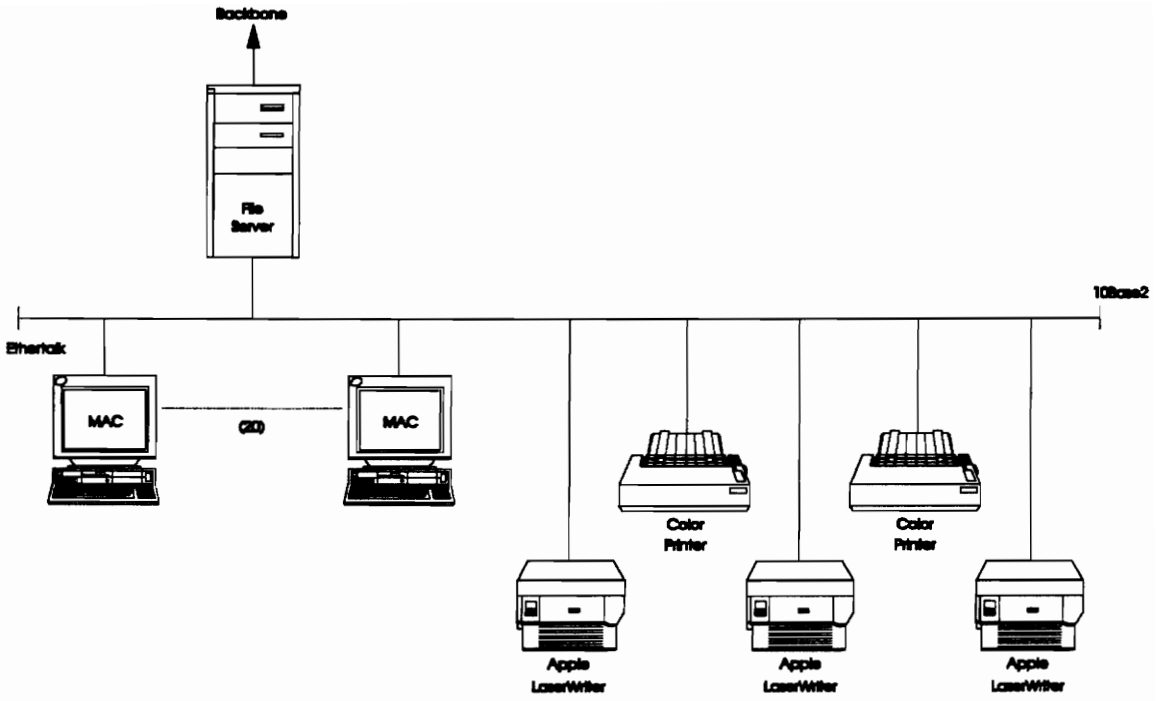


Figure 4.4: The Publishing Configuration at Headquarters

Research and Development

The Research and Development LAN is implemented using a number of Ethernet LAN's connected through the use of an Ethernet Backbone. The Ethernet is comprised of Thin-Net and 10BaseT Ethernet segments. Novell file server is used for the Administration Division, with IBM PC's and a networked HP printer. SUN SPARC servers and a combination of SPARC, HP, SGI, and DEC workstations are used for the rest of the divisions. Novell and SUN SPARC servers are used to route traffic onto the backbone and allow workstations to have access to the large disks and printers. An NIU provides access to the Wide Area Network and ties together remote LAN's. It is important to note that the SUN SPARC servers and the Novell File Servers provide routing capability via their dual network adapters. This is a cost effective method for connecting two LAN segments together. Figure 4.5 depicts the LAN architecture of the research and development facility.

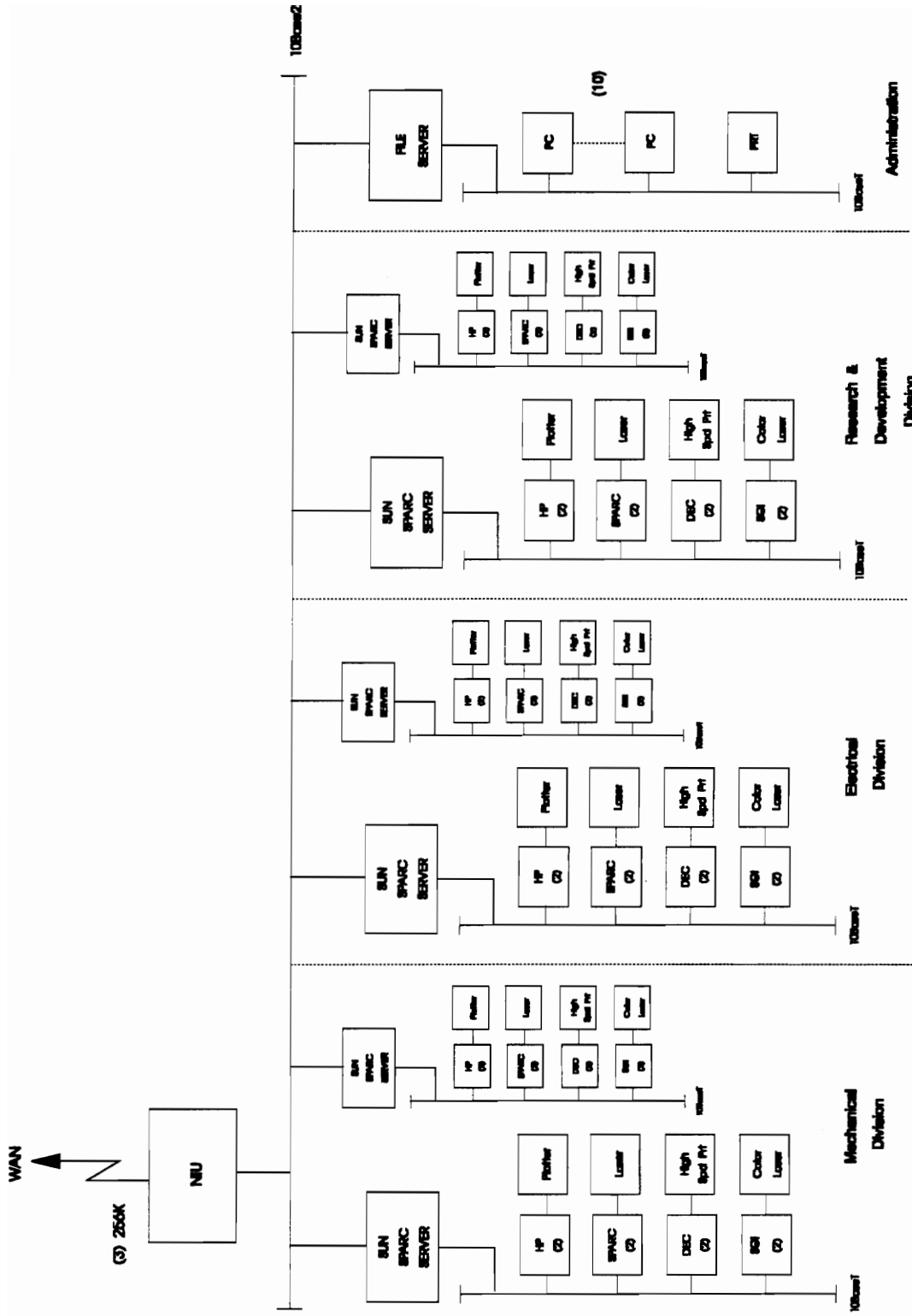


Figure 4.5: The LAN Configuration at the Research and Development Facility

Shipping and Receiving

The Shipping and Receiving facility is designed with a simple Ethernet LAN with no switches or repeaters. Devices are attached to the hub with stub cables, which are comprised of 10BaseT Ethernet segments. The Novell file server acts as a Router between the 10BaseT LAN and the 10Base2 Ethernet Backbone. The SNA Gateway provides access to the Headquarters IBM mainframe computer. Figure 4.6 depicts the LAN architecture of the shipping and receiving facilities.

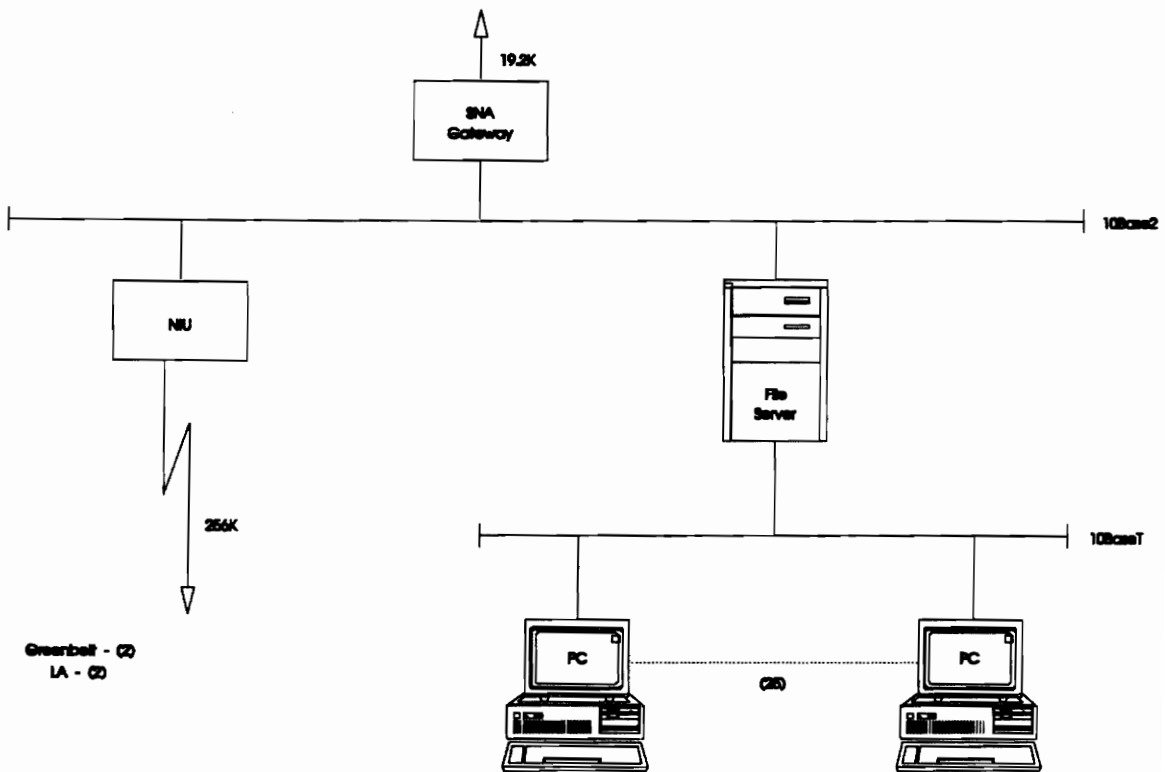


Figure 4.6: The LAN Configuration at the Shipping and Receiving Facilities

Manufacturing

The Manufacturing facilities are also complicated LAN's. The Backbone connects the VAX, Novell, and NIU together using a 10Base2 Ethernet segment. The SUN SPARC servers and the SGI and HP workstations are used to download the CAD/CAM data from the Research and Development facility via the NIU. Each DEC VAX has 100 terminals connected to it via terminal servers which take ASYNC data and convert it to Ethernet for access to the VAX. The terminal servers serve as an entry point for the DEC systems. The PC's access the mainframe via the Network Interface Unit and the SNA gateways which are located in the Headquarters data center. Figure 4.7 depicts the LAN configuration of the Manufacturing facilities.

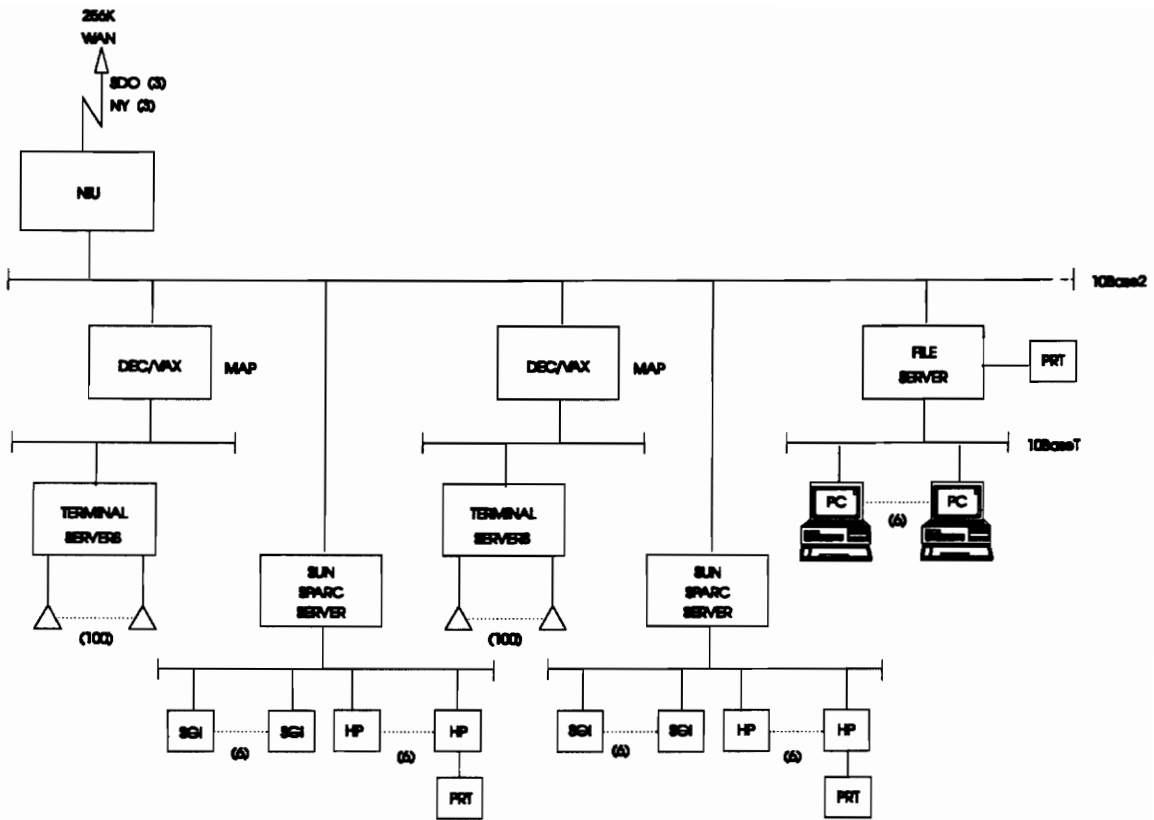


Figure 4.7: The LAN Configuration at the Manufacturing Facilities

Marketing

The Marketing facilities are identical to the Shipping and Receiving facilities, with a simple 10BaseT Ethernet LAN connected to a 10Base2 Ethernet Backbone through a Novell file server. Figure 4.8 depicts the LAN configuration of the Marketing facilities.

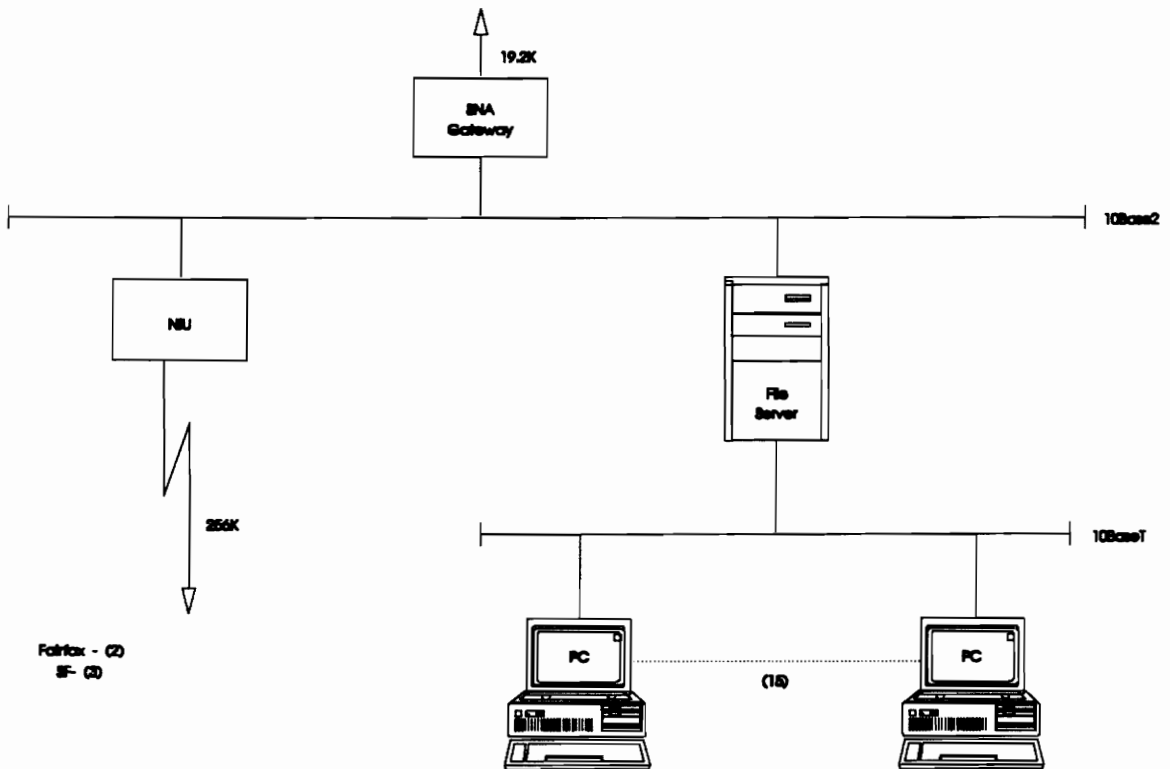


Figure 4.8: The LAN Configuration at the Marketing Facilities

Suppliers

The Supplier's facilities are also identical to the Shipping and Receiving facilities, with a simple 10BaseT Ethernet LAN connected to a 10Base2 Ethernet Backbone through a Novell file server. Figure 4.9 depicts the LAN configuration of the Supplier's facilities.

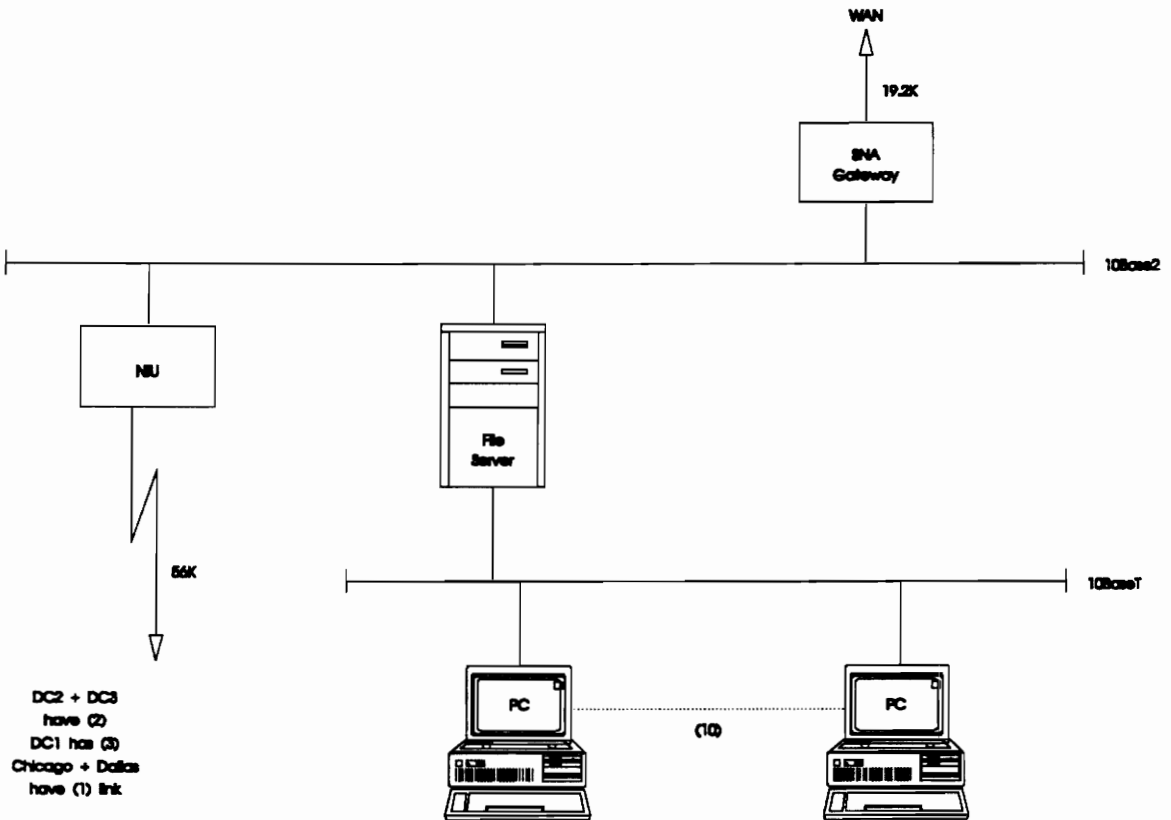


Figure 4.9: The LAN Configuration at the Supplier's Facilities

4.3 LAN Cost

This section addresses the LAN costs for designing the LAN configurations described in section 4.2. Only the six components evaluated were priced to provide a sample of what particular LAN components cost and to demonstrate the funding involved in implementing a network. A per client cost is provided for the comparison of the SNA Gateways, the Token Ring Hubs, the 10BaseT Hubs, and the Workstations.

The SNA gateway manufactured by Novell costs approximately \$30 per LU, DCA Communications IRMALAN/EP costs approximately \$93 per LU, and the Rabbit gateway costs approximately \$124 per LU.

The Token Ring Hubs by IBM and Madge are close in price and in quality, however Madge is slightly less expensive. The Proteon Hubs are more expensive, however Proteon Hubs provide better network management and have better diagnostic capabilities. IBM Token Ring Hubs are approximately \$100 per port, Proteon Hubs cost \$150 per port, and Madge hubs cost \$90 per port.

The Ethernet 10BaseT Hubs vary in price. The 3COM and Cabletron prices are close in price because both are high end products. However, Synoptics 10BaseT hubs are very competitive and provide the same capability. All of the hubs have excellent network management. Additionally, 3COM and Synoptics have a larger installed base. Cabletron 10BaseT hubs are more flexible and therefore cost \$229 per port, Synoptics 10BaseT hubs cost \$180 per port, and 3COM hubs cost \$357 per port.

Workstations all vary in price based upon speed, performance, microprocessor, disk storage, system memory, and graphics capabilities. The use of benchmarks and product specifications are important guidelines when selecting a workstation. In addition, subjective differences, such as graphic preferences, must also be taken into consideration. Upgrade options are another important consideration when selecting a workstation, considering the pace of improvement in the workstation market. The ability to integrate the prospective workstations and servers into a network must always be considered. Using these considerations, along with compliance with open systems and industry standards, the HP workstations (costing \$37,400 a piece) and DEC workstations (costing \$39,000 a piece) were chosen. The Silicon Graphics workstations, costing \$75,000 a piece, were chosen for their high-end graphics capabilities. The Silicon Graphics workstation will be used to support the CAD/CAM operations.

File Servers and PC's also vary in price based upon speed, performance, microprocessor, bus architecture, disk storage, system memory, and graphics capabilities. However, when selecting a PC it is important to first decide what functionality will be performed on the PC, and then based on that functionality determine the microprocessor (286, 386, or 486), the bus architecture (ISA, MCA, or EISA), and the speed (25, 33, 50, or 66 MHz) which is needed for the specific application. When the microprocessor, the bus architecture, and the speed have been determined it is important to select a vendor which provides that type of PC with the most performance for the dollar. In addition, upgradability can also be another consideration based on the applications which are to be used on the PC. Therefore using these considerations, the Gateway 2000 PC's and File Servers were chosen since they provide PC's and File Servers, of all types, which have the most performance for the dollar in each of the different types. The Gateway 2000

486 33 MHz EISA File Server costs \$2,895 a piece and the 486 33 MHz ISA PC costs \$1,995 a piece.

The LAN's utilize Token Ring, 10BaseT/10Base2/10Base5 Ethernets, and Appletalk. The SNA gateways provide access to the mainframe for the PC and Macintosh computers. The workstations meet the demanding computing requirements of a manufacturing information system, and provide the vast memory and storage capabilities, along with a high-resolution graphics display. The File Servers and PC's provide the functionality for the LAN, office automation, business, database, quality assurance, and marketing applications. The following hardware will be needed to be purchased in order to implement this LAN:

- 14	DCA SNA Gateways	\$1,302
- 4	Madge Token Ring Hubs	\$720
- 15	Synptics 10BaseT Concentrators	\$2,700
- 24	Hewlett Packard Workstations	\$897,600
- 14	DEC Workstations	\$546,000
- 26	Silicon Graphics Workstations	\$1,950,000
- 17	Gateway File Servers	\$49,215
- 182	Gateway PC's	\$393,090

The total cost for purchasing the LAN hardware is approximately \$3,810,627. In conclusion, the LAN is designed using current technology which meets the functional requirements detailed in section 3.3 and the system operational requirements stated in section 4.1.1.

5. WIDE AREA NETWORK

This section identifies the following: a feasibility study for FONEX's Wide Area Network (WAN), the system operational requirements of the WAN, the protocols used with the design of their WAN, the WAN design, how the WAN will be implemented, a vendor comparison, the equipment choice, and the total cost for implementing the WAN.

5.1 WAN Feasibility Study

A detailed description of the NIU's requirements and protocols are discussed within this section. The NIU is a microprocessor based device which is used to provide data transmission to one or more attached devices. The NIU therefore transforms the data rates and protocols of the attached devices to the local network transmission medium and vice versa. The NIU has the capabilities to perform the following functions:

- accepts data from attached devices,
- buffers data,
- transmits data in addressed packets,
- scans packets on medium for own address,
- transmits data on attached device at the proper data rate.

The NIU can be either a bridge or a router. The bridge is a device used to connect two or more LAN's that use identical LAN protocols. The bridge operates at layer 2 of the OSI model (Data Link Layer), reference Figure 5.1. The bridge acts as an address filter,

which picks up packets from one LAN that are intended for a destination on another LAN and transmits those packets to their destination. The bridge does not modify the contents of the packets and does not add anything to the packets. Bridges have the following advantages and disadvantages:

Advantages

- reasonably priced,
- easy to configure,
- requires little training to use effectively,
- capable of learning device addresses,
- very fast,

Disadvantages

- prohibits a "closed loop" topology (reference Figure 5.2),
- interconnect only similar LAN types,
- broadcast messages that can be sent everywhere in the network,
- "broadcast storms" - packets contain a destination address which doesn't exist (homeless packet).

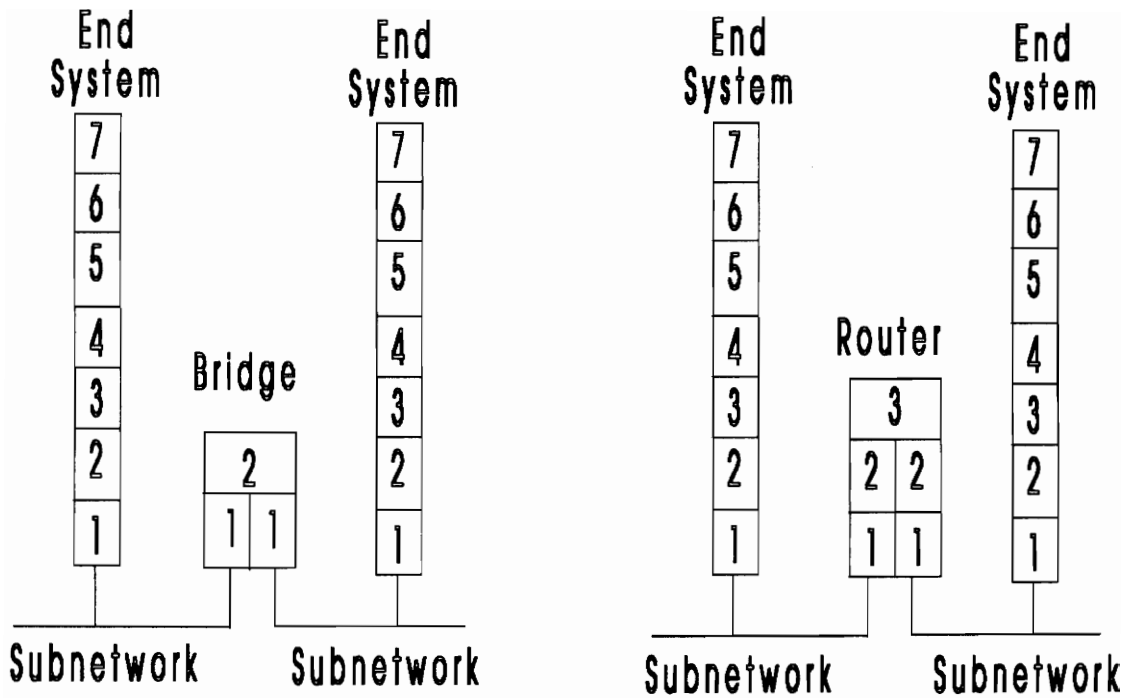
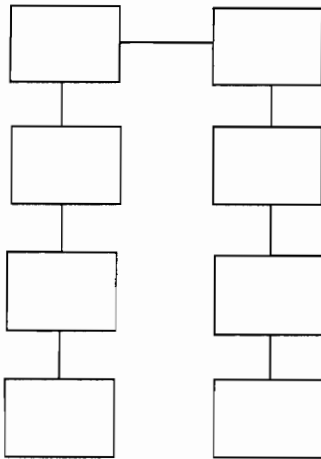


Figure 5.1: Bridges versus Routers

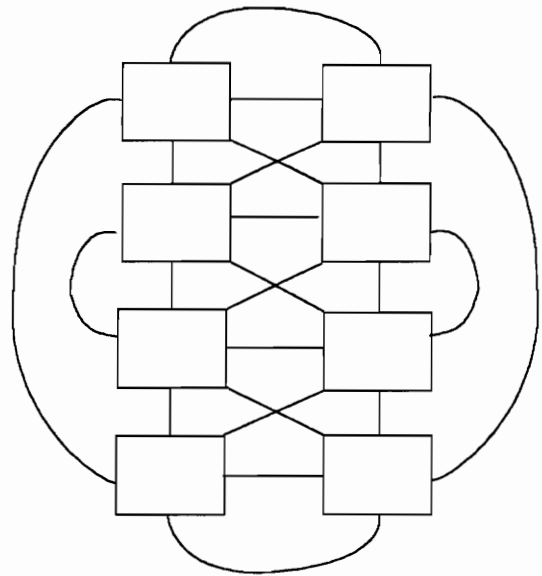
Bridge Topology

No 'Loops' Allowed



Router Topology

Allows Mesh Network Configuration



LEGEND:

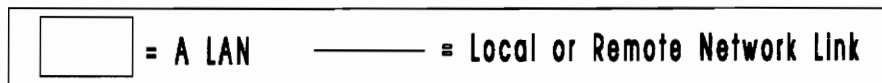


Figure 5.2: Bridge Topology versus Router Topology

The router is a device used to connect two or more networks that may or may not be similar. The router operates at layer 3 of the OSI model (Network Layer), reference Figure 5.1. The router employs an internet protocol which is present in each router and in each host of the network. The router will route each packet to a specific LAN, and therefore will modify or add to the contents of each packet. Routers have the following advantages and disadvantages:

Advantages

- permits configurations with a mesh topology (reference Figure 5.2),
- filters the data types which reduces "broadcast storms",
- interconnects any LAN types,
- provides alternate path routing,
- transmits packets to its destination LAN directly,

Disadvantages

- expensive,
- difficult to configure,
- need to configure with all networks and device addresses,
- requires significant training to use effectively.

5.1.1 WAN System Operational Requirements

The following system operational requirements were established to be used in the evaluation of an appropriate vendor of an NIU:

1. The NIU shall provide a bandwidth which is capable of supporting data rates from 56 Kbps to 1544 Kbps,
2. The NIU shall provide a serial interface connection which is capable of supporting a RS-449/422 medium,
3. The NIU shall provide a console port, for supporting the monitoring and control functions of the network, via a RS-232 medium,
4. The NIU shall provide a LAN interface connection which is capable of supporting an Ethernet IEEE 802.3 medium,
5. The NIU shall have the capability to perform a self test,
6. The NIU shall be capable of supporting closed loop configurations,
7. The NIU shall provide software which is capable of performing a remote or local network status and network testing,
8. The NIU shall be capable of a simple setup by providing self configuration,
9. The NIU shall not limit the network from the ability of expansion.

5.1.2 WAN Protocols

This section identifies the protocols supported by the NIU which are to be evaluated in conjunction with the system operational requirements listed in section 5.1.1.

Spanning Tree Protocol (STP)

As stated earlier, bridges prohibit a "closed loop" topology, therefore there is a need for loop detection. To illustrate the limitation, consider the simple network shown in Figure 5.3. If the pairs of bridges between the two LAN's are unaware of the existence of the other bridges, Station A will transmit a packet at time t_0 to Station B. Bridge 1 and 3 will each pass packets onto Bridges 2 and 4. Bridge 2 will retransmit the packet to LAN Y at time t_1 , and Bridge 4 will retransmit the packet to LAN Y at time t_2 . This is unacceptable, since Station B will receive two copies of the packet and might treat the two copies as separate packets. However, a more serious problem is that Bridge 2 and 4 will receive each other's transmission on LAN Y. Hence, Bridge 2 and 4 will not be capable of forwarding a packet to Station A because each bridge thinks that Station A is on its local network (LAN Y).⁵¹

A protocol, called Spanning Tree Protocol, was developed which enabled bridges to overcome the problem of a "closed loop" topology. STP was adopted, in 1989, as an International Standard by the subcommittee of the IEEE responsible for the standardization of LAN bridging, STP is known as 802.1d.⁵²

⁵¹ Stallings, William, Local Networks, Third Edition, Macmillian Publishing Company, New York, New York, 1990.

⁵² Fetterolf, Peter, "Connectivity: The Sum of its Parts," *BYTE*, November 1991, pp.197-208.

Mathematicians define a spanning tree as a minimum set of lines necessary to fully interconnect a set of points. By its nature, a spanning tree contains no loops. The IEEE adopted the spanning tree concept as the basis of an algorithm that dynamically detects loops within a bridged network. This algorithm and the protocol messages that the bridges exchange in order to implement it are known as the Spanning Tree Protocol. Therefore, STP will maintain the connectivity of the network but contains no closed loops. Each Bridge is assigned a unique identifier, and the bridges select one possible spanning tree from the network paths. The links which are members of the spanning tree carry traffic, and the other links are called backup links. Should a spanning tree path fail, then the highest speed backup path available will automatically become a spanning tree path in order to take its place.

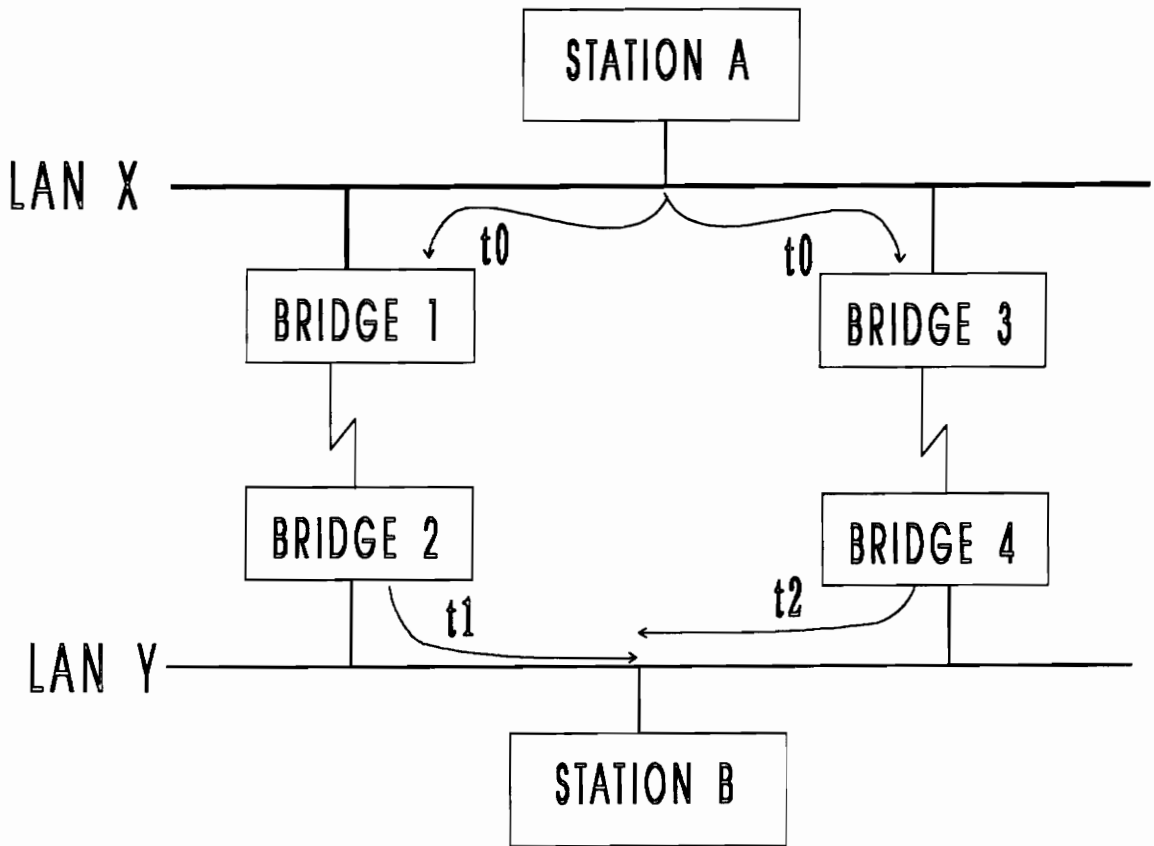


Figure 5.3: The Problem of a "Closed Loop" Topology

Distributed Load Sharing (DLS)

A limitation of STP is that redundant links are placed in a backup state and only utilized if a primary path fails. This is especially undesirable in wide area networking, since expensive communications links may remain unused. Therefore, Vitalink has developed an enhancement to STP known as Distributed Load Sharing.⁵³

DLS permits alternate routing by allowing backup links to carry data when it is appropriate, as shown in Figure 5.4. Without DLS, STP selects two of the three paths to be spanning tree paths, and places the third path, between Bridge B and Bridge C, in a backup state. Traffic between Bridge B and Bridge C must then travel via Bridge A. DLS allows traffic between Bridge B and Bridge C to travel via the direct path BC. The link between Bridge B and Bridge C is called a DLS path.

⁵³ Vitalink Networking Products, "Spanning Tree Protocol and Distributed Load Sharing Overview," Vitalink Communications Corporation, 1990.

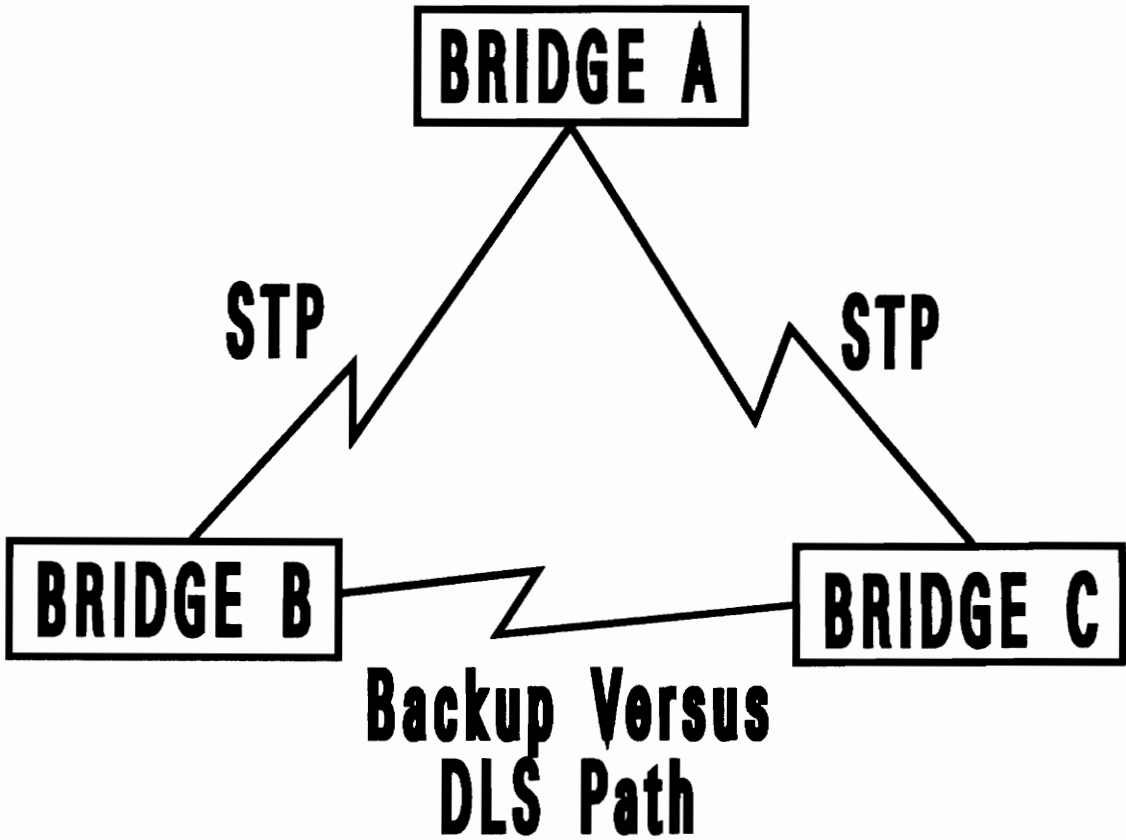


Figure 5.4: Distributed Load Sharing versus Spanning Tree Protocol

5.1.3 WAN Vendor Comparison

The following vendors were considered: Cisco Systems, Hewlett Packard, Hughes LAN Systems (HLS), and Vitalink Communications. These four NIU manufacturing companies are evaluated using the system requirements, from section 5.1.1. A comparison table, Table 5.1, is provided after all the vendors are evaluated.

5.1.3.1 Cisco Systems⁵⁴

Cisco Systems manufactures a router with the following features:

Strengths

- Capable of connecting a closed loop with direct links,
- Single box can connect to multiple LAN's,

Weaknesses

- Difficult to configure,

Costs

- Per box: \$14,500 (without software),
- Total for whole network: \$188,500 (13 sites).

⁵⁴Specification data listings acquired from sales personnel from Cisco Systems Inc.

5.1.3.2 Hewlett Packard⁵⁵

Hewlett Packard manufactures a bridge with the following features:

Strengths

- Performs Diagnostics: self test and an inter-unit test,
- Simple configurations,

Weaknesses

- V.35 serial interface,
- One bridge per link,
- Some links are used as backup (using spanning tree),

Costs

- Per box: \$3,000 (including software),
- Total for whole network: \$99,000 (33 boxes).

⁵⁵Specification data listings acquired from sales personnel from Hewlett Packard.

5.1.3.3 Hughes LAN Systems⁵⁶

Hughes LAN Systems manufactures a bridge with the following features:

Strengths

- Performs Diagnostics: self test and an inter-unit test,
- Simple configurations,

Weaknesses

- One bridge per link,
- Some links are used as backup (using spanning tree),
- No integral power supply,

Costs

- Per box: \$2,800 (including software),
- Total for whole network: \$92,400 (33 boxes).

⁵⁶Specification data listings acquired from sales personnel from Hughes LAN Systems Inc.

5.1.3.4 Vitalink Communications⁵⁷

Vitalink Communications manufactures a bridge with the following features:

Strengths

- Router features (Distributed Load Sharing),
- Simple configurations,
- Handles 4 to 8 links per bridge box (aggregate T-1),
- Performs Diagnostics: self test and inter-unit test,
- System configuration across the network,

Costs

- Per box (with 4 ports): \$9,437 (including software),
- 4 port RS-449/422 Card: \$1,875 (for HQ),
- Total for whole network: \$124,556 (13 sites).

⁵⁷Specification data listings acquired from sales personnel from Vitalink Communications Corporation.

Table 5.1: NIU Vendor Comparison Table

	CISCO ⁵⁸	HP ⁵⁹	HLS ⁶⁰	VITALINK ⁶¹
Total Cost	\$188,500	\$99,000	\$92,400	\$124,556
RS-449 Serial Interface	Yes	No (V.35)	Yes	Yes
Physical Dimensions (HxWxD)	4x13x14	2x9.5x16.7	7x3.4x14.5	5x17x23.5
Configurations / Status Across Network	No	No	No	Yes
Integral Power Supply	Yes	Yes	No	Yes
Bandwidth	56K-4056K	56K-1544K	up to 1544K	56K-2048K
Supports Closed Loops	Yes	Spanning Tree	Spanning Tree	Yes
Ports Supported / Unit	9	1	1	4 - 8
Self Configuring	No	Yes	Yes	Yes

⁵⁸ Specification data listings acquired from sales personnel from Cisco Systems Inc.

⁵⁹ Specification data listings acquired from sales personnel from Hewlett Packard.

⁶⁰ Specification data listings acquired from sales personnel from Hughes LAN Systems Inc.

⁶¹ Specification data listings acquired from sales personnel from Vitalink Communications Corporation.

5.1.4 WAN Equipment Choice

Cisco Systems was not chosen because they manufacture routers. In order for Cisco Systems to meet the system operational requirements specified in section 5.1.1 they would need to be self configuring. Hewlett Packard was not chosen because their bridge doesn't support the RS-449/422 serial interface. Therefore, the choice was between the remaining bridges, Hughes LAN Systems and Vitalink Communications. Both bridges satisfy the system requirements, however the Vitalink bridge was chosen because the goal of designing an efficient wide area link is to minimize the number of bridges and links between any two sites that desire to communicate. Vitalink also provides more beneficial features to FONEX, such as expandability of up to 8 ports/bridge, distributed load sharing, an integral power supply, and the capability to status bridges across the network.

The following hardware was chosen in order to implement this network:

- One Vitalink Bridge Box with software at each site,
- One RS-449/422 four port card for the bridge box at HQ,
- One Thick to Thin wire transceiver at each site.

5.2 WAN Design / Implementation

The network configuration, shown in Figure 5.5, illustrates all the connections which need to be established between each LAN. Using this figure, the spanning tree network

can be designed. The design of the spanning tree network is shown in Figure 5.6 was developed in the following manner:

1. Headquarters in Washington, DC was chosen as the spanning tree root of the network since it is the central hub,
2. The bridges which are one network hop away from Headquarters are considered as STP. These connections are drawn with solid lines from the HQ. The bridges in this category consist of Chicago, Dallas, Washington DC Supplier #1, San Francisco, Raleigh, Greenbelt, and Fairfax,
3. For the importance of quick and reliable transmission it was decided to directly connect the designers and the two manufacturing plants. These connections are considered as STP and are drawn with solid line from Raleigh, NC (designers) to New York, NY and San Diego, CA,
4. To reduce the costs of leasing a transmission line it was decided to connect Los Angeles, CA directly to San Francisco, CA instead of having a direct connection from LA to HQ. This connection is considered as STP and is drawn with a solid line from LA to SF,
5. To reduce cost of having two bridges at HQ it was decided to connect the Washington DC Suppliers #2 and #3 directly to Supplier #1. These connections are considered as STP and are drawn with solid line from DC#1 to DC#2 and DC#3,
6. Since each location has already been used in the spanning tree, the remaining links are STP backup paths. These remaining paths are drawn with a dotted line. Therefore, if two locations are connected on different STP paths from Headquarters (the root), then these paths are known as a DLS path.

7. For the importance of quick and reliable transmission it was decided to directly connect the manufacturer of the FONEX analog models in New York to their shipping/receiving facility in Greenbelt, MD and to a west coast marketing office in San Francisco, CA,
8. For the importance of quick and reliable transmission it was decided to directly connect the manufacturer of the FONEX digital models in San Diego to their shipping/receiving facility in Los Angeles, CA and to an east coast marketing office in Fairfax, VA.

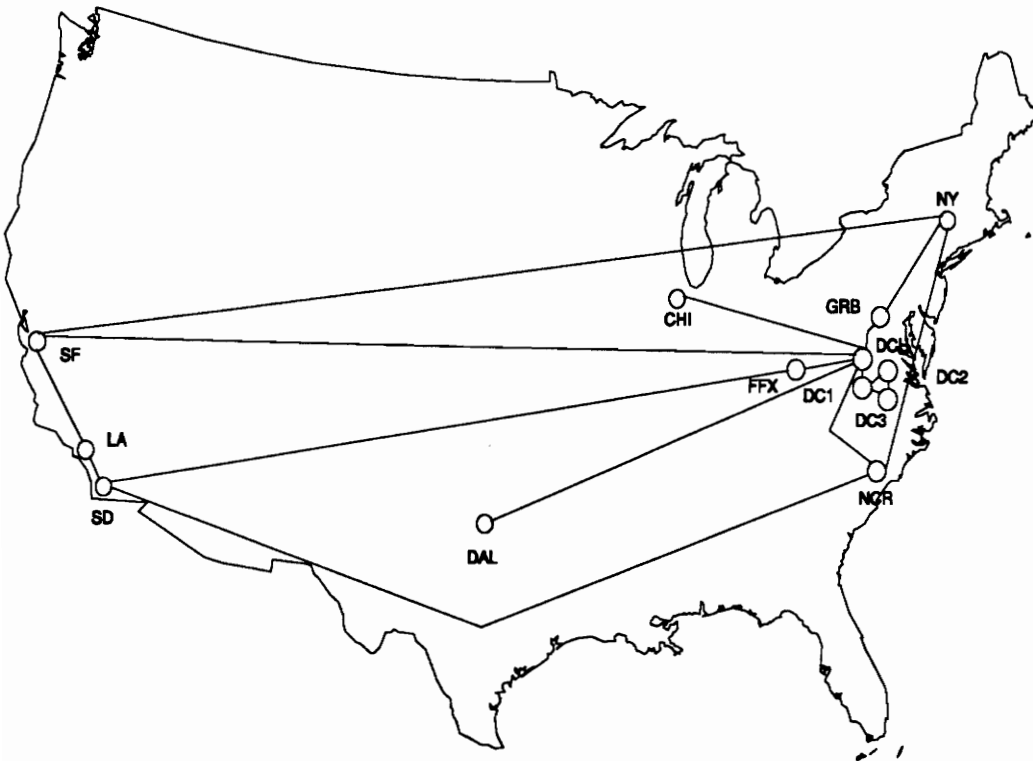


Figure 5.5: The Network Configuration

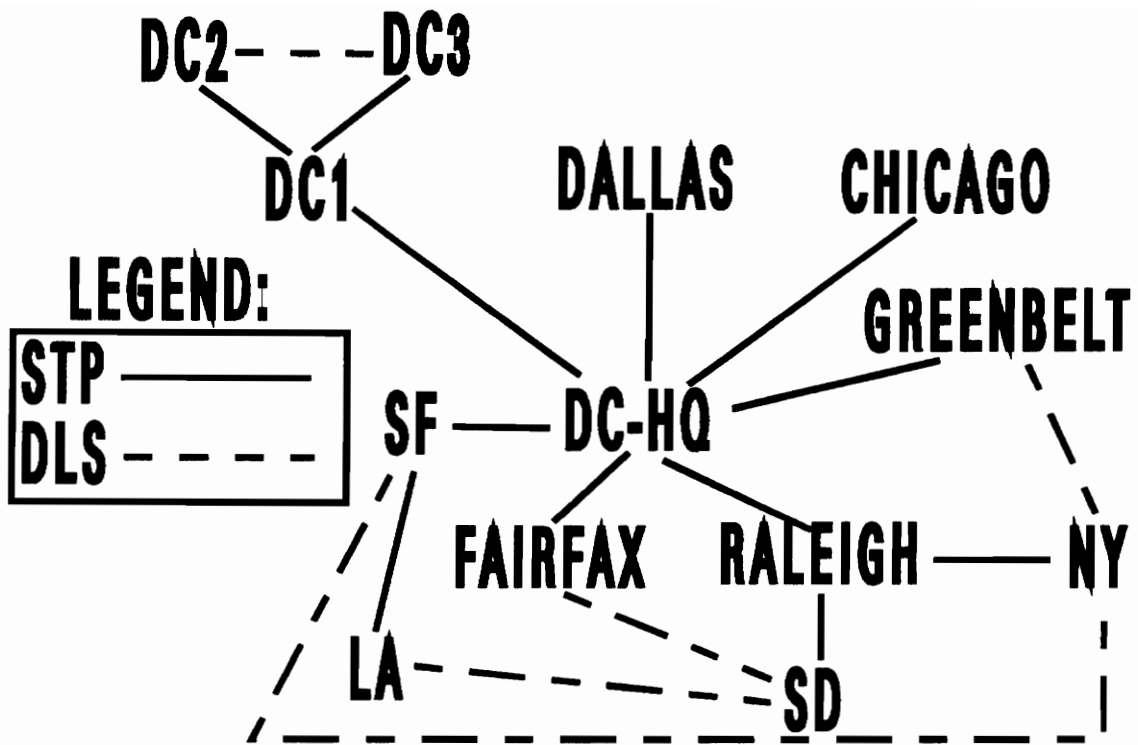


Figure 5.6: Spanning Tree Design

In determining the adequate bandwidth of each of the links the link congestion, the size of transfers, and the amount of access were all taken into consideration. Therefore, it was decided that the appropriate bandwidth for the suppliers (Chicago, Dallas, DC#1, DC#2, and DC#3) would be 56 Kbps, and for all the other links the appropriate bandwidth is 256Kbps. These data rates are displayed in Figure 5.7.

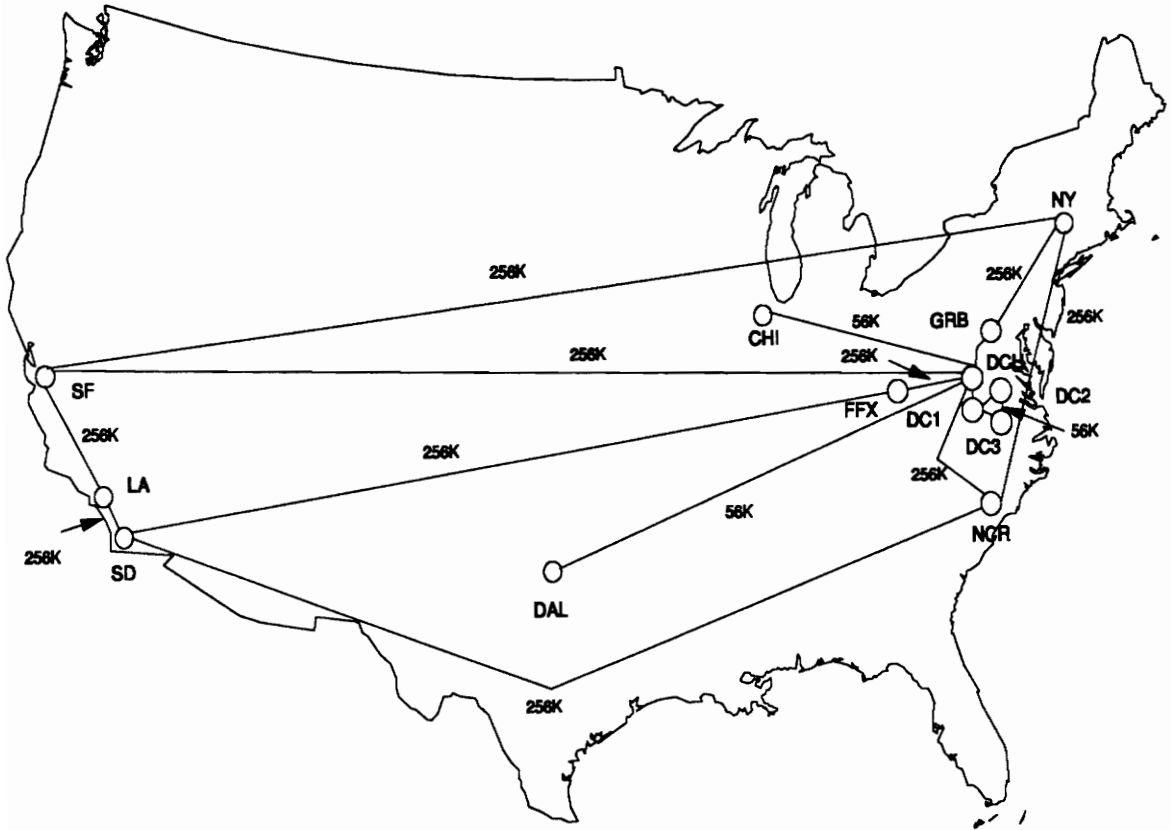


Figure 5.7: Data Rates

5.3 WAN Cost

This section addresses the WAN costs for designing the WAN configurations described in section 5.2. The following hardware will be needed to be purchased in order to implement this WAN:

- 18 Vitalink Bridge Boxes with Software: \$122,681
- 1 Four Port RS-449/422 Card: \$ 1,875
- 18 Thick to Thin Ethernet Transceivers: \$ 4,500

The total cost for purchasing the LAN hardware is approximately \$129,056. In conclusion, the WAN is designed using current technology which meets the functional requirements detailed in section 3.3 and the system operational requirements stated in section 5.1.1.

6. MULTIPLEXING

This section identifies the following: a feasibility study for FONEX's Multiplexers, the system operational requirements of the multiplexers, the design of the multiplexer, how the Multiplexers will be implemented, a vendor comparison, the equipment choice, and the total cost for implementing the multiplexers.

6.1 Multiplexer Design Parameters

Both the WAN design parameters and the WAN design configuration, described in Section 5, were utilized in the multiplexer design.

6.1.1 Multiplexer System Operational Requirements

The following multiplexer system operational requirements were established to be used in the evaluation of an appropriate vendor of a Multiplexer:

1. The Multiplexer shall be capable of supporting data rates from 19.2 Kbps to 1544 Kbps,
2. The Multiplexer shall provide a serial interface connection which is capable of supporting an RS-449/422 medium,
3. The Multiplexer shall provide a console port, for supporting the monitoring and control functions of the network, via a RS-232 medium,
4. The Multiplexer shall have the capability to perform a re-allocation of bandwidth,

5. The Multiplexer shall provide software which is capable of performing remote network monitoring,
6. The Multiplexer shall have the capability to perform automatic time-of-day transmission,
7. The Multiplexer shall provide software which provides network management which is driven by a user friendly icon,
8. The Multiplexer shall provide the capability to perform network utilization monitoring,
9. The Multiplexer shall not limit the network from the ability of expansion.

6.1.2 Vendor Hardware and Software Products

Taking into account the data rates identified in Section 5, each location would require the capabilities of a T-1 multiplexer and network management software. There are various vendors which offer T-1 multiplexers and network management software systems. Using the system requirements listed in section 6.1.1 as a guide, the following four vendors and their products are evaluated:

1. TELCO Systems

- Route-24 T-1 multiplexer
- MuxView network management software

2. Rad Data Communications

- FLM-1 T-1 multiplexer
- MANAGE1 network management software

3. Raycom Systems

- 5100 T-1 multiplexer
- 5100-NMS network management software

4. AT&T Paradyne

- MUX-1.5 multiplexer
- T-1 Management Software (TMS)

Each vendor is well known for their high standings in the area of T-1 multiplexing. The products which they offer provide a high level of reliability and quality. The system operational requirements listed in section 6.1.1 was used in determining which T-1 multiplex system best satisfies the multiplexing requirements.

6.1.3 Vendor Comparisons

The four vendors which manufacture multiplexers are summarized below with their weaknesses, strengths and overall cost. A comparison table, Table 6.1, is provided after all the vendors are evaluated, and lists those capabilities that are necessary to satisfy the system requirements.

6.1.3.1 TELCO Systems⁶²

Strengths

- Intelligent cards,
- Interface compatible,
- Provides a bandwidth allocation capability,
- Provides a time of day transmission capability,
- Icon driven software provides ease of use and minimum training,
- Provides for network utilization monitoring,

Weaknesses

- High cost,

Cost

- \$165,300 to equip all thirteen locations.

⁶²Specification data listings acquired from sales personnel from Telco Systems Inc.

6.1.3.2 Rad Data Communications⁶³

Strengths

- Intelligent cards,
- Provides a bandwidth allocation capability,
- Provides a time-of-day transmission capability,
- Provides for both local and remote software configuration,
- Provides for network utilization monitoring,

Weaknesses

- Software is confusing to use,
- Not compatible with the RS-232 interface,

Cost

- \$163,000 to equip all thirteen locations.

⁶³ Specification data listings acquired from sales personnel from RAD Data Communications Inc.

6.1.3.3 Raycom System⁶⁴

Strengths

- Intelligent cards,
- Interface compatible,
- Provides a bandwidth allocation capability,
- Low cost,

Weaknesses

- Software is confusing to use,
- Does not provide time-of-day transmission,
- Does not provide the capability to monitor the utilization of the network,

Cost

- \$153,000 to equip all thirteen locations.

⁶⁴Specification data listings acquired from sales personnel from Raycom Systems Inc.

6.1.3.4 AT&T Paradyne⁶⁵

Strength

- Intelligent cards,
- Interface compatible,
- Provides a bandwidth allocation capability,
- Provides for network utilization monitoring,

Weaknesses

- Software is confusing to use,
- Does not provide time-of-day transmission,
- Does not provide the capability to monitor the utilization of the network,
- High cost,

Cost

- \$168,000 to equip all thirteen locations.

⁶⁵Specification data listings acquired from sales personnel from AT&T.Paradyne.

Table 6.1: Multiplexer Vendor Comparison Table

	TELCO ⁶⁶	RAD DATA ⁶⁷	RAYCOM ⁶⁸	AT&T ⁶⁹
INTELLIGENT CARDS				
Digital Data	YES	YES	YES	YES
Video	YES	YES	YES	YES
Fiber	YES	YES	YES	YES
COMPATIBILITY				
RS-449/422	YES	YES	YES	YES
RS-232	YES	NO	YES	YES
DATA RATES				
19.2 K - T-1	YES	YES	YES	NO
NETWORK MANAGER				
Bandwidth Allocation	YES	YES	YES	YES
Local Management	YES	YES	YES	YES
Remote Management	YES	YES	NO	YES
System Diagnostic	YES	YES	YES	NO
Auto-System Recovery	YES	NO	NO	NO
Time-of-Day Transmission	YES	YES	NO	NO
Network Utilization Monitoring	YES	YES	NO	YES
ICON Driven	YES	NO	NO	NO
TOTAL COST	\$165.3K	\$163K	\$153K	\$168K

⁶⁶Specification data listings acquired from sales personnel from Telco Systems Inc.

⁶⁷Specification data listings acquired from sales personnel from RAD Data Communications Inc.

⁶⁸Specification data listings acquired from sales personnel from Raycom Systems Inc.

⁶⁹Specification data listings acquired from sales personnel from AT&T.Paradyne.

6.1.4 Equipment Choice

TELCO, Rad Data, Raycom, and AT&T total initial costs were all close in price. However, the four vendor's life cycle cost, maintenance cost, and reliability factors revealed that TELCO provides the least expensive and the most reliable multiplexer over a five year period.

The TELCO Route-24/MuxView system was chosen based on its reliability, network management capabilities, long term cost saving, and to a smaller extent the icon driven management system. The only drawback to the TELCO system was the initial cost, however the benefits provided with TELCO more than justify the additional cost. For example, large cost savings are possible through the use of MuxView's capability to designate data for transmission only during times when the rates are the lowest. Furthermore, with MuxView, FONEX will have the capability to monitor the bandwidth use of their T-1 lines to ensure that they are not over charged for the unused portion of the T-1.

6.2 System Design and Implementation

TELCO Systems offers the Route-24, a 24 channel T-1 voice, data, and video device multiplexer. The Route-24 is based on a modular design, and offers several types of "smart" channel cards (i.e., data, video, fiber, Private Branch Exchange - PBX, FAX, and LAN NIU) that are capable of local or remote configuration control. All of these intelligent channel units use non-volatile memory to store configuration parameters. Therefore, in the event of a power failure the units automatically restore to their

individual configurations upon power recovery. This flexible system is designed to provide access to both private and public networks.

The Route-24 can be easily configured to maintain a T-1 network from a common PC equipped with TELCO Systems' network management software, known as MuxView. This system uses a Graphical User Interface program to enhance the functionality of the management software. With this system, the network supervisor can perform local and remote diagnostics, reconfigure channel units, view performance monitoring, and generate statistical reports. The intelligent variable speed channel cards can be controlled by the network management software. Each card, as well as the T-1 multiplexer, periodically performs a built-in system self test. As a safety feature, MuxView offers a multi-layered password protection designed to control access to the system.

The configuration of a multiplexer at each location is dependent on the hardware architecture and the anticipated data rates. Output from all the T-1's will be in the Digital Signal Level 1 (DS-1) format (a multiplexing scheme used for carrying information).

Headquarters

The multiplexer at Headquarters multiplexes nineteen digital lines, four of which are 256 Kbps, three are 56 Kbps, and twelve are 19.2 Kbps. Data from the four 256 Kbps line will be routed to the R&D facility, two Marketing offices, and one Shipping and Receiving facility (San Francisco, Greenbelt, and Fairfax). The Headquarters multiplexer is where the Network Manager interfaces with the WAN and manages the system. Figure 6.1 illustrates the multiplexer at Headquarters.

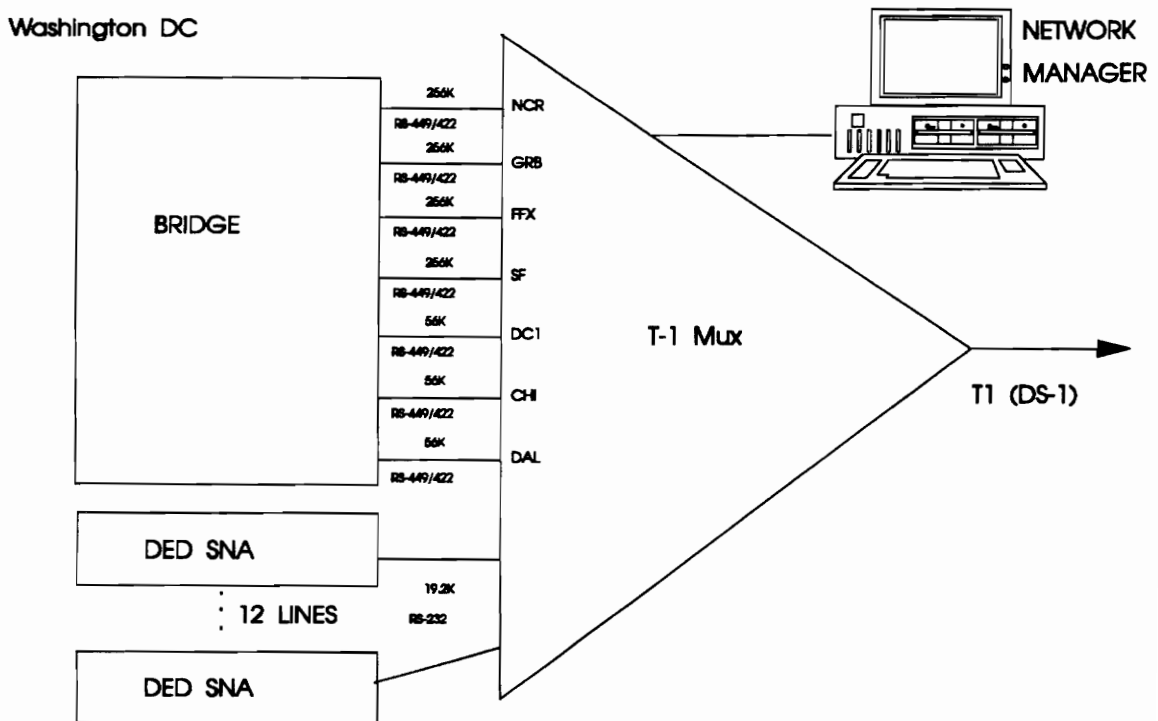


Figure 6.1: The Multiplexer at Headquarters

Manufacturing

The multiplexers at the two manufacturing locations multiplex four digital lines, three of which are 256 Kbps and one is 19.2 Kbps. One of the lines will be used to route information between the manufacturing plant and its designated shipping and receiving facility. The remaining two 256 Kbps lines are links with the R&D facility and one of the marketing offices. Figure 6.2 illustrates the multiplexer at the manufacturing facilities.

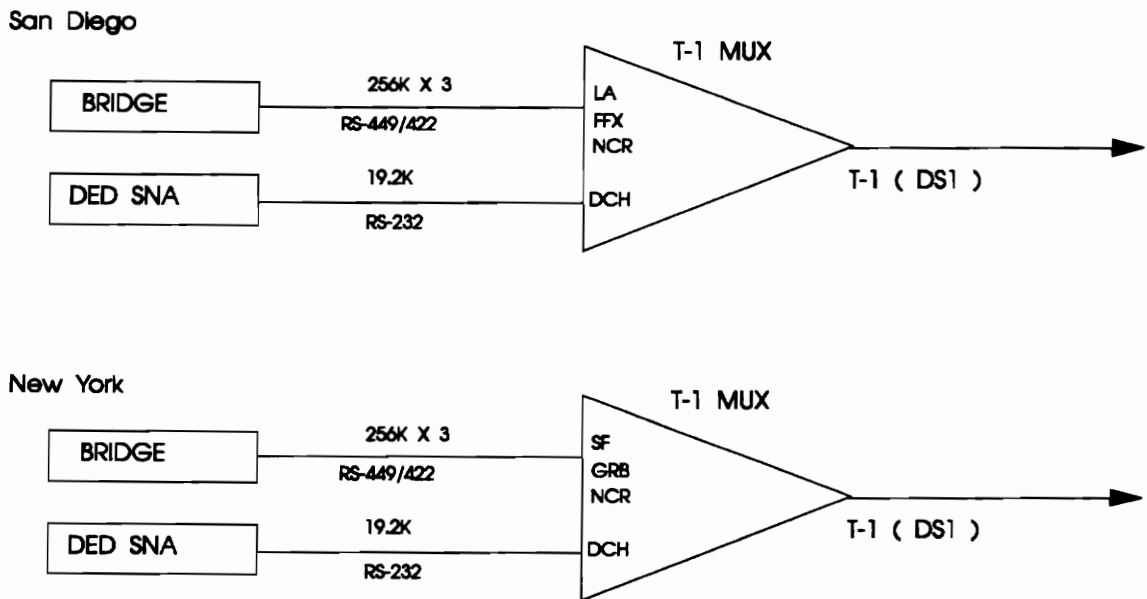


Figure 6.2: The Multiplexers at the Manufacturing Facilities

Research and Development

The multiplexer at the Research and Development site multiplexes four digital lines (three 256 Kbps and one 19.2 Kbps). Two of the 256 Kbps lines will be configured to route data between the R&D facility and the manufacturing sites. Figure 6.3 illustrates the multiplexer at the Research and Development facility.

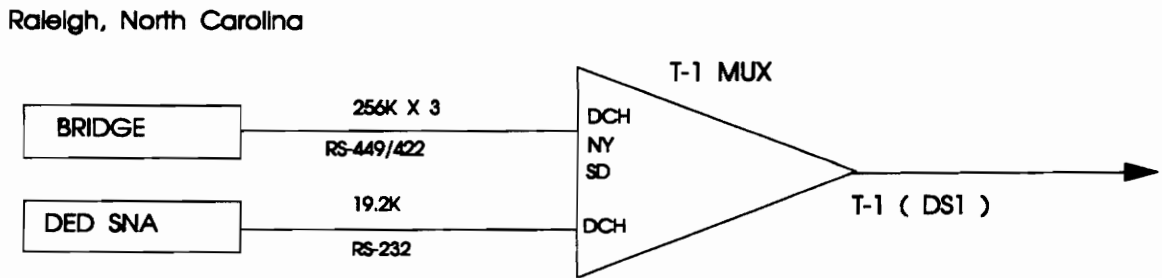
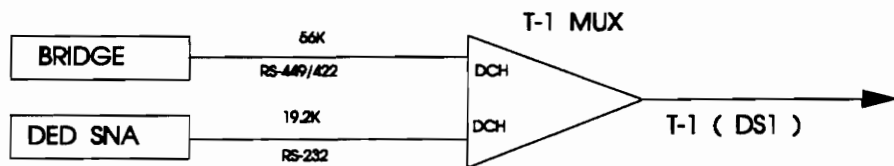


Figure 6.3: The Multiplexer at the Research and Development Facility

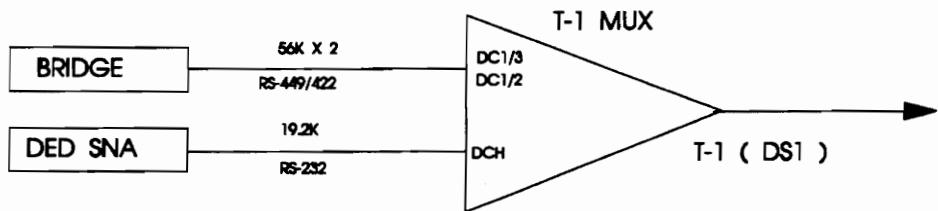
Supplier's

The multiplexer at the Washington DC Supplier #2 and #3 will multiplex traffic from the bridge and SNA gateway over two digital lines, one of which is 56 Kbps and the other is 19.2 Kbps. The multiplexer for the Suppliers at Chicago and Dallas will multiplex only two digital lines (one 56 Kbps and one 19.2 Kbps). The DC #1 multiplexer will route traffic from the bridge and the SNA gateway over four digital lines, three of which are 56 Kbps and one is 19.2 Kbps. Figure 6.4 illustrates the multiplexer at the Supplier's facilities.

Chicago And Dallas



Washington DC (2&3)



Washington DC (1)

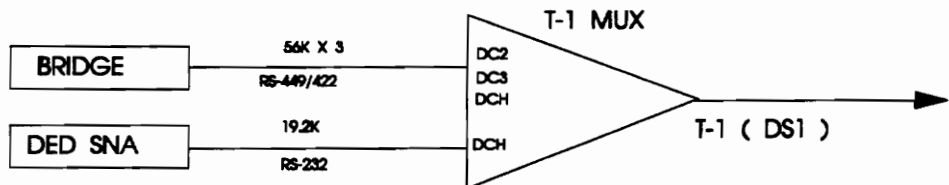


Figure 6.4: The Multiplexers at the Supplier's Facility

Shipping and Receiving

The Shipping and Receiving multiplexers located in Los Angeles and Greenbelt support traffic from both the bridge and the SNA gateway over three digital lines, two of which are 256 Kbps and one is 19.2 Kbps. One of the 256 Kbps lines will link directly to their respective manufacturing plant. Figure 6.5 illustrates the multiplexers at both of the east and west coast Shipping and Receiving facilities.

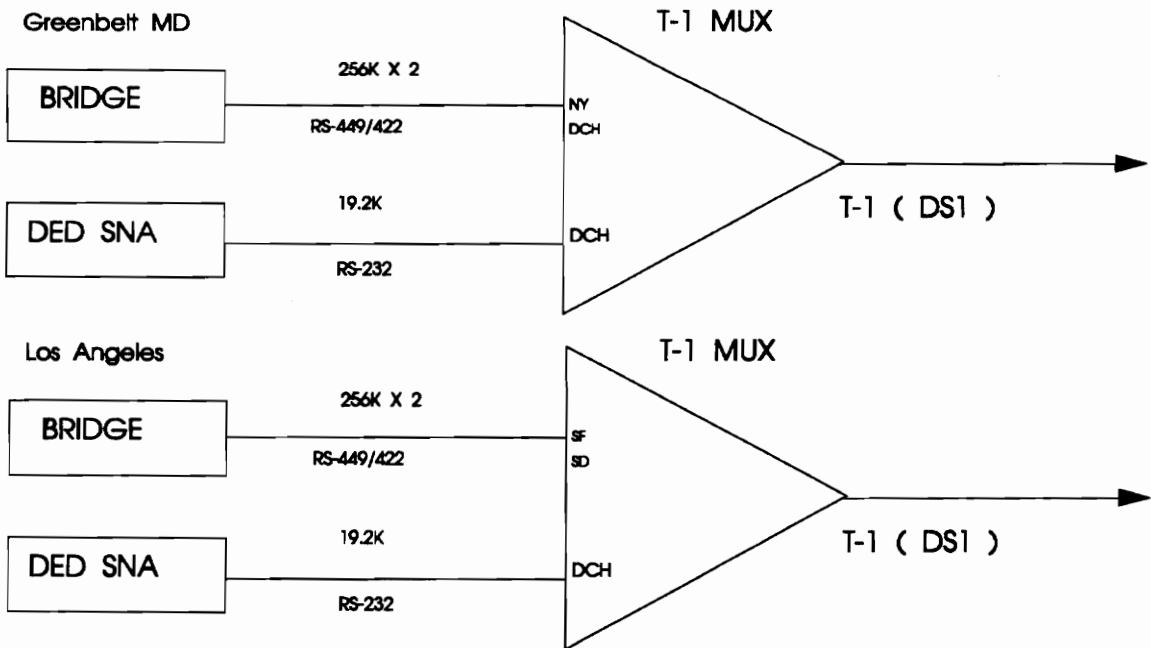


Figure 6.5: The Multiplexers at the Shipping and Receiving Facilities

Marketing

The Marketing office's multiplexer located in San Francisco supports traffic from both the bridge and the SNA gateway over four digital lines, three of which are 256 Kbps and one is 19.2 Kbps. The Fairfax multiplexer supports traffic from both the bridge and the SNA gateway over three digital lines, two of which are 256 Kbps and one is 19.2 Kbps. Each of the marketing offices has one of the 256 Kbps lines linked directly to a different manufacturing plant. Figure 6.6 illustrates the multiplexers at both of the east and west coast Marketing offices.

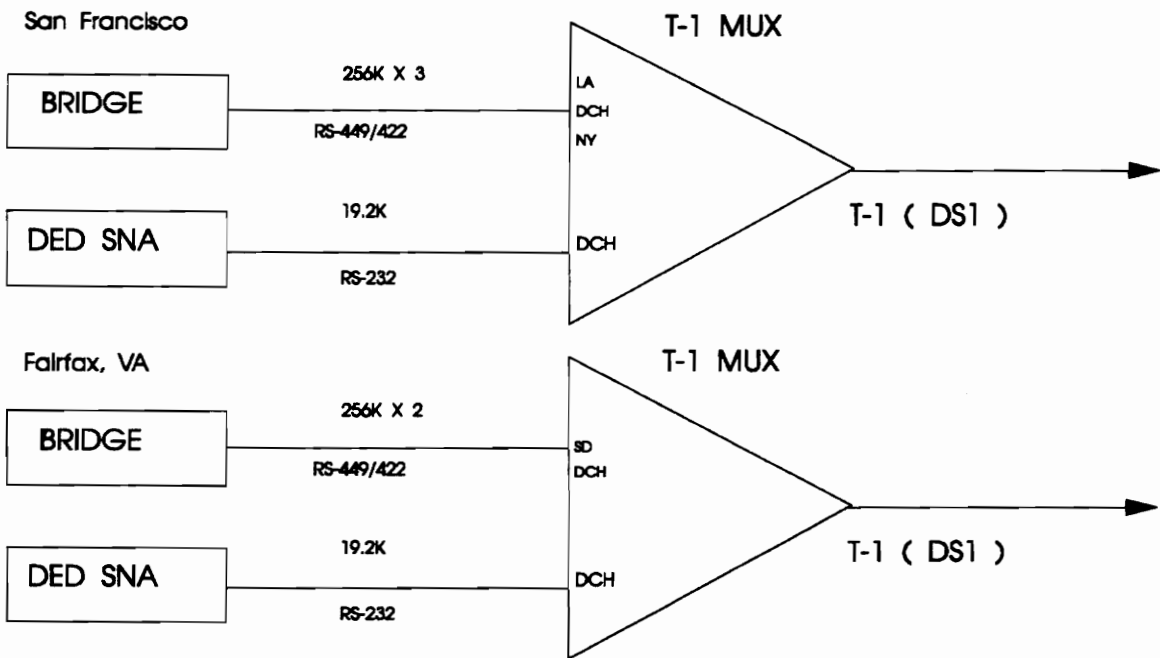


Figure 6.6: The Multiplexers at the Marketing Offices

6.3 Multiplexer Costs

Of the four vendors considered, TELCO's system was chosen because they satisfied the most multiplexing system operational requirements. Network management capabilities provided by this system help to offset the initial costs, which makes this system the most attractive over a long term. Headquarters is the only location that utilizes a majority of the T-1 bandwidth. Some of the other locations will utilize only a small fraction of their T-1 bandwidth with the remaining designated for growth. The total cost for purchasing the Multiplexer hardware at all the locations is approximately \$165,300. In conclusion, the multiplexers are designed using current technology which meets the functional requirements detailed in section 3.3 and the system operational requirements stated in section 6.1.1.

7. TRANSMISSION MEDIA

This section addresses the transmission media that is used to connect the various locations together. In this network, the transmission media is comprised of circuits that are provided from various telephone carriers such as Sprint, MCI, AT&T. The data rates are already specified in section 5.2. The main focus of this section is to explore the various kinds of transmission media and provide the best solution for FONEX. The design of the transmission will utilize the service from a carrier that costs the least. Other considerations include network management and quality of service. Over the life of a network the transmission media tends to be the largest portion of expenditures.

7.1 Transmission Media Feasibility Study

There are many choices for transmission media available from the various carriers. The following is the transmission media that was considered:

1. Dial-up Analog (to 19.2 Kbps)
2. Dedicated Analog Service (to 19.2 Kbps)
3. Dedicated Digital Service (to 56 Kbps)
4. Fractional T-1 (64 Kbps to 1.544 Mbps)
5. T-1 (1.544 Mbps - U.S. Standard)

Dial-up analog lines are used for backup of dedicated lines or for file transfer of small files. The connection is made using dial-up modems whenever a circuit is required. For

circuits that span large areas the charges are expensive. These charges are billed at the same rate as a long-distance phone call. Additionally, the quality of the circuit is somewhat less than that of a dedicated line.

Dedicated analog service is a circuit that allows analog modems to provide bandwidth up to 19.2 Kbps. These circuits are voice grade and are available as either 2 or 4 wire circuits.

Dedicated Digital Service (DDS) provides all digital, simultaneous two-way transmission of data at synchronous speeds of 2.4, 4.8, 9.6 and 56 Kbps. A DDS circuit requires modems that communicate digitally. The names for these modems are Digital Service Units (DSU) and Channel Service Units (CSU).⁷⁰

Fractional T-1 service is similar to DDS, however Fractional T-1 provides much greater bandwidth and is provided by all of the major carriers. This service is provided in different bandwidth increments based on the carriers capacity and marketing strategy.

In the U.S. a T-1 circuit provides 1.544 Mbps. Customers have the choice of selecting from different service, routing, carrier and performance options. AT&T's T-1 service is called ACCUNET T1.5 service. This T-1 provides throughput that approaches LAN speeds, and connects physically separated sites by operating at a rate of 1.544 Mbps via a DS-1 transmission link. This DS-1 signal is often broken into 24 DS-0 or 64 Kbps channels. By splitting the DS-1 signal, it is possible for a T-1 to be shared by many

⁷⁰Derfler, Frank Jr., "Making the WAN Connection: Linking LANs," *PC Magazine*, March 16, 1993, pp. 183-206.

devices (i.e. Fractional T-1). Conversely, it is also possible for the complete DS-1 signal to be used by one device.⁷¹

7.2 Transmission Media System Operational Requirements

The following system operational requirements were established to be used in the evaluation of an appropriate vendor for the Transmission Media:

1. The Transmission Media shall provide the lowest recurring monthly costs,
2. The Transmission Media shall be capable of supporting a data rate equal to the U.S. T-1 standard (1.544 Mbps),
3. The Transmission Media shall be capable of supporting a digital signal level 1 (DS-1),
4. The Transmission Media shall provide the capability of network management support .

7.3 Transmission Media Costs

This section addresses the costs involved in the transmission media for the network. The main issue in WAN communications is bandwidth, the aggregate amount of traffic that can be moved over a link in a given period of time. Generally, the greater the bandwidth, the greater the costs associated with WAN links. The distance between communicating locations can also affect costs. Local systems are able to explore near-

⁷¹ Stallings, William, Data and Computer Communications, Third Edition, Macmillian Publishing Company, New York, New York, 1991.

site technologies such as microwave, which cannot be used over greater distances. Also, communicating sites in the same phone company's local service area can realize substantial savings over inter-LATA (Local Access Transport Area) links. The more distant the sites the greater the potential cost of the connections.

Transmission media costs are comprised of two portions, recurring and non-recurring costs. Recurring costs or monthly service charges are assessed for usage of a particular service such as 56 Kbps digital service between Chicago and Washington. Non-recurring charges or installation costs are assessed once during the installation of a service. This design tries to minimize the numbers and recurring costs of circuits in order to save money over life of the network.

AT&T was chosen to provide the transmission lines for the network architecture of the manufacturing information system. AT&T was selected based on their reputation, cost, and reliability.

A pricing tool named the E.T.I Private Line Pricer (PLP) was used to provide costs for the transmission lines specified in section 5. Table 7-1 depicts the estimated costs from AT&T for all circuits required for the Wide Area Network. The circuit costs for the network using AT&T is approximately \$30,000 per month. This amount does not include LEC (Local Exchange Carrier) charges for the T-1 circuits. These circuit costs are controlled by the Federal Communications Commission (FCC) using Tariffs and are readily available which allows for accurate forecasting of cost data.

The method for pricing a circuit is as follows: a circuit is comprised of two endpoints signified by their NPA-NXX or Area Code and Exchange (for example, Fairfax, Virginia has an NPA-NXX of 703-273). The NPA-NXX is key to successfully pricing and ordering a circuit, and is what is used to locate the local Point of Presence (POP) in which the circuit connects to the telephone network. NPA and NXX numbers map to Vertical and Horizontal (V&H) coordinates.

V & H coordinates are assigned to the rate centers, the wire centers, and the Points of Presence based on relative location. V&H coordinates are used to measure distances for calculating rates. A circuit is priced in three sections, two of the sections are the local circuits from the place of business to the Local POP, and the third section connects the two Local POP's over the long-haul telephone network. Thus, the cost is derived by adding the three segments together to comprise a total recurring and non-recurring cost. However, if the circuit does not cross over LATA boundaries then the long-haul segment is minimized.

Table 7.1: Transmission Media Costs using AT&T

CIRCUIT	SPEED Kbps	CITY	NPA-NXX	NPX-NXX	MONTH COSTS	INSTALL COSTS
CKT0001	256	FFX-DCH	703-273	202-205	\$700	\$1054
CKT0002	56	DC1-DCH	202-205	202-205	\$221	\$946
CKT0003	56	DC2-DC1	202-205	202-205	\$221	\$946
CKT0004	56	DC2-DC3	202-205	202-205	\$221	\$946
CKT0005	256	NCR-DCH	919-231	202-205	\$1240	\$1054
CKT0006	256	LA-SF	213-228	415-202	\$1383	\$1054
CKT0007	256	SF-DCH	415-202	202-205	\$3293	\$1054
CKT0008	256	SD-FFX	619-221	703-273	\$3704	\$1054
CKT0009	256	NY-SF	518-421	415-202	\$4068	\$1054
CKT0010	56	CHI-DCH	312-201	202-205	\$2559	\$2300
CKT0011	56	DAL-DCH	214-216	202-205	\$3319	\$2199
CKT0012	256	GRB-DCH	301-770	202-205	\$683	\$1054
CKT0013	256	LA-SD	213-228	619-221	\$1092	\$1054
CKT0014	256	SD-NCR	619-221	919-231	\$3631	\$1054
CKT0015	256	NCR-NY	919-231	518-421	\$1617	\$1054
CKT0016	256	GRB-NY	301-770	518-421	\$1328	\$1054
TOTALS					\$29,280	\$18,931

Note:

All 56 Kbps circuits include Local and Inter-LATA charges

All 256 Kbps circuits include only Inter-LATA charges

8. CONCLUSION

In conclusion, the network architecture of the manufacturing information system utilizes current technology that is cost effective and provides ample room for growth. The results of the research from this project provide an initial conceptual design of a network architecture for a typical manufacturing information system that is driven by needs analysis and feasibility studies, meets both physical and functional requirements, and also reflects current technology. The initial conceptual design identifies the definition of need for the manufacturing information system's network architecture and produces feasibility studies for each of the areas in the open systems architecture. This project also provides an understanding of open systems integration. In addition, this project supplies recommendations on how best to implement the manufacturing information system's network architecture, including pricing of vendor's products and vendor comparisons in the areas of Local Area Networking, Wide Area Networking, Multiplexing, and Transmission Media.

The technologies researched in this project produce an open systems architecture that includes Local Area Networking, Wide Area Networking, Multiplexing, and Transmission Media. The Local Area Networking involves the latest in PC's and workstations and the connectivity across diverse platforms. The Local Area Networking is designed around Token Ring, Ethernet, and Appletalk architectures utilizing DCA Communication SNA Gateways; Madge Token Ring Hubs; Synoptics 10BaseT Hubs; HP, DEC, and SGI Workstations; and Gateway 2000 File Servers and PC's.

The Wide Area Networking includes connectivity between all the locations in the manufacturing organization, and the Multiplexing of all the data links at each of the locations. The WAN is designed using Vitalink bridges with transmission rates of 56 Kbps and 256 Kbps. The Multiplexer design utilizes Telco's Route-24 multiplexer to provide line sharing among locations. This is a very cost effective way to share bandwidth between different applications. Lastly, the Transmission Media which is used to connect each of the locations to one another. The Transmission Media utilizes AT&T's transmission lines to provide the network with low cost and reliable communications.

The overall cost for the portions that were designed is approximately 4.13 million dollars. In addition, the LAN costs are approximately 3.81 million dollars, the WAN costs are approximately \$130,000, the Multiplexer costs are approximately \$165,000, and the initial Transmission Media costs are approximately \$20,000 and the recurring monthly costs for the Transmission Media are approximately \$30,000 per month. Therefore, over the life of the network the line costs will be a significant percentage of the total implementation.

9. RECOMMENDATIONS

There are a number of recommendations for additional research which flow from the conclusion of this project. This section will provide some of these recommendations which could be accomplished with additional research. These recommendations fall into two basic categories - the system engineering process and the manufacturing information system.

In this project the initial conceptual design only uses a limited application of the system engineering process. My recommendation for further research in this area would be to provide a conceptual design which takes the following operational feasibility factors into consideration:

1. Designing for Reliability - dealing with such topics as MTBF and Failure Mode and Effect Analysis (FMEA),
2. Designing for Maintainability - dealing with such topics as Mean Corrective Maintenance Time, Mean Time Between Maintenance (MTBM), and Mean Time Between Replacement (MTBR),
3. Designing for Supportability - dealing with such topics as Logistics Support Analysis (LSA) and Computer-Aided Acquisition and Logistic Support (CALs),
4. Designing for Economic Feasibility - dealing with such topics as Life Cycle Cost (LCC) and a Cost Breakdown Structure (CBS).

Another recommendation for further research is to expand on the initial conceptual design and provide any of the following portions of the system life cycle process: a Preliminary Design, a Detailed Design and Development Plan, a Production and/or Construction Plan, a Utilization and Support Plan, and a Phaseout and Retirement Plan.

In this project the design of the manufacturing information system only included the network architecture portion of the manufacturing information system. My recommendation for further research would be to produce an entire design of the manufacturing information system.

LIST OF ACRONYMS

AFP	Apple File Protocol
ANDF	Architecture Neutral Distribution Format
ANSI	American National Standards Institute
ARPANET	Advanced Research Projects Agency computer network
AUI	Attachment Unit Interface
CAD	Computer Aided Design
CALS	Computer-Aided Acquisition and Logistic Support
CAM	Computer Aided Manufacturing
CBS	Cost Breakdown Structure
CIM	Computer Integrated Manufacturing
CPU	Central Processing Unit
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
CSU	Circuit Service Units
DBMS	Database Management Systems
DCE	Distributed Computing Environment
DDN	Defense Data Network
DDS	Dedicated Digital Service
DEC	Digital Equipment Corporation
DIX	Consortium of DEC, Intel, and Xerox
DLS	Distributed Load Sharing
DME	Distributed Management Environment
DOS	Disk Operating System
DS-1	Digital Signal Level 1

DSU	Digital Service Unit
EISA	Extended Industry Standard Architecture
FAX	Facsimile
FCC	Federal Communications Commission
FEP	Front End Processor
FMEA	Failure Mode and Effect Analysis
FMS	Flexible Manufacturing Systems
GB	Gigabytes
GUI	Graphical User Interface
HLS	Hughes LAN Systems
HP	Hewlett Packard
HQ	Headquarters
IBM	International Business Corporation
IEEE	Institute of Electrical and Electronic Engineering
IP	Internet Protocol
IPX	Internet Packet Exchange
ISA	Industry Standard Architecture
ISCA	Intelligent Synchronous Communications Adapters
ISO	International Standards Organization
JIT	Just-In-Time
Kbps	Kilobits per second
LAN	Local Area Network
LATA	Local Access Transport Area
LCC	Life Cycle Cost
LEC	Local Exchange Carrier

LSA	Logistics Support Analysis
LU	Logical Units
MAP	Manufacturing Automation Protocol
MAU	Multi-Station Access Unit
MB	Megabytes
Mbps	Megabits per second
MCA	Micro Channel Architecture
MHz	MegaHertz
MRP	Manufacturing Requirements Planning
MS	Microsoft Corporation
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
MTBR	Mean Time Between Replacement
MUX	Multiplexer
NIU	Network Interface Unit
NOS	Network Operating System
OSF	Open System Foundation
OSI	Open Systems Interconnection
PBX	Private Branch Exchange
PC	Personal Computer
PLP	Private Line Pricer
POP	Point of Presence
POSIX	Portable Operating System Interface for Computer Environments
QLLC	Qualified Logical Link Control
R&D	Research and Development

RAM	Random Access Memory
RISC	Reduced Instruction Set Computer
RJE	Remote Job Entry
SDLC	Synchronous Data Link Control
SGI	Silicon Graphics Inc.
SNA	Systems Network Architecture
SNMP	Simple Network Management Protocol
SPEC	Standard Performance Evaluation Corporation
SPX	Sequenced Packet Exchange
STP	Spanning Tree Protocol
SUN	Sun Microsystems
SVR4	System V Release 4
T-1	A 1.544 Mbps communication circuit
TCP	Transmission Control Protocol
TMS	T-1 Management Software
TQC	Total Quality Control
UTP	Unshielded Twisted Pair
V&H	Vertical and Horizontal
XPG3	X/Open Portability Guide 3
WAN	Wide Area Network
W/S	Workstation

Background Definitions

Systems Engineering refers to the process of designing, developing, testing, and evaluating an effective and efficient man-made system from the time a need is identified to the delivery of the system. The **System Engineering Process** involves the technical application of engineering and scientific efforts to transform an operational need into a description of system performance parameters and desirable system configuration through the process of functional analysis, synthesis, optimization, definition, design, test, and evaluation. The system engineering process also combines technical parameters and assures compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design, and integrates performance producibility, reliability, maintainability, supportability and other specialties in the entire engineering effort. Systems engineering requires that all engineering disciplines combine experience to ensure all elements of the system are considered in a proper and timely manner.⁷²

Information Technology refers to a field which deals with technical and managerial issues of merging the technologies of computing, telecommunications, and office automation. Information technology is closely related to systems engineering in that information technology uses the systems engineering process of a system life cycle, however information technology provides analysis of an industry's or organization's activities in which different industries or organizations are being affected in fundamentally different ways. Each industry or organization has different strategic

⁷² Blanchard, Benjamin S. and Wolter J. Fabrycky, Systems Engineering and Analysis, Second Edition, Prentice Hall, Englewood Cliffs, New Jersey, 1981.

impacts, organization structures, and organizational learning (technology identification, technological learning, and technology transfers). The product, services, and decisions which are produced from information technology can be referred to as an **Information System**.