A STRATEGIC ANALYSIS OF GE LENTRONICS' RAIL SWITCH PROJECT

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ABSTRACT

The utility communications equipment market consists of conservative adopters of new technology, who have started to embrace Ethernet technology for their substation distribution communications. GE Lentronics is developing an industrial Ethernet switch for this developing market.

Examination of external factors reveals a market that is in a growth phase. The overlap of Ethernet technology used in business markets provides low technology barriers of entry for new entrants. However, brand identification and access to distribution channels offer higher barriers to entry for new entrants. Internally, the organisation has adequate resources to meet the critical success factors demanded of the market. The Rail Switch complements the current strategy by creating potential for pull-through sales of the multiplexer products.

We proposed and evaluated various scenarios using these criteria to arrive at a recommendation. A subproject was proposed to develop network management compatibility between the Lentronics multiplexer and the existing GE MultiLink industrial switch.

DEDICATION

This paper is dedicated to my family who has supported me throughout the ups and downs of this program and to Sparky for her constant companionship.

- Vivian Lam

I dedicate this to my wife Kim who has sacrificed as much as I have in the last two and half years of this program and to my five-month old daughter Mia, whose smile and laughter has infused a new purpose for me to complete this project.

- Raymond Lee

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GLOSSARY

Circuit-switch: A type of network where a physical path is used for a dedicated single connection between two end-points in the network.

Managed switch: A switch that has administrative privileges that can be configured to meet specific network traffic needs.

Multiplexer: A device that combines two or more signals into one output.

Packet-switch: A type of network where small units of data called packets are routed through based on a destination address within each packet.

Port: A physical jack on a network device that allows it to connect to the network.

Unmanaged switch: A preconfigured switch with no administrative privileges.

LIST OF ABBREVIATIONS

C&I: Commercial & Industrial

CS: customer service

CSFs: critical success factors

ELCON: Electricity Consumers Resource Council

EMI: electromagnetic interference

EMS: Employee Management System

ERP: enterprise resource planning

GE: General Electric

IEEE: Institute of Electrical and Electronic Engineers

I/O: input/output

ITU: International Telecommunications Union

LAN: local area network

R&D: research & development

RFP: request for proposal

RFQ: request for quote

SDH: synchronous digital hierarchy

SONET: synchronous optical network

VARs: value added resellers

1 INTRODUCTION

1.1 Project Overview

This paper is an analysis of the strategic decisions faced by General Electric Lentronics (GE Lentronics) to undertake the development of a new industrial Ethernet switch for the utility substation local area network (LAN) market called the Rail Switch. [Please refer to Appendix A for further information on Ethernet technology.] As utility communications have evolved from circuit-switched technology to packet-switch technology, GE Lentronics faces new market challenges. New technology competences are required to develop innovative products demanded by the customers. The new demand has also attracted new entrants into the market. Enterprise class switching product companies are trying to market versions of their Ethernet switches to the utilities. With traditional applications changing and competition increasing, new marketing strategies for GE Lentronics are unclear. This paper offers a series of recommendations for GE Lentronics to consider in offering a switch product for this new market.

1.2 The Company

GE Multilin is part of the Power Controls Technologies group of companies within GE's Consumer and Industrial business (C&I). The company specializes in many products for the industrial and utility electric markets. For

communications they offer a variety of products such as SONET multiplexers, SDH multiplexers, managed and unmanaged switches, media converters and data converters. Protection, control, and metering products offered are: protective relays, current transformers, voltage transformers, power meters, and quality meters. In addition, a complete range of value added services are available in the areas of training, testing services, and consulting services.

In 2004, C&I had total revenues of $6B US, of which GE Multilin contributed $120M US from sales of products and services worldwide. The company owns and operates production facilities in Spain and Mexico and also makes use of contract manufacturers for assembly and testing of printed circuit boards. Systems assembly and test are located at the headquarters in Markham, Ontario (GE Multilin). The majority of the product lines are managed from Markham with the exception of the multiplexer products, which are managed from the Burnaby, British Columbia facility (GE Lentronics). The Rail Switch project is a GE Lentronics initiative. [Please see Appendix B for further information on switch technology.]

1.3 Utility Communication Networks Overview

The reliance on the electric power distribution system is often forgotten or taken for granted in the course of our regular daily routine. The environment faced by the power utility companies (utilities) has changed over the years as demand for both more electricity and better availability has increased. The electric distribution grid has grown and evolved into a complex network. Utilities rely on an equally complex communications network to monitor, control, and

protect their distribution grid. Due to the critical nature of the protection traffic, utilities do not rely on communication services from telephone companies or other service providers but instead design, build and maintain their own networks.

The main network, or backbone, is formed from linking substations to a main control centre. (See Figure 1-1) There are different approaches for network designs but the preferred topology is the ring architecture due to its fault tolerant characteristics. [Please see Appendix C for more information on Communication Network Topologies.]

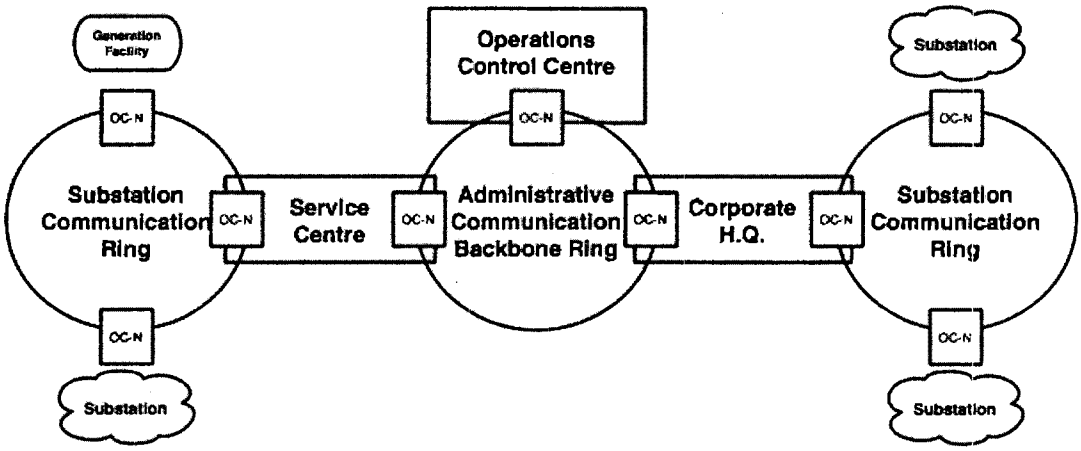


Figure 1-1: Typical Utilities Network

If there is a break in the ring, all traffic is routed in the alternate direction to ensure that any two nodes on the ring maintain their communications link. Multiple rings are connected together to form the complete system. Within the substations there are smaller networks that connect the end devices to the ring network. The focus of this project is on the product needs of modern substation networks.

Communications equipment designed for business or enterprise applications are not suitable for the conditions encountered in a substation nor do they meet the stringent requirements imposed by the critical nature of the traffic carried. The high voltage charges encountered in the substation offers an extreme environment for communications equipment (or any electronic equipment) to contend with. Communications products must meet environmental and EMI (electromagnetic interference) immunity requirements to operate reliably in substations. In addition, substations may not be equipped with environmental heating or cooling systems further subjecting equipment to extreme highs and lows in temperatures. Since signals that control the protective relaying equipment must be available all the time, the communications system has to be fault tolerant. The communications system must be able to survive any single failure in the path and switch to a backup route. This switching time has to be very fast to minimize the outage time to the relaying equipment. This is normally more than an order of magnitude faster than what is acceptable in business and enterprise systems.

1.4 Evolution of Substation Communications

The communications technologies used within the substation has evolved along with the advances in telecommunications technology but at a guarded pace. With each new adoption came the demand for a new generation of communications equipment in the utility market. In the early days of the substation, tone frequency schemes carried in analogue voice channels and transported over microwave links were used, which fit well with the analogue

circuit based devices of the time. With the arrival of the computer and digital era, substation devices became microprocessor-based and evolved from analogue to more data-centric. This initiated the first generation of substation automation. As a result, the communications requirements changed first to modem links (still using voice channels) and eventually to true dedicated data links (56 or 64 kilobits per second).

Although the new communications technology offered more advantages, their implementation were vendor-specific, lacked compatibility, were difficult to scale, and were labour intensive to install and wire. More recently, as the need for utilities to become more efficient grew, substations required technologies to improve automation and integration with other systems. The most prominent technology from the Internet revolution that would afford substations to achieve this was Ethernet. This spawned the industrial Ethernet market for switches and routers. One advantage of choosing Ethernet is that it is an established standard that is used in virtually every computer network in the world today. This offered greater flexibility for software applications to interface and access substation devices and greatly reducing the manual wiring and configuration required in the past. Figure 1-2 shows a typical substation automation setup. However, the utility system requirements identified in the previous section make commercial-grade switches and routers, intended for the wiring closets of organisations, unsatisfactory in meeting the needs of the substation LAN distribution markets. This project focuses on the switch product needs for substation distribution, the market factors, and the position GE Lentronics should take within the market.

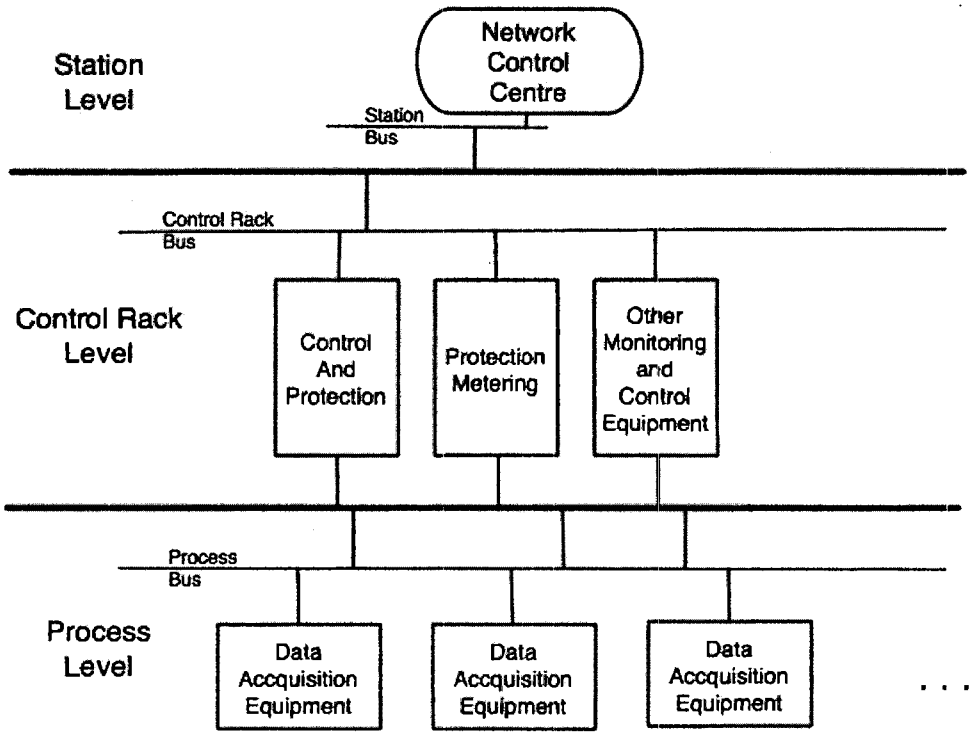


Figure 1-2: Typical Substation Automation Setup

1.5 The Utility Communications Markets

Currently, GE Lentronics sells multiplexers to customers worldwide but essentially have two geographic segments: North America and International. This segmentation is due to established communications standards: Telcordia standards in North America and International Telecommunications Union (ITU) used basically everywhere else except for Japan, who has their own variant. GE Multilin offers SONET based multiplexers for the North American market and SDH based multiplexers for the International market. The situation for the Rail Switch will be different since Ethernet is a worldwide standard; the potential to operate in all markets through minor product modifications is possible.

The North American utility communications market is a mature one where GE Lentronics have sold their multiplexers for over 11 years and continue to service and sell to over 90 customers. While they have the largest share of the market, most customers have now developed the majority of their systems and revenue growth for the last few years have been relatively flat. Upgrades and network expansions of existing customers account for the majority of sales while sales of systems to new customers are relatively fewer.

1.6 Product Description

The Rail Switch provides an economical Layer 2 switched Ethernet extension for power distribution applications in substations. In Release 1, the Rail Switch extends from an Ether100 port using either copper (RJ45) or fibre optic cables. By Release 2, the Rail Switch will be highly scalable and have the ability to cascade from each other allowing even further LAN extensions. A maximum of seven switches can be cascade for a maximum port density of 48 ports. Cascaded switches can be formed into a ring for fault tolerant operation. The rail switch is capable of protection switching in less than one millisecond.

The Rail Switch incorporates a hardened design to withstand harsh substation environments. It is capable of operation over an extended temperature range and meets IEEE 1613 and IEC 61850-3 standards for substation operation. Figure 1-3 shows how the Rail Switch will fit into a substation's network.

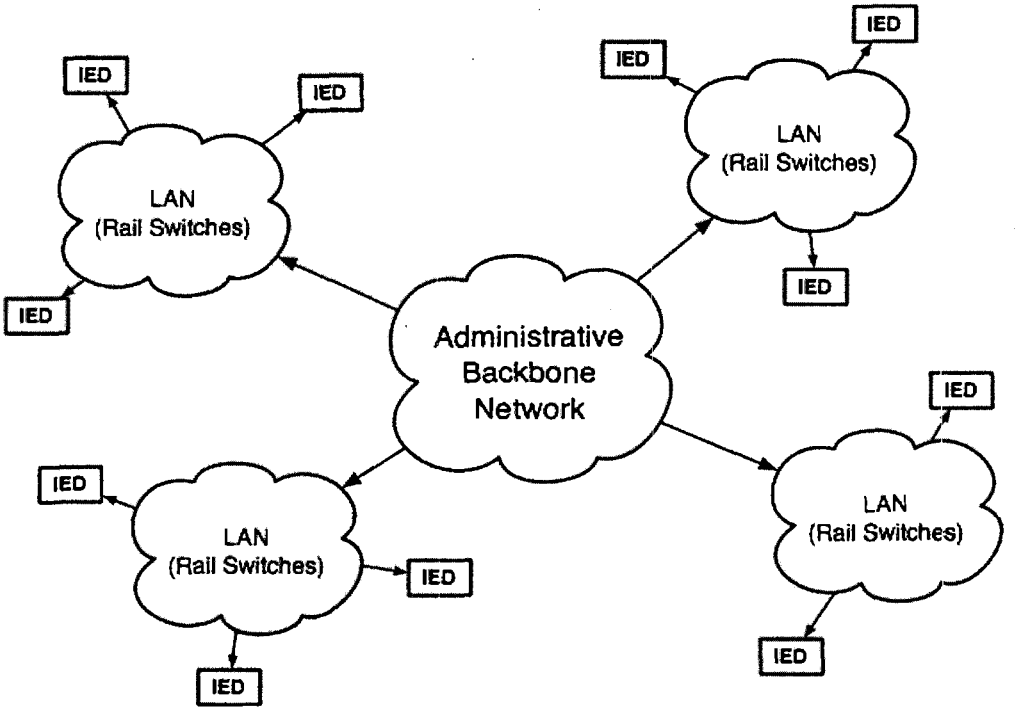


Figure 1-3: Rail Switch Conceptual Model

The following table summarizes the differences between the legacy technology using classical bus architecture and switch technology using the Ethernet standard.

	Ethernet	Legacy
Interface Compatibility	World-wide standard	Vendor specific
Device connection ease	Simple, standardized connectors	Complex wiring and non-standard
Data speeds	1 Gbps, 100 Mbps, and 10 Mbps	Up to 10 Mbps
Programming model	Based on ISO model	Vendor specific
Cost of interface hardware	Commodity prices	Varies with vendor implementation – typically more than Ethernet
Communications protocols	Standard developed by IEC	Several competing fieldbus standards

Table 1-1: Ethernet vs. Legacy

2 EXTERNAL ANALYSIS

2.1 Market Analysis

2.1.1 Size and Growth

The market size for the utilities communication industry is difficult to determine because statistics are not readily available. The current estimation of the size of this market is 75 million US and is based on GE's marketing estimate and historical figures.

The market size for the industrial Ethernet switches is even more difficult to establish since it is an emerging market. The best estimate we could find is $5 million US is which based on estimates and requests for proposals received by GE Lentronics' sales personnel. Based on historical figures, growth within this market is expected at 20% per year and GE Lentronics is aiming to capture at least 5% of this market.

2.1.2 Customer Profile

Markets that involve high technology, especially those based on computer hardware and advanced electronics, have become hypercompetitive with extremely short product life cycles. The utility communications market is one exception; it is one that prefers the evolutionary path to the revolutionary one. When it comes to technology, utilities have specialized needs and prefer what's proven rather than what's progressive. After evaluating and choosing a solution,

they will stay with that choice for a while and use that equipment for 10 years or more. In fact, it is quite common for utility customers to negotiate service and supply contracts for periods of 10 years or more. There are two main reasons why utilities are so unadventurous, or of the pragmatist profile in Moore (Moore, 2002, p.46) terms, towards adopting new communications technologies.

- **Budget Justification:** A utility's core business is power distribution, significant capital investments must have direct benefits to this operation. The communications systems are extensive and represent potentially huge sunk costs.
- **Whole Product Solution:** Utilities do not have the resources to debug or build stopgap solutions for incomplete products. As conservatives, they require products designed specifically for their needs, including training, technical support and repair services. The critical nature of their operation cannot accommodate system outages from lengthy implementation schedules involving patches and upgrades.

2.1.3 Customer Requirements

Unlike the typical office Ethernet networks, a substation environment has much more stringent requirements (Hirschmann, 2005). These differences can be broken down into 3 major categories: installation needs, data requirements and environmental conditions.

- **Installation Needs.** A typical office Ethernet network has a basic fixed installation within the building and has a variety of devices connected

to that network at standardized workstations. Redundant cabling is rarely required and the need for error recovery is low. Substation Ethernet cabling is different from plant to plant and can have a large variety of device and protocols connected to the networks. Devices can range from data monitoring devices, video surveillance, voice communication to input/output (I/O) control. Redundant cabling is evident through the network and the mean time between network failures cannot be less than 20 years.

- **Data Requirements.** In an office environment, the Ethernet network handles large data packets in a busy environment; but in a substation, the networks must be designed to handle small data packets in relatively quiet networks. All the data sent on a substation Ethernet network must reach its destination in the smallest time possible because a substation requires real-time behaviour to prevent catastrophic results during a high voltage power line failure. The data packets are required to be small because this makes error recovery much simpler, traffic on the network must be light because that reduces the likelihood of packet collision. The data on the network needs to be secured to ensure that the network is not subject to attacks.

- **Environmental Conditions.** In most office buildings, the temperature, moisture and vibration are under strict control. A substation is not afforded that luxury. Parts of the network are expected to operate in

outdoor conditions that can range from -40°C to +70°C with atmospheric humidity reaching up to 95%. Within a substation environment, other factors must be considered, such as electric fields (electrostatic discharge, power surges), magnetic fields, vibration (seismic activity), pollution (dust, solar radiation), and climatic variations (rain, snow, lightning). There is also a much higher risk of mechanical and chemical damage.

	Office	Substation
Installation	- fixed installation - low redundancy - low need for accuracy	- variable cabling - high redundancy - high need for accuracy
Data	- large data packets - high traffic - real-time not required	- small data packets - low traffic - real-time required
Environment	- normal temperatures - little dust, vibration - niminal climatic change	- large range of temp. - outdoor environment - large range of environmental change

Table 2-1: Differences In Office & Substation Ethernet

2.1.4 Market Needs

As seen above, the utilities market is very specific about the reliability and durability of the equipment on their network. Some of the key features (and the requirement from which it extends from) of this market are:

- **Enhanced Reliability (Data requirement, need for accuracy):** The switches need to be able to detect and report irregularities as soon as possible to prevent serious problems from occurring. It must return

detailed reports so operators can quickly determine problem spots on the network instead of wasting hours trying to find the problem.

- **Enhanced Performance (Data requirement, need for redundancy):** The switches need to ensure that the networks are always running and must have built in redundancies to ensure continued operations after a break in one of the communication pathways. When one path is lost, the switch needs to automatically re-route all messages.
- **Real-time Performance and Priority Delivery (Data requirement, need for real time performance):** Real-time performance is important to this market as well as priority queuing. The switch needs to determine how to route messages to avoid collisions and loss packets as well as determine which messages have a high priority and route those ensure those messages are delivered first.
- **High Environmental Performance (Environmental requirement, need for operating in harsh environments):** Industrial Ethernet switches need to work reliably through a large temperature range. These switches would be meant for outdoor environments through out the continent and need to be able to withstand harsh winter nights to hot summer days.
- **Advanced Security (Data requirement, need for security):** Since these switches are used to monitor and control utility devices, security is very important. Ethernet switches need to be secure to ensure the entire network is secure.

2.1.5 Porter's Five Forces Analysis of the North American Industrial Ethernet Switch Industry

This section analyses the competitive structure of the industrial Ethernet industry using Michael Porter's Five Forces Framework (Porter, 1979, p.137). The framework models the industry as being influenced by five forces: power of suppliers, power of buyers, threats of substitutes, threats of new entrants and competitive rivalry. The tool provides an assessment of the industry conditions and helps identify the sources of competition.

2.1.5.1 Bargaining Power of Suppliers -- moderate

Designs of industrial Ethernet switches use off-the-shelf electronic components, which are readily available from most electronics suppliers making switching cost from one distributor to another relatively low. For most of the components, brand value of the supplier is of very low importance since they are commodity products with the exception of a few specialized components that are designed and manufactured by a small group of companies, but would have a number of distributors that firms can source from.

Worldwide hi-tech manufacturing output has seen a turnaround since the internet bubble burst and is expected to continue over the next five years. (Baugh, 2005) This puts a strain on the capacity of the contract manufacturers that many industrial switch firms outsource to. These firms need to ensure that they don't get locked-in to one particular manufacturer and should maintain contact with other firms to ensure that their options remain open. Switching costs from one contract manufacturer to another requires significant search,

evaluation, and operations setup time. A complete loss of production could result if the transition is not seamless.

In July 2006, the European Union's Restriction of Hazardous Substances in Electrical and Electronic Equipment Directive (RoHS) will become law (Dionics, 2005). The directive restricts the use of lead, mercury and cadmium within electrical and electronic equipment. Although the equipment may be manufactured outside the European Union (EU), all equipment that is imported into the EU must comply with the directive. Since the RoHS is an EU requirement, it has no direct impact on any electrical or electronic equipment installed in North America but there are significant indirect impacts. Industrial Ethernet switch firms sell their switches to a global customer base; this puts pressure on their design and manufacturing processes due to inventory and economy-of-scale concerns. The industry may experience price pressures from suppliers when the lead-free components are requested.

2.1.5.2 Bargaining Power of Buyers – moderate to high

The industrial Ethernet switch is designed to target small concentrated markets such as the substation automation market and the oil and gas industry. These are relatively concentrated markets that make high dollar value purchases. Since there are a number of competitors that offer very similar products and although there is a transition time for installing and training on the new equipment, switching costs are low.

Most utilities have a set budget per year and as it is set on a "use it or lose it" basis and they tend to buy standard packages (purchase all parts of the network from one supplier). Once a utility has standardized on one particular type of equipment, it is usually difficult to break in to sell them another brand of hardware.

Substations networks that switch over to Ethernet technology may not always be able to convert all their systems; these systems will require legacy support. Utility buyers will demand that the switches have legacy support from their selected supplier or they will seek out a supplier who is willing to provide that legacy support.

While utilities are direct customers, there are indirect customers through system integrators, value-added resellers and consulting firms. This distribution chain has significant influence over the indirect customers' buying decision.

Significant amounts of R&D are required to develop industrial Ethernet products but the majority of the production cost will be the component and material costs. As a result, buyers will shop around for best material prices. From the utilities perspective, there is low differentiation in the market thus far and they also may pressure the equipment suppliers to bid lower prices to win contracts.

2.1.5.3 Threat of Entry – moderate to high

There are relatively few technological barriers to entry. Ethernet technology is an open standard that can be replicated by any company with

sufficient R&D funds. There are currently a number of industrial Ethernet switch manufacturers and a large number of enterprise class switching products. Although enterprise class switches are not suited for use in harsh environments, such as utility substations, the reliability and durability of these switches can be changed in order to meet the industries needs if the companies employ the correct expertise.

Utilities deploy equipment into their systems with a long-term outlook. New entrants will not only have to demonstrate the long-term reliability of their products but also the long-term availability of the company. Start up and smaller companies may have difficulty portraying a convincing profile of stability.

2.1.5.4 Threat of Substitution – low to moderate

Ethernet technology is the current substitute for aging analogue and legacy data systems. Utility customers demand proven technology that has little margin for error so the threat of substitution by new technology is very low. The biggest threat of substitution is the utilities reluctance to give up their legacy system and replace it with an Ethernet driven network.

2.1.5.5 Competitive Rivalry – high

The market is still relatively young and growing but with no established leader. The competitive rivalry among the current companies is growing and is expected to increase as other firms enter soon to fight for their positions in a market that is still relatively undifferentiated. No apparent market niches have

been identified nor have any competitors signalled to move into those positions. Currently all firms appear to be targeting the same main market.

The industrial Ethernet product development cycle is shorter than the traditional communications equipment product cycle. For companies whose operations have been used to longer cycles there is pressure to adapt resources to meet the quicker pace set by the new competition. The pace disparity is growing as some companies have already released second generations of their products while others are still developing their first. The companies who are unable to turn their organisations around to keep pace will have to find alternative strategies to compete with.

The balance of the competitors in this market is difficult to determine. There are some obvious small and medium sized companies but there are others whose effective operational size is less clear. GE Lentronics is an example of the later situation. The internal analysis below will show that although GE is a very large organisation, GE Lentronics competes in the market with the attributes of a small company.

Exit barriers vary for different companies. For smaller firms with a slim product portfolio and limited access to financial resources, the exit barriers are high, possibly costing them their existence. For other firms with alternate revenues from a wider product portfolio and more robust financial capability, the exit barriers may be more bearable. With the prevalent use of contract manufacturers for production, the sunk costs are those specific to the product development. For larger firms, this further reduces the exit barrier.

2.1.5.6 Porter Analysis Summary

The industrial Ethernet market is an emerging market that is in the growth phase where firms are fighting for market share. In order to establish a presence in this market, firms face competitive pressure from a variety of sources.

With a changing landscape in the production chain, production teams are faced with new challenges and pressures. As the use of contract manufacturers becomes more commonplace, firms have to shift their expertise from manufacturing skills to managing relationships with the contract manufacturers. The RoHS Directive in the EU forces firms to re-evaluate the inventory of parts that they keep and the suppliers who provide these parts. Regardless of whether manufacturing occurs outside of the EU or not, a global marketplace puts pressure on firms to take these new directives into account.

With firms currently offering fairly undifferentiated industrial Ethernet products to a fragmented group of utility customers, the power of the buyer is moderately high. Utilities have their annual budgets to spend and with switching costs low, they can pressure suppliers to lower their prices.

Although the threat of substitution is low, the threat of new entrants remains moderately high. The key and underlying competitive forces that firms face in the industrial Ethernet market are:

- **Key Forces**: As substation networks migrate to Ethernet based networks, the industrial Ethernet market is emerging where new entrants have notice the potential of this market. Traditional utility communications companies are now facing increased competition

from new entrants familiar with Ethernet technology but previously unfamiliar with the substation market. As a result the dynamics of the markets that the traditional companies have been used to have changed. Product development cycles have shortened, the number of competitors has increased, and margins have come under pressure from lowered differentiation.

- **Underlying Forces**: As utilities become more profit aware and the demand for electric power increases, they need to seek out solutions for efficiency improvement and better reliability. Industrial Ethernet technology reduces the cost of equipment installation and maintenance in the substation while providing greater control and monitoring capability. Another underlying force is that high tech contract manufacturers are very capable and so readily available that they have lowered the cost of entry into equipment markets. Much smaller firms can now develop and market products at the same level of firms that had huge manufacturing resources.

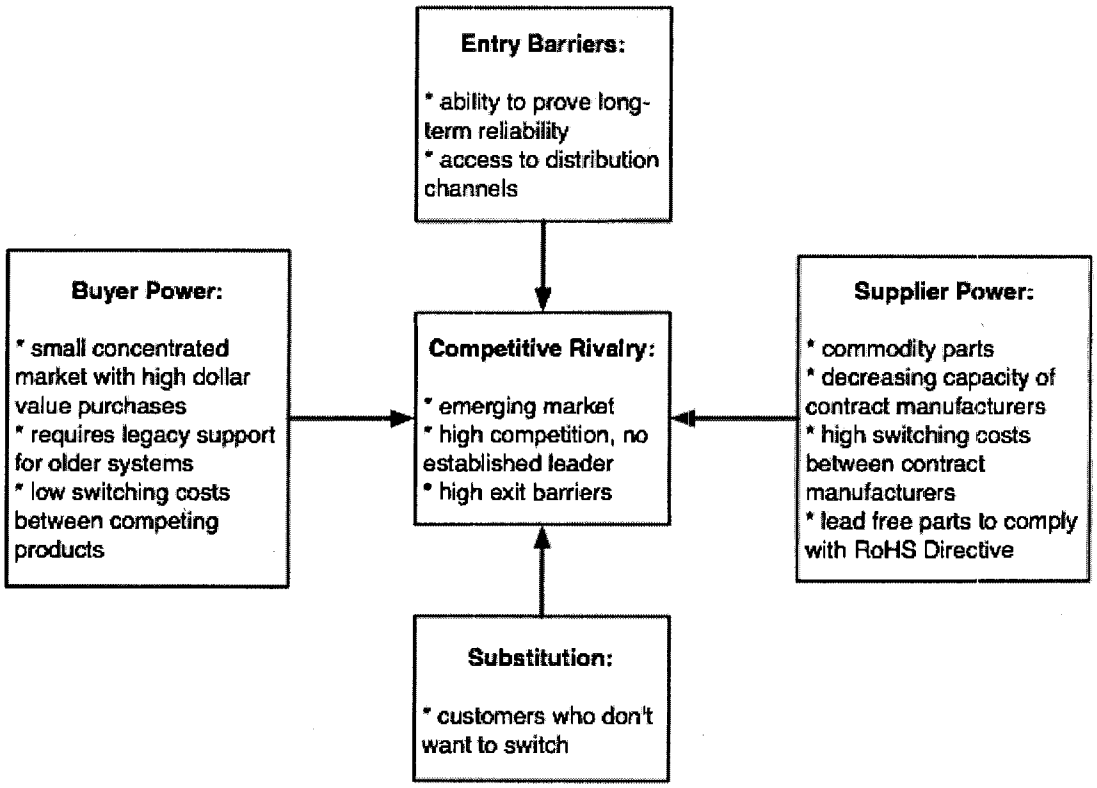


Figure 2-1: Porter's Five Forces Analysis of the North American Industrial Ethernet Switch Industry (adapted from Porter, 1979, p.137)

2.2 Competitor Analysis

In the industrial Ethernet switch market, the top five revenue producers are: SIXNET, GarrettCom, Hirschmann, RuggedCom, and Ontime Networks (Industrial Ethernet Book, 2005). It is important to understand the features of the products that GE Lentronics' Rail Switch will be competing directly against to determine what features they need to build into their product to compete and which features would be needed to differentiate them from their competitors.

2.2.1 SIXNET

Located in Clifton, New York, SIXNET designs and manufactures products for industrial automation, data acquisition and control products for harsh environments. SIXNET uses an open systems strategy because SIXNET believes that through open systems, greater interconnectivity can be achieved as curbing the high cost of piracy. SIXNET's distribution channel includes independent distributors, system integrators as well as selling OEM's as a private label.

SIXNET's ET-9MS is a managed Ethernet switch designed for harsh industrial environments. SIXNET ensures reliability by employing a ring topology with an automatic switchover on any detected failures. The switch operates in a wide-range of temperatures (-40C to +70C) with no fan, which means less mechanical failures. The switch includes up to nine copper ports and 2 fibre ports. A web-based management utility is included by there is no configuration utility.

2.2.2 GarrettCom, Inc.

GarrettCom designs and manufactures heavy-duty Ethernet products for specialty and stressed applications. Founded in 1989, GarrettCom is a privately held company that is headquartered in Fremont, California. Some of the products that GarrettCom produces for these markets are: Ethernet switches, hubs, media converters, repeaters, transceivers, and chassis. GarrettCom's market strategy focuses on the telecommunications, industrial automation, power utility

and traffic control markets. Their channels include selling product through resellers, OEMS, integrators and distributors.

The GarrettCom's 6K16V managed Ethernet switch provides two modular slots that provides up to 6 copper ports and 8 fibre ports, which allows the user to select 10Mb, 100Mb, gigabit fibre or 10/100 copper. The switch does not utilize the features of a ring topology and dies not establish alternate route when the system encounters any trouble. The unit has small form factor connectors and allows for a variety of power input choices. The software includes telnet, command line interface, a secure web management and configuration utility. It operates in the -40C to +60C temperature range.

2.2.3 Hirschmann Electronics Company

Hirschmann Electronics Company, headquartered in Chambersburg, Pennsylvania, is a subsidiary of the Germany based Hirschmann Group. HEC specializes in Automation and Network Solutions and is comprised of two business units: Industrial Connectors and Industrial Networking. The Industrial Networking unit produces a line of industrial Ethernet products that include: hubs, switches, and network management software.

Hirschmann's RS2-4R is an industrial Ethernet switch that has a store and forward switching mode and can operate at Ethernet or fast Ethernet speeds. The product includes two copper ports and two fibre operates, it operates at a voltage of 24VDC and a current consumption of 200mA. For service

management, the unit has a serial interface and web interface. Diagnostic LEDs are included for power, error, redundancy manager, link status, and data)

2.2.4 RuggedCom Inc.

Another competitor in the industrial Ethernet switch market is RuggedCom. Headquartered in Concord, Ontario, RuggedCom produces communications equipment designed to withstand severe electrical environments and harsh climates. The "Zero-Packet-Loss ™" technology developed at RuggedCom replaces traditional protective relaying devices and has the same EMI immunity performance levels. RuggedCom's market consists of power utility substation automation and transportation systems.

RuggedCom's RS8000 family of switches offer eight Ethernet ports as well as multimode and single mode optical transceivers. It is a fully managed switch that was designed for harsh environments and utilizes RuggedCom's "Zero-Packet-Loss" technology to provide EMI immunity. The RS8000 switch also offers a wide variety of power options and has a large range of temperature tolerances (from -40C to +85C). The software for managing the switch utilizes RuggedCom's custom RuggedSwitch Operating System that is designed for Ethernet networks in mission-critical applications.

2.2.5 OnTime Networks

OnTime Networks is a privately help company based in Oslo, Norway. They design and manufacture harsh environment industrial real-time Ethernet products such as ring networks and switches for a variety of industries such as

substation automation, traffic control, mining, defence and railways. OnTime Network's speciality is their real-time design, which increase accuracy and response time in automation projects.

LynxSwitch is OnTime Network's series of managed industrial Ethernet switches that were designed for the industrial, marine, substation automation and defence industries. OnTime Networks offers a Fast Re-configuration of Networks Topology (FRNT) technology that minimizes failures due to faulty network lines. The largest drawback of this switch is the lack of a web-based management system and configuration utility.

Features	SIXNET ET9-MS	Garrettcom 16K16V	Hisrchmann RS2 - 4R	RuggedCom RS8000	Ontime Lynx
Managed Switch	YES	YES	YES	YES	YES
Fibre Speed	100 Mb/s	100 Mb/s	100 Mb/s	100 Mb/s	100 Mb/s
Copper Speed	10/100 Mb/s	10/100 Mb/s	10/100 Mb/s	10/100 Mb/s	10/100 Mb/s
# of Copper Ports	Up to 9	Up to 6	Up to 2	Up to 6	Up to 6
# of Fibre Ports	Up to 2	Up to 8	Up to 2	Up to 6	Up to 2
Traffic Prioritation	YES	YES	YES	YES	YES
# of Queues	4	2	2	2	4
Time to establish alternate route	500 ms	N/A	500 ms	5ms x bridge diameter	30 ms
Configuration Utility	NO	YES	YES	YES	NO
Web Based Management	YES	YES	YES	YES	NO
Bandwidth	100 Mb/s	100 Mb/s	100 Mb/s	100 Mb/s	100 Mb/s
Operating Temperature	-40C to +70C	-40C to +60C	0C to +60C	-40C to +85C	-40C to +70C
Emissions Standards	NO	N/A	N/A	YES	N/A

Table 2-2: Competitor Feature Analysis

2.2.6 Competitor Summary

The current feature set for the GE Lentronics Rail switch include: four copper ports, four fibre ports, traffic prioritization, four queues, 500ms transfer time and a integrated management and configuration utility through VistaNet. Comparing this feature set to the feature sets of the Rail Switch's direct competitors, it is clear that the Rail Switch is a "me-too" product that offers little differentiation. This is the key issue that GE Lentronics faces; they need include features that would distinguish the Rail Switch from currently available products. One source of differentiation that GE Lentronics can offer is the integrated management and configuration utility that is not only used with the Rail Switch but also with the multiplexor system that GE Lentronics customers currently use.

3 INTERNAL ANALYSIS

3.1 Organization

3.1.1 Business History

GE Lentronics developed its line of optical multiplexers when it was an entity known as Nortel Lentronics, a unit within Global Utility Networks, a division of the Optical Networks line of business of Nortel Networks. The specialized multiplexers were sold primarily in the utility, industrial, and oil and gas pipeline markets. In August 2001, GE Multilin, a unit within Industrial Systems, a division of the General Electric Company, acquired the Nortel Lentronics line of multiplexers. Job offers were made to all key personnel from Lentronics to ensure continued success of the business. The GE Lentronics operation was then relocated to a GE facility but within the same city of Burnaby.

3.1.2 Structure

GE Lentronics remains a self-contained entity with its former internal Nortel structure virtually unchanged. The company is organized in a functional structure with the following functional groups: design, marketing and business development, product management, systems engineering, sales, operations management and product support functions. New projects are conceived by the functional managers and then delegated to staff in each department as required. Projects are run with minimal coordination across functions – a cross-functional

team approach is rarely used. The details of the structure are depicted in the diagram below.

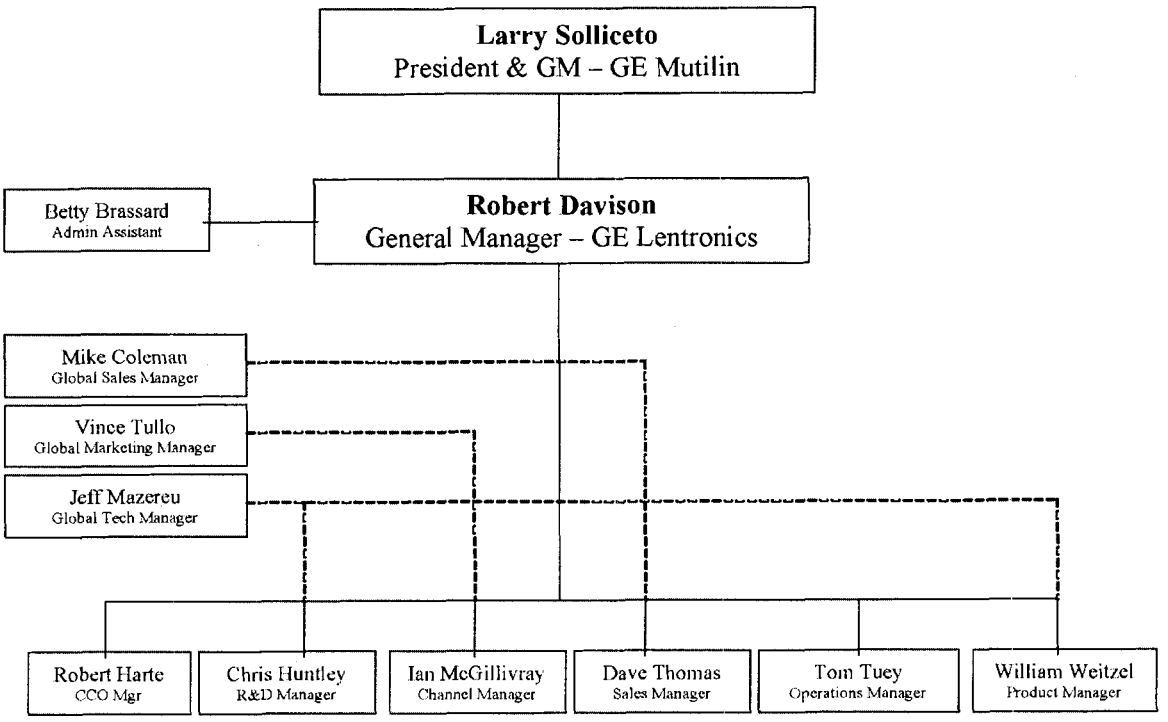


Figure 3-1: Organizational Chart

The main changes to the structure occurred in the reporting relationships. The general manager now reports directly to the president of GE Multilin. For the functional managers, in addition to reporting to the general manager, now have a dotted line relationship to similar global managers in the GE Multilin organization.

3.2 Current Strategy

3.2.1 Multiplexer Market Strategy

This section is an analysis of GE Lentronics' current strategies to understand the starting point from which direction new strategies for the Rail Switch should take. The main strategies in place are a balance of product,

market, and price. In pursuing the substation LAN market the company will experience a shift focus to a position of higher product complexity but less uncertainty (as shown in Figure 3-2). This positioning shift may require alterations in the organisational areas such as differentiation, process, structure, operations, and behaviour.

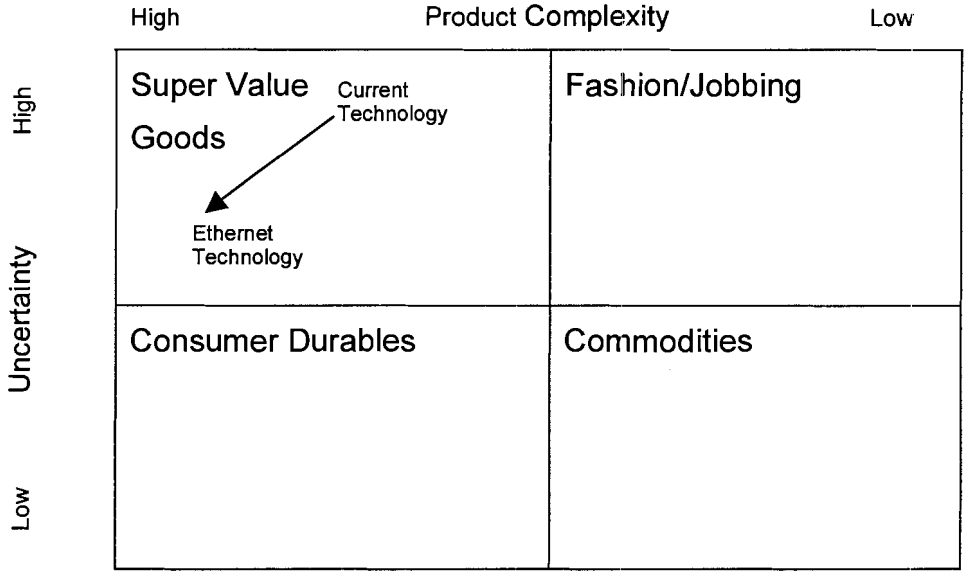


Figure 3-2: Complexity Grid (Department of Trade, 1995)

The current product strategy taken with the optical multiplexer product is one of differentiation with one of the fastest protection switching times in the industry, product configuration, flexibility, and superior customer service. Most new product initiatives originate through feedback from the close relationships GE Lentronics has developed with its key customers. Although Christiansen's theory of the Innovators' Dilemma suggests that listening too closely to your customers stymies innovation, GE Lentronics' approach seems reasonable considering that its top ten customers account for over 50% of revenues and the

technology buying profile of utility customers. One pitfall with this approach has been the abuse of the relationship by customers to solve problems that are unique to their own networks. This influence has resulted in the development of products that were purchased by only a small number of customers and in small quantities due to the over statement of the original problem.

The market strategy has been to focus on and dominate the utility communications segment. Having achieved a dominant share of this segment, and having serviced it for almost 11 years, the market in North America is maturing. As customer requirements change, repositioning is a strategy consideration to find developing markets that could be served with the current product features. Market development plans now include expansion into other segments such as intelligent transportation systems (highways), industrial (oil refineries and mining operations), and pipeline communications. These segments were chosen because some of the product features valued by the customers were deemed compatible with those in the utility market. The ability to withstand harsh environments proved to be a desirable feature in the industrial and pipeline markets where the product met a successful introduction. The transportation market, however, demands other features such as higher bandwidth, video over IP, and low cost, which reduces the suitability of the product in this market.

The pricing strategy is to not compete on a low cost basis since the multiplexers are differentiated products produced in low volumes. If required to win key or strategic projects where price is the determining factor then discounts

will be offered. The multiplexer has been designed for great configuration flexibility so that a customer can build a solution tailored to his needs. This flexibility comes with a cost, as it is more expensive to produce and manufacture than products offered as standardized packages that can be mass-produced. The level of differentiation achieved by the rail switch may not be as high therefore, a modified approach to pricing may be required.

The disruptiveness of Ethernet technology reduces the possible markets available to the legacy technology as developing countries skip older generation equipment to adopt the latest. This can be seen in the telephone industry where developing nations have skipped building a wired line infrastructure and have proceeded to install wireless communications networks instead. The potential to sell cable based equipment to these markets was eliminated by the disruptive nature of wireless technology.

3.2.2 GE Multilin's Industrial Switch Strategy

Recently, GE Multilin (GE Lentronics' parent company) announced the availability of their own family of industrial Ethernet switches, to be branded as Multilink switches. The offering includes a 24 port and a 16 port managed switch with gigabit uplinks and a 6 port unmanaged switch. All models offer both copper and fibre optic port options and meet requirements for use in harsh environments. The Multilink switches were developed rapidly by licensing core technologies from a third party and combined with software and hardware modifications done using internal Multilin resources. The Rail Switch team did not know prior details of the Multilink products.

GE Multilin is marketing the switches to the industrial automation, power utility, and traffic control markets as communications solutions for their substation and industrial equipment. These are competing markets for the Rail Switch and directly affect the forward strategy choices.

3.3 Critical Success Factors

This section is an analysis of what customers in this segment value. This will set the basis from which to analyse the fit with GE Lentronics capabilities in the following sections. First, is the concept of threshold values, which are needs that have to be met by a product, be it a feature or service, in order to remain in the market.

Threshold product features for substation LAN market are:

- Operation in harsh environments. Meet IEEE 1613 and IEC 61850-3 standards. Copper and fibre optic port interfaces.
- 10/100Mb speed ports
- Operate with different power inputs.

Critical Success Factors (CSF) are the product features that are most valued by a group of customers and provide differentiation among other products with threshold features. This is where the company must excel at to achieve a competitive advantage. The competences and resources required to meet the CSFs will be analysed in the following sections. Features that have been identified as CSF for the substation LAN market are:

- Fast switching upon path failures
- Leverage existing hardware and software investments
- High reliability
- Exceptional after sales service
- 1Gb speed WAN ports

In determining the CSFs for this market, it was apparent that many of the valued features were similar to those that made the multiplexer products so successful. This is not surprising since they are essentially the same customers. The first four of the CSFs listed above are shared by the multiplexer market with the last item, 1Gb port being driven the growing bandwidth requirements of intelligent substation devices. Prioritisation of the CSFs will vary by customers depending on their own internal capabilities and past experiences. Achieving all the CSFs will ensure wide acceptance by the market.

3.4 Resources

Resources underpin the capability to carry out the organisation's strategy. This section looks at the resources available to the organization internally and those accessible externally within its network of suppliers and contacts. Similar to customer values, there are threshold resources and unique resources. Threshold resources are the minimum requirement to exist in a market and support the strategy. Unique resources are those needed to achieve the CSFs and create competitive advantage. They are often take the form of tacit knowledge within individuals or embedded with company systems or processes

and are difficult to imitate. We will examine the four general categories of resources: human, physical, financial, and intellectual.

3.4.1 Human Resources

The human resources of an organisation include knowledge and skills of people who are employees of the company or those in the organisation's network of contacts. GE Lentronics operates, for the most part, as a self-contained business unit, drawing on very few external resources. The internal human resources in terms of functional capability are:

Product Technology:

- Hardware and software design
- Feasibility studies
- Product verification
- Printed circuit board layout.

Product Management and Marketing:

- Feature definition
- Setting prices
- Use of discounts
- Identifying field trial customers
- Development of sales channels
- Technical documentation

- Product training

New product introduction:

- Building of prototypes
- Creation and control of all manufacturing documentation
- Interface and transfer of documentation to contract manufacturers and test groups

Systems Engineering:

- System designs and applications support
- Provide technical responses to RFQ, RFP, etc
- Technical sales support

Sales:

- Dedicated sales manager per territory
- Customer calls

Field Services:

- Customer technical support
- Equipment installation
- Field commissioning and testing

To date, the following resources have routinely been obtained externally:

- Embedded firmware development for Ethernet projects.

- Mould and extrusion design and manufacture
- Machining and tooling work.
- Prototype printed circuit board manufacture and unit assembly
- Contracts and legal paperwork.

3.4.2 Physical Resources

These are the tangible resources found in an organization that can be easily valued. They are often threshold resources since they are accessible from the company's network of suppliers and unless there are exclusive arrangements in place or customization performed, the same resources are normally available to the company's competitors also. The physical resources available at GE Lentronics are:

- 5000 square feet of dedicated lab space for product development and prototype building
- Electronic test and measurement equipment – oscilloscopes, Ethernet testers, SONET/SDH testers, datacom test sets, logic analysers, video testers, etc.
- Computer Aided Engineering and Computer Aided Design software – VHDL tools, schematic design tools, PCB layout tools, etc.
- Software development tools – Visual Basic, C/C++ compilers, Forth, Motorola assemblers, etc
- Engineering workstations

- Data Networking equipment – switches, routers, etc.
- Printed circuit board reworking tools

3.4.3 Financial Resources

GE Lentronics is a wholly owned subsidiary of Industrial Systems of General Electric (GE). GE is a publicly listed company on the NY stock exchange under the symbol GE. In 2004, GE earned a net profit of $16.8B on revenues of $156B.

Funding for this project is available from three sources. One source of funds is through GE corporate. This route requires approval through the GE strategic planning process that is comprised of three sessions (simply called A, B and C). Session planning is done for a three to five year outlook and approved funds would be available in the following budget. A second possible source of funds is from the GE Multilin budget. This pool of funds is allocated to product development and technology projects and is part of the Multilin operations budget. If the project fund requirements exceed the capacity of this pool then corporate funding will have to be sought. The last source of funds comes from GE Lentronics own operating funds. This method would be suitable if the project costs are not capital intensive and remain relatively small. Capital expenditures require approval from GE Multilin but otherwise this source would be the most flexible.

The current GE Lentronics R&D budget of $950K covers departmental salaries and the development program costs. Traditionally, Lentronics has

always tried to fund its product development internally to reduce the obstacles, longer approval times, and resources required to obtain funding through higher level and corporate sources.

3.4.4 Intellectual Capital

These are the intangible resources of an organization, which are difficult to value and are often undervalued. As a technology company, GE Lentronics has a significant amount of intellectual capital in the form of knowledge acquired by its employees, and captured in its products, and brands.

- The technical knowledge and experience of the staff is growing continually through hands-on development, self-learning, formal training, and problem solving. More important than the volume of knowledge captured is the exact blend, which is hard to imitate. Knowledge competences will be explored in subsequent sections.
- Many product innovations have been implemented into the products that offer greater reliability, performance, and flexibility not achieved by competitors. Currently, there have been no patents filed for any of the innovations; they are guarded through trade secrets only. The innovations are in the form of algorithms, hardware architectures, and coding schemes that are implemented in code or programmable hardware, which are very difficult to copy.
- The GE Lentronics Multiplexer brand already has a reputation for excellent customer service and also as the market leader in North America. Now,

combined with the GE name, which is known worldwide for its expertise in industrial products, the brand value has even greater reach.

3.5 Knowledge

GE Lentronics ability to compete in the market relies primarily on its knowledge resources. Since knowledge is critical for its competitive advantage, this section takes a more detailed view of the knowledge components underlying the resources identified in the previous section. The areas of knowledge have been classified into knowledge required to participate in the market and is similar to the competitors, known as Threshold Knowledge, and Unique Knowledge, which is difficult for competitors to acquire or imitated.

3.5.1 Threshold Knowledge

The following are knowledge resources within the organization that help to maintain a presence in the market.

- Knowledge of what customers' value is obtained from strong industry linkages and close customer relationships. Several groups interact routinely with main customers to extract desired values for new product ideation.
- The marketing and sales groups stay abreast of competitor product offerings and positioning through market analysis efforts and sales reconnaissance.
- Knowledge of industry trends in technology adoption, government procedures, standards, and environmental policies. The organisation's

network of suppliers, contractors, and equipment partners are an invaluable source of external information. For example, the European directive for the Restriction of Hazardous Substances (RoHS) has a profound affect on all electronic manufacturing and early awareness is required to make appropriate arrangements with suppliers and manufacturers.

- Advanced electronics system and software skills are required to implement new product ideas into actual products. Specific skills are: high speed digital hardware design, mixed signal circuit design, embedded firmware development, Windows application, developers

3.5.2 Unique Knowledge

The following are knowledge resources that are unique to the organization. The resources are also very difficult to obtain or replicate.

- **Industry Expert Knowledge.** Some of the R&D staff are members of key industry organizations that influence the standards adopted by the markets. For example, one staff is a contributing member of the Institute of Electrical and Electronics Engineers (IEEE) committee that developed the optical standard for relay communications in substations. Another staff is a member of the international network synchronization committee working on standards for clock synchronization in Ethernet networks.

- **Design Experience Depth.** The senior designer has over thirty years experience designing communications equipment specifically for the utility market. His primary areas of expertise are in analogue circuit design but the last ten years have focused on high-speed digital circuits and microprocessor-based systems. A majority of the design team hold advanced degrees in engineering (PhD, MASc, MEng, etc) and have extensive experience in running product design projects efficiently and successfully. Most of the technical knowledge remains tacit, since all hardware projects report to the senior designer while the project designers tend to work individually with minimal interaction with other group members. Hence the knowledge learned by the project designers also remains with the individual.

- **Customer Feedback.** As part of the annual user group conference, senior staff from across the organization gets to interact and listen to customers praises and complaints. In a short three-day session, a broad spectrum of issues from manufacturing quality to product performance gets addressed. The feedback also reveals what the organization is doing well. In addition, the attending customers compile a wish list for problems to be resolved and features/products they wish to see. No other competitor in the market currently hosts a similar user conference.

3.5.3 Organisational Knowledge

Organisational knowledge is the process through which knowledge is shared and/or integrated. It is important in new product development where knowledge about product feature and development and market knowledge need to be blended to create commercially successful products. The speed at which knowledge is developed and exploited will be of particular importance in fast-changing environments.

As a result of the strong linkages with our customers a positive knowledge flow has made our customers more knowledgeable about our company. Many customers know the names of the people that deal with their problems.

3.5.4 Knowledge Gaps

GE Lentronics ventures into new areas with the development of the Rail Switch in terms of knowledge. The Rail Switch has a much larger software component than its previous products did. The R&D group does not possess the experience to develop these software features. In the past, additional software coding resources were contracted externally on a project basis. The Rail Switch is classified as a computing device under FCC rules and must comply with part 15 of the regulations for sale in the US. The FCC procedures and test requirements are extensive and very complicated and require experienced leadership to achieve. The only exposure GE Lentronics has had with FCC type compliance was during the CE (European Compatibility) compliance project for the multiplexers based on international standards. However, the project was

managed by a Nortel group in the U.K. who are not longer accessible to GE Lentronics. As a note, the Multilink Switch products are FCC approved.

3.6 Value Chain

The value chain concept describes the activities associated with an organization used to create a product or service. The value chain diagram can be used to understand how value is created or lost by the company. It provides an integrated view of the internal analysis presented thus far and can be used to identify areas of efficiencies and inefficiencies. Activities in the value chain are classified as either primary or support activities. Primary activities are directly involved with the creation or delivery of a product. The purpose of support activities is to improve the effectiveness of the primary activities. The primary and support activities of GE Lentronics and its parent organization in the industrial Ethernet industry are discussed in detail below.

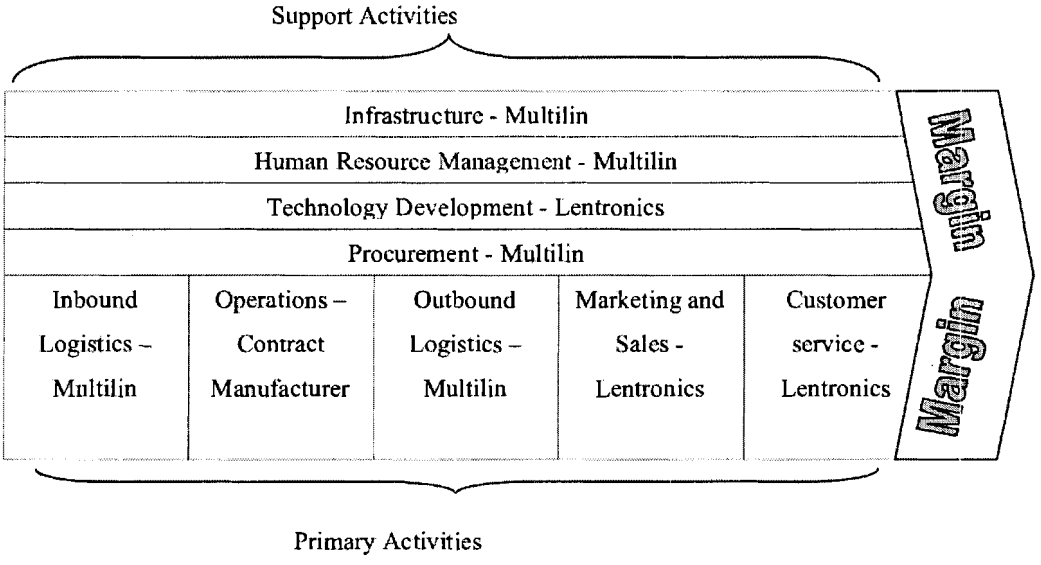


Figure 3-3: GE Lentronics' Value Chain (adapted from Porter, 1979, p.161)

3.6.1 Primary Activities

3.6.1.1 Inbound Logistics

Inbound logistics include all activities that receive, store and distribute the inputs to the product, in this case, industrial Ethernet switches. Aside from prototype units and specialized components, the buyers at GE Multilin purchase all materials. Purchased materials may be delivered to GE Multilin first and then distributed to contract manufacturers later in situations such as last time buys of discontinued components. GE Multilin manages inventory control.

3.6.1.2 Operations

Operations are activities that transform inputs into the final product. The printed circuit board manufacturing and production, machining of parts and casing, castings, extrusions, design and build of moulds, and unit level assembly are achieved through contract manufacturers. GE Multilin currently performs unit level testing but this is in transition to be transferred to the contract manufacturers. Repair of defect returns are performed by GE Multilin but this mostly entails troubleshooting and problem identification as the equipment to replace complex components resides with the contract manufacturer.

The heart of the operations activities is printed circuit board manufacturing as it is the main component of all unit production. GE Multilin qualifies two manufacturers, one in India and one in Ontario, to reduce the risk of production down time.

3.6.1.3 Outbound Logistics

Outbound logistics are the activities that collect, store, and distribute the final product to customers. Finished units are shipped from the contract manufacturers to Multilin for assembly into shelves, interconnection wiring, custom configuration, and systems test. The assembled systems are then shipped to the customer locations.

3.6.1.4 Marketing and Sales

Marketing and Sales are the activities that make customers aware of the products and how to purchase them. All marketing and sales functions for the multiplexer products are managed from Lentronics with sales personnel located in their responsible regions.

Traditional advertising is not utilized by GE Lentronics; instead most of their promotion is achieved by attending trade shows and major conferences such as the Utility Telecommunications Conference. Further promotional reach is obtained through relationships developed with value added resellers (VARs). Once VARs are trained on the products they promote them within their own network of customers.

The biggest marketing event is the annual users group conference. Customers come to learn about latest developments in the products and attend workshops but they also take an active role in voicing their top concerns or needs into what has become known as the to top ten list. The list may contain desired features or functionality or problems that need resolution. Many opportunities are

made available for GE Lentronics senior staff to interact with the customers to learn what they value most.

Sales staff routinely updates their knowledge on new product features and applications through internal training courses and documentation. For complex technical presentations, systems engineers are consulted.

3.6.1.5 Service

Service are the activities that enhance or maintain the value of the product. After sales service is an important part of Lentronics whole product offering. In addition to the standard 2-year warranty return and repair service, customers can also receive emergency technical support by contacting a product specialist during regular business working hours (pacific time zone).

A full-time customer service (CS) manager looks after all non-technical customer issues such as project schedules, delivery changes, and general logistics. For complex technical problems that cannot be solved by the technical support staff, the CS manager acts as facilitator to gather the relevant personnel to find a solution. It is not uncommon for the CS manager to rapidly involve senior technical people and managers for service affecting issues.

Value added services are also available for purchase by customers. Services available are: product training and field services. Detailed, hands-on product training courses are available at the Burnaby location several times a year, or for larger groups, customized courses can be delivered on customer premises. The courses are four to five days in length covering, basic theory and

operation, configuration, and applications. Field services covers equipment installation, commissioning, and testing services. The CS manager coordinates all valued added service requirements.

3.6.2 Support Activities

3.6.2.1 Infrastructure

Financial reporting, accounts receivable and payable, and GE Multilin manages capital spending control activities. Payroll activities are managed by GE Canada in Missasaga, Ontario. GE subscribes to the Six Sigma approach to quality management for manufacturing and product design. Six Sigma is a corporate initiative but GE Multilin have their own Black Belts (Six Sigma project leaders) that manage all Six Sigma projects. The IT group in GE Multilin also manages the Clarify call tracking system and the Oracle ERP system.

3.6.2.2 Human Resource Management

The human resource management group is located in GE Multilin and there is no human resource staff assigned locally to GE Lentronics. Aside from the dotted-line management relationships presented in the company structure section above, Lentronics manages its internal staff directly. Yearly employee performance reviews and assessments are performed using GE's Employee Management System (EMS) as part of the session C process.

3.6.2.3 Technology Development

All technology activities for the multiplexer products are undertaken and managed by Lentronics. The R&D group is responsible for hardware design,

firmware development, software development, and feasibility studies. The Verification group is responsible for ensuring products meet performance and standards specifications, are compatible at the network interface, are scalable, and that overall functionality is met. The operations group performs assembly and rework activities during the prototype iteration cycle and coordinates the sourcing of new components and materials for evaluation.

3.6.2.4 Procurement

The sourcing group located in GE Multilin manages all the activities related to acquiring inputs for the primary activities. The group consists of buyers and materials management staffs that utilize their network of suppliers and the buying power of GE corporate to obtain the best prices for their material inputs. The standard GE terms are net 90 and there is a continuous effort to minimize inventories on hand.

3.7 Competences

This section is a synthesis of the company's strategic capabilities from the internal analysis presented so far. Although GE Lentronics has always belonged to large multinational companies such as Nortel and now GE, it has operated much on it's own merit, relying little on the resources of its parent business. Its advantages in the market are result of the competences the organization has developed. We start by acknowledging the threshold competences and then present the core competences of the organization. Many of the competences are rooted in the knowledge of its employees and the organization.

3.7.1 Redundant competences

Redundant competences are activities where performance standards are below the level need to stay in business. They may be adequate for other segments. The rail switch is about mitigating redundant competences as the evolution to Ethernet grows, expertise in circuit switched technology becomes less valuable.

3.7.2 Threshold Competences

Threshold competences are activities that underpin the meeting of threshold product features. These are required to maintain a minimum position in the market. These competences are:

- **Technical capability**. Hardware and software design skills capable of developing complex communications equipment on schedule.
- **Understanding market requirements**. The ability to understand the nature of the market and extract specific product requirements and customer needs. Provides inputs to product development.
- **High technology manufacturing knowledge**. A thorough understanding of current manufacturing technology is required, even with the use of contract manufacturers, to evaluate appropriate manufacturers to use and to ensure product designs can be efficiently produced and tested.

3.7.3 Core Competencies

GE Lentronics, as a business unit is relatively small, yet has been able to obtain a majority share of the market against much larger players with seemingly greater resources. This position has been achieved by excelling in areas of its business over that of the competitors. These areas of excellence are Lentronics' core competences. Core competences are activities that underpin the ability to meet the critical success factors. These are hard to imitate by competitors and thus create competitive advantage.

3.7.3.1 Product Development

To create successful products for the utility market requires blending several areas of knowledge, skills, and experience. Knowledge of appropriate technical standards, application interfaces, industry trends, functional requirements, and performance requirements are necessary to conceptualize a new product. Then experience is required to abstract the new concept into hardware and software architectures, to choose the most appropriate technologies to use, and to manage the complex projects efficiently. And finally, technology skills are required to implement the design. Although there are many methods to manage the product development process, such as phase reviews or stage gates, there is no formal method in which the processes themselves are actualized.

3.7.3.2 Building Customer Loyalty

The large and growing base of loyal customers is evident by the increasing number of user group participants, year over year. Approximately 50 representative customers attended the user group conference in 2005, which is sponsored by Lentronics but participants are responsible for their own travel and lodging. The loyalty was earned generally through commitment to responding to and solving customer problems. However, no specific aspect of the activity or type of reported problem can be identified as the primary reason. Some problems are solved within hours and others in weeks. Product modifications are performed in some cases and work-arounds are suggested in others. The interaction is involved enough in most cases that customers will reference their problems by the names of the persons they have contacted rather than a call ticket number.

3.7.3.3 The Mega-Corporation Contradiction

By managing its own internal relationships with the parent business, GE Lentronics has been able to maintain its autonomy within the larger corporate structure. This independence allows closer interaction and faster response to customer problems and complaints. This creates a unique experience for the customer by offering the security and assurance of a large corporation but with the responsiveness of a small, nimble, customer focused company.

3.7.3.4 Systems engineering and applications

Customers in this market may not seek out your product explicitly regardless of brand; they have unique problems and are looking for solutions. Often there will be several solutions to the problem but with experience and knowledge of the other systems found in utility infrastructures, a solution using the company's products can be designed. This provides a very compelling reason to purchase our equipment over the competitors. To excel at these activities requires a group with wide communications knowledge and experience, dynamic group interaction, and strong customer focus.

3.8 Chapter Summary: Internal Analysis

GE Lentronics is an experienced utility communications company with strong brand awareness within the utility communication industry. It has strengths in the areas of product development and customer service. The key questions are which internal resources are needed to compete in the new substation LAN market and which resources need to be developed. Learning is a big part when transitioning to new markets but often unlearning is just as important. The insights from the above analysis can be further summarized as internal strengths and weaknesses of the organisation.

Strengths:

- **Self-sufficiency.** GE Lentronics profitability as a business unit has allowed it to fund most of its own project initiatives.

- **Independence.** This allows GE Lentronics to pursue strategies that fit well with them without significant influence from corporate goals and objectives.
- **Loyal Customer Network.** Current customers demonstrate a strong loyalty towards the product and actively participate to identify bugs and areas for improvement.
- **Industry Experience.** Collectively, the staff has over 50 years of product development and marketing experience in the industry.

Weaknesses:

- **Underdeveloped organisational relationships.** The potential to tap the vast resources and reach of the GE corporation requires developing relationships with other business units within the organisation.
- **Dependency on a few key designers for product development.** This puts the business at risk if these personnel are lost. Also creates bottlenecks for other projects and limits the skill development of other designers.
- **Lack of software development and development process experience.** Specifically in the areas higher layer protocol software as identified previously.
- **Lack of FCC Compliance Experience.** The rail switch will fall under FCC part 15 class A device requirements. The FCC compliance documentation and testing requirements are a very complicated process.

4 STRATEGIC ANALYSIS

4.1 Strategic Direction

This section is an analysis of possible strategic directions for the Rail Switch project.

4.1.1 Market Development

To start, we consider whether existing products can be used to service this market. From a pricing perspective, the current multiplexer product uses a focused differentiation approach: a price premium is warranted due to the perceived value added from the harsh environment capability. The Rail Switch market still demands the environmental criteria but the market has crossed over into the realm of computer networking, where premium pricing is less common. The current Ethernet 100 Mapper product (E100) was designed for wiring closet applications and not Ethernet extension applications. It has a maximum of eight available ports and another eight could be added but requires another E100 unit. This makes the cost per port relatively expensive.

A combined product differentiation and competence-based approach would draw on multiple strengths of the organization. A portion of older substation equipment still utilizes legacy data interfaces (RS232, RS485, and output contacts) and may not be upgraded. It has been planned to add legacy data ports to the rail switch as a product differentiator from other substation

switches. Another area of product differentiation is that the rail switch supports VistaNet network management. VistaNet is proprietary software management system used by GE Lentronics multiplexers. Customers already using VistaNet would not need to invest capital and training into another management system. The organisation's competences in building customer loyalty and in customer response can combine naturally with the product differentiation to achieve a broader range of dimensions that customers value.

4.1.2 Internal Development

4.1.2.1 Hardware Development Expertise

The technology design group has already successfully designed 10Mb and 100Mb Ethernet Mapper products. The architecture design and hardware implementation was performed completely in house whereas the majority of the microprocessor firmware was contracted to an external software company. A significant amount of hardware experience was gained through these projects, which can be applied towards the Rail Switch development.

The organization has strength in hardware design but there is reliance on uniquely competent individuals in the product design functions. Projects are usually assigned to single individuals and with no formal mentoring process, the codification of knowledge and experience into other designers is minimal. The designers over time become experts in certain areas of technology with little or no cross training to develop other areas of expertise. The current Ethernet expertise level at GE Lentronics' needs to be improved upon in order to meet the

short production cycle required. Although they have one Ethernet expert, this area of expertise needs to be expanded if the Rail Switch product is to succeed.

4.1.2.2 Software Development Expertise

Competitive products offer more software features than developed for the Mapper products. The Rail Switch development will have to consider software features such as: Spanning Tree, IGMP snooping, Telnet, RMON, and SNMP. There is very little internal experience within GE Lentronics in developing these types of software features. The lack of experience in developing the additional software features may require an extended timeline. It is recommended that GE Lentronics hire expertise in these fields of software or outsource the software component to external software contractors.

4.1.2.3 Manufacturing Expertise

The NPI group has extensive experience in prototype building and the transfer of new designs to manufacturing. The group has successfully transitioned both toe 10Mb and 100 Mb Ethernet Mapper products, which form a hardware manufacturing consideration are very similar to the Rail Switch. In addition they have also been responsible for a broad spectrum of products ranging from 622 Mb and 52 Mb optical aggregate cards, synchronization cards, to voice channel cards. There are no NPI aspects for the rail switch project that pose any risks.

4.1.3 Strategic Alliances

Another route to developing the Rail Switch would include creating a strategic alliance either with an existing competitor or an enterprise switch manufacturer. Licensing the core hardware and software and adding a few custom GE Lentronics' features would significantly reduce the development cycle time. At this time, it is difficult to determine if this is a viable option because information about licensing possibilities with competitors have been difficult to obtain.

4.2 Strategic Fit

The primary strategy with the Rail Switch is to make available a product with which to access the substation LAN market. The secondary strategy is to pursue pull-through sales of multiplexor products, which are more expensive. Rail switch complements the current multiplexor strategy.

Other paths of GE Lentronics technology roadmap depend on the development of the rail switch project. Future products such as E-Bank, an Ethernet based channel bank, and video over Ethernet products will rely on the technologies developed in the rail switch or for transport access.

5 KEY ISSUES

Based on the external and internal analysis, a number of issues have become evident. This chapter will summarize the key issues that GE Lentronics faces as it considers the Rail Switch project. In the next chapter, these issues will be used to form the criteria on determining and evaluating the alternatives that GE Lentronics has to consider.

5.1 External Issues

5.1.1 Competition

Direct competition for the Rail Switch already exists in the industrial Ethernet market. GE Lentronics currently face numerous direct competitors and that inevitably, that number will only continue to grow. In order to gain a foothold in the market and leverage their current brand presence, GE Lentronics needs a fast time-to-market product so they don't lose any potential market share.

5.1.2 Differentiation

The biggest hurdle that GE Lentronics' Rail Switch faces is differentiating the Rail Switch from their competitors' products. The actual Rail Switch itself is a "me-too" product that cannot differentiate easily differentiate itself from other industrial Ethernet switches. One of the features that GE Lentronics can leverage is the integrated VistaNet management software that is currently in use with the multiplexor backbone system. By incorporating VistaNet into the Rail

Switch, it provides GE Lentronics clients with a unified network management system. GE Lentronics also has a roadmap of future Ethernet products that would be designed to work directly with the Rail Switch and VistaNet system but would be far less efficient if they were to be used with their competitor's industrial Ethernet switch.

5.1.3 RoHS Compliance

Although the RoHS Directive in the European Union currently does not directly affect GE Lentronics' Rail Switch, there are many indirect ramifications for GE Lentronics. The Rail Switch's primary target will be in North America, but the Ethernet standard is global and GE Lentronics may consider providing the Rail Switch to their multiplexor customers in Europe. The entire production chain from the contract manufacturer to component supplier will need to be evaluated to ensure that meets the RoHS requirements.

5.2 Internal Issues

5.2.1 Competences

GE Lentronics has a proven track record in designing communications equipment but the Rail Switch requires expertise in areas that are new to the current staff. The expertise to develop higher layer protocol software features does not exist within the organisation. These features are available in competitor products and are required to compete within the market.

The Rail Switch will qualify as a Type A computing device and will have to meet FCC part 15 regulations in North America and eventually, the CE

equivalent for entering the European markets. There are no internal resources with expertise to lead a FCC compliance project.

5.2.2 Knowledge Diversity

Product development expertise for the Rail Switch is concentrated within several individuals. This greatly reduces the flexibility in assembling a project team and is a potential risk if any of the members becomes unavailable to complete the assigned tasks.

5.2.3 Growth

GE Lentronics has serviced the utility communication market for almost 11 years and have established the largest share amongst its competitors. Revenues for the past several years have levelled off as the market for optical multiplexers have started to mature. Efforts have been made to reposition the multiplexer products into other geographic territories and market segments but the results so far seem to replace the growth lost in the North American markets. The substation LAN market offers a new opportunity with growth potential.

5.2.4 Internal Conflicts

Although GE Lentronics and GE Multilin are an integrated unit from an organisational perspective, they have a distant relationship. This is in part due to Lentronics' inclination towards self-sufficiency from its parent business. A result of this is the Multilink switch, a competing product with the Rail Switch, which was developed without any consultation or planning with Lentronics. The Rail

Switch, if developed, will compete directly with the Multilink switch. This conflict duplicates product design, marketing, and sales resources.

5.2.5 Project Funding

The Rail Switch project cost is estimated to consume more than a third of the current R&D budget. While this may be warranted to enable Lentronics to enter a new market space, it jeopardizes other R&D projects that may impact other parts of the business. Additional funding can be sourced from the parent business or corporate but the approval process would lengthen the project schedule and increase the project reporting requirements.

6 RECOMMENDATIONS

This chapter presents an analysis of the different possible alternatives faced by GE Lentronics to enter the substation LAN market. The alternatives are evaluated using four criteria, which were derived from the previous analysis and deemed the most important to the organisation. The decision making process is presented in a decision tree format to elucidate the underlying ideas.

6.1 Evaluative Criteria

The following criteria were synthesized from the external and internal analysis presented earlier.

- **Time to market.** One of the issues that GE Lentronics faces is direct competition. Competing products already exist on the market and GE Lentronics needs to evaluate the amount of time they can devote to development and still meet the industry's needs in a timely fashion. The other market timing consideration is related to the buying habits of utility customers who have to spend their yearly budget in order to qualify for next years. By not offering a switch product to the market this year GE Lentronics will allow competitors another year to anchor their position within the market. It is in GE Lentronics best interest to pursue a course of action that results in a market presence as early as possible.

- **Funding sources.** The success of this project for GE Lentronics is best served if the project costs remain low so that it can be funded internally. Seeking funding from higher-level sources increases the project length and reporting overhead but these are not the only reasons qualifying funding as a criteria. By maintaining funding internally, GE Lentronics maintains its autonomy and reasserts its self-sufficiency. These were unique strengths of the organisation as identified in the internal analysis.

- **Resources.** The availability of resources that can be deployed is key to the viability of any project. Several resource types are required to support the Rail Switch project but the critical ones are the knowledge resources. The required hardware design expertise can only be found in a few individuals and compete with the demand from other projects. Resource demand also ties into funding, as more resources are needed, the funding requirements go up.

- **Brand loyalty.** GE is a recognized and respected brand in the industrial and utility equipment market. In addition to this, GE Lentronics multiplexer products have a strong customer loyalty in the utility communications market. This loyalty is a result of company wide response to all customer problems big or small. This may be a determining factor in a market that is increasingly difficult to create differentiation.

6.2 Decision Tree

A decision tree was created with the evaluative criterion to establish the different alternatives that GE Lentronics needs to evaluate on how to proceed with the Rail Switch project.

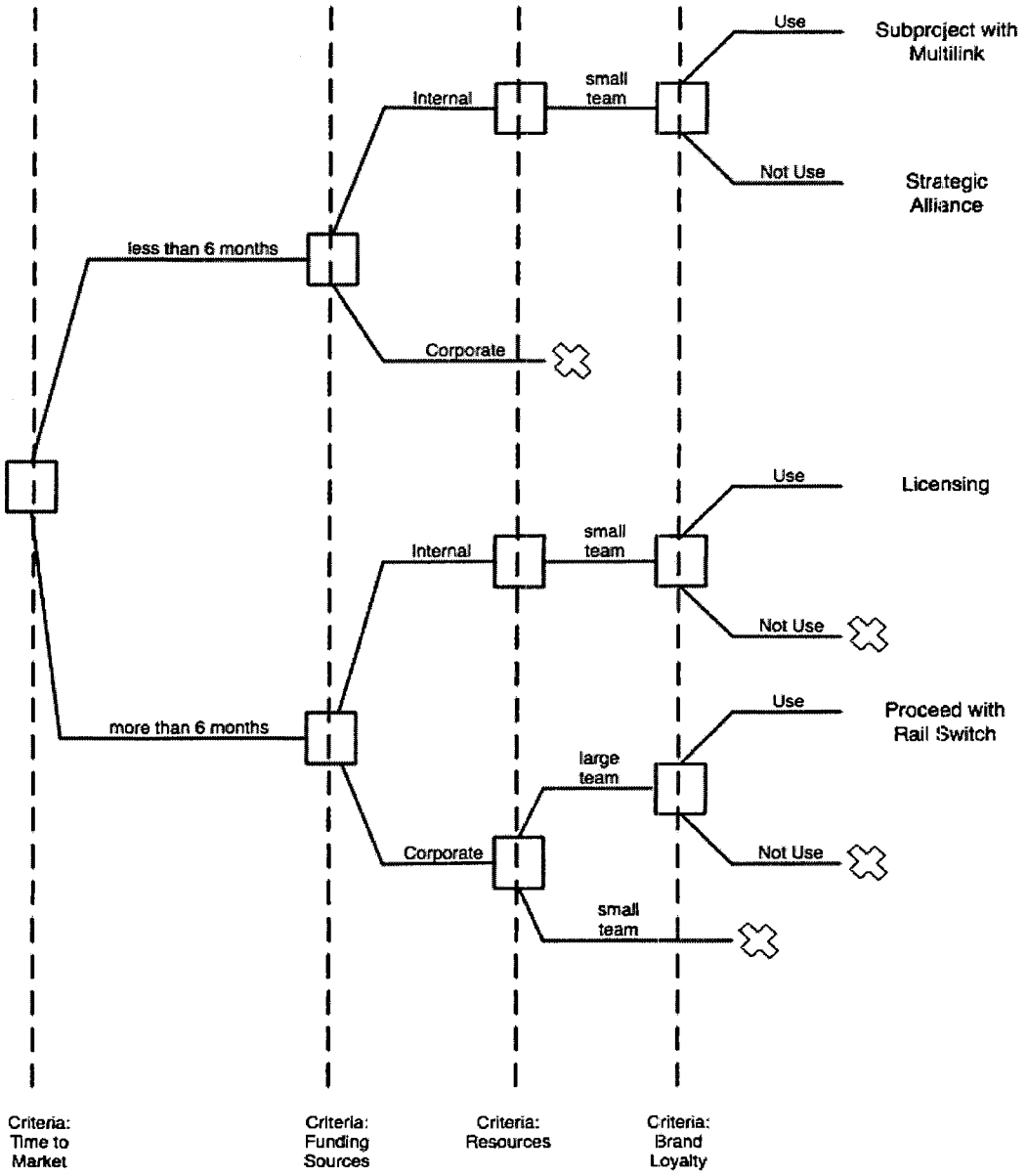


Figure 6-1: Decision Tree for GE Lentronics' Industrial Ethernet Product Strategy (adapted from Porter, 1979, p.388)

The first decision faced by GE Lentronics is the time to market factor. A six-months or less time frame is considered a short time-to-market because that would allow the production team to provide saleable units before the end of the current fiscal year. If a short time-to-market time frame is required, the next decision is where to acquire funding; if corporate funding is required, the time it would take to acquire the investment would push the development date out beyond six months. In order to meet the six-month requirement, GE Lentronics would need to fund the project from their yearly R&D budget. The amount that would be available from that budget would only allow for a small team of developers. The last decision to be made is whether or not GE Lentronics' wants to leverage their brand recognition. If they do, then that path leads to creating a relationship with GE Multilin to create a sub product within the Multilink industrial Ethernet switch family. If GE Lentronics decides not to leverage their brand presence, then they need to consider a strategic alliance with one of their competitors and package the competitor's switch with GE Lentronics' multiplexor backbone system.

An alternative to the six-month time to market time frame is to go beyond the current fiscal year and market the product in the second quarter of the following fiscal year. The next consideration would be the funding source; with the longer time frame, GE Lentronics can pursue corporate funding and acquire a bigger budget. If GE Lentronics decides to fund the project internally, again, they would only be able to staff the project with a small team. In order to meet the requirements, the team would have to license the core technology from a

competitor and build the VistaNet system on their own. By funding the project through corporate investment, GE Lentronics is able to staff a larger team of developers and develop the entire project in-house.

The alternative where GE Lentronics decides on a time-to-market time frame of more than six months but decides not to leverage their brand recognition was not viable and therefore was pruned from the decision tree because if brand recognition were not important, they could shorten the time frame and pursue the strategic alliance route instead. The other potential alternative where GE Lentronics would pursue corporate funding but not staff a larger team makes little sense.

6.3 Strategic Alternatives

From the criteria identified on the decision tree (Figure 6-1), there are several alternatives that GE Lentronics needs to consider. The following section evaluates each of the viable alternatives based on the criteria.

6.3.1 Create A Subproject Within MultiLink Switch Family

GE Multilin (GE Lentronics' parent company) has developed a family of industrial Ethernet switches branded as MultiLink but it is not compatible with the Lentronics' VistaNet network management software. Since GE Multilin has already sunk the funds into developing an industrial Ethernet switch in Markham, it makes more sense for GE Lentronics to leverage GE Multilin's new switch technology.

GE Lentronics should approach GE Multilin to use the existing technology and create a switch for the product family that utilizes the VistaNet network management software. This allows GE Lentronics' to reduce the cost of developing switch but at the same time, be able to provide their customers with the same benefits.

- **Time to market.** Since only VistaNet compatibility needs to be added, it would take approximately four months for the Rail Switch to hit the market.
- **Funding.** This project is expected to take four calendar months and a cost of 16 man months at $7,500 / month. The budgeted cost of this project would be approximately $160,000 and can be taken from GE Lentronics' R&D budget. [Please see Appendix D for more detail calculations.]
- **Resources.** Since the core Ethernet hardware and firmware has already been developed, GE Lentronics can staff the project with a smaller team. They already have VistaNet software expertise in-house
- **Brand loyalty.** Since the Multilink switch already carries the GE Multilin brand. GE Lentronics will be able to leverage the GE name marketing the Multilink switch with VistaNet software capabilities.

6.3.2 Form a Strategic Alliance with a Competitor

An alternative that GE Lentronics can consider is to form a strategic alliance with a competitor. They can bundle a competitor's industrial Ethernet switch with their multiplexor backbone network. The switch would not carry the GE Lentronics brand nor will it have VistaNet compatibility. This scenario would still achieve the objective of pulling in sales of multiplexer products with switch sales.

- **Time to market.** Since no development is required, the only time that would be required is time spent evaluating their competitors on which one GE Lentronics feel would best fit with their current products and to negotiate an alliance with that chosen firm.
- **Funding.** The only costs associated with this scenario are the marketing research effort and legal effort to develop a working relationship.
- **Resources.** Since no development effort is needed, only a small team of marketing and legal personnel are required.
- **Brand loyalty.** There will be no brand recognition on GE Lentronics part since the industrial Ethernet switch will not be considered their own product.

6.3.3 License the Core Technology

In this alternative, where there is a longer time-to market but only internal funding is in place, only a small team of developers can be used. In order to

lessen the work, GE Lentronics will need to license the core hardware technology from a competitor and develop the VistaNet compatibility in-house. This option gives GE Lentronics the brand recognition without spending the time to develop their own technology from scratch.

- **Time to market.** To transform the licensed technology into a product and add VistaNet compatibility would take approximately six to seven months for a Rail Switch product to hit the market.
- **Funding.** It is difficult to determine the cost of this scenario at this time. The cost of developing the VistaNet software would be approximately be the same as the Multilink option, but the ongoing cost of the licensing agreements will have to be determine with the firm that GE Lentronics decides to partner up with.
- **Resources.** Since the core hardware technology will be licensed, only a small team of developers will be needed to develop the VistaNet compatibility and learn the technology.
- **Brand loyalty.** Since the technology is licensed, GE Lentronics will be able to brand the switch with the GE name.

6.3.4 Proceed With the Project

Although the Rail Switch is a "me-too" product, the VistaNet network management software is allows customers to create and manage a "whole product" network that allows the customer the advantage of creating a seamless network that runs together. An added benefit for current GE Lentronics'

customers is that the Rail Switch will provide additional ports that support all legacy data.

- **Time to market.** It is estimated that developing the Rail Switch internally will take approximately nine months.
- **Funding.** The project is expected to take nine calendar months and a cost of 27 man months at $7,500 / month. The budgeted cost of this project would be approximately $350,000 and would require corporate funding. [Please see Appendix D for detailed calculations.]
- **Resources.** The budget allows for a larger team to be used for the project. GE Lentronics currently lacks the software expertise required to write the Ethernet protocol applications (STP, RSTP, RMON, TELNET) that the Rail Switch requires. GE Lentronics will have to acquire the resources either through hiring or outsourcing. The hardware and VistaNet software expertise is already in-house.
- **Brand loyalty.** Since GE Lentronics is developing all aspects of the Rail Switch in-house, the switch will carry the GE brand.

6.3.5 Recommendation

It is recommended that GE Lentronics proceed with adding VistaNet compatibility to the Multilink family of switches. This alternative has the shortest time to market (four months) as well as a lower cost at $160,000, which is more than a 40% reduction over developing the entire Rail Switch from scratch. GE

Lentronics will be able to secure an earlier position in the market while still retaining its autonomy in this project. The product will be perceived by the market as a genuine GE Lentronics product and enjoy the same brand loyalty but will also demand the same superior customer service. And by working together, this gives both businesses a chance to bridge the communication gaps and foster a new working relationship in which both companies can benefit from.

6.4 Implementation Plan

This following is a suggested project objectives and implementation plan.

6.4.1 Objectives

The main objectives of the project are:

- Develop VistaNet network management functionality into the Multilink family of managed switch within 4 months.
- Develop VistaNet client graphical user interface within 2 months.
- Complete verification and execute test plan within 1 month.
- Complete NPI plan and factory test procedure within 1 month
- Complete product documentation within 1 month.

6.4.2 Establish Responsibilities

The following are the staff needed for the project.

- **Project Champion.** Requires a senior manager or product manager with sufficient influence to authorize the project and resolve any of the project managers organizational issues.
- **Project Manager.** Applies organizational resources to meet the specified objectives.
- **VistaNet Software Prime.** Responsible for the Multilink VistaNet application development.
- **Multilink Software Prime (from GE Multilin).** Responsible for the development of the Multilink VistaNet NMS feature.
- **Verification Prime.** Responsible for developing test plan.
- **NPI Prime.** Responsible for the manufacturing and test knowledge transfer to manufacturing.
- **Product Management Prime.** Product documentation and training manuals.

6.4.3 Tasks/Actions

The following defines the tasks required.

- Define data points for ML1600 and add to Units XML document – Multilink Prime/VistaNet Prime.
- Develop ML1600 H7 parser and Ethernet packet wrapper to interface to remote VistaNet client requests – Multilink Prime

- Develop ML1600 CLI interface for local VistaNet client requests – Multilink Prime.
- Develop ML1600 custom control – VistaNet Prime.
- Develop verification test plan – Verification prime.
- Build and load prototypes (Alpha) – NPI Prime.
- Debug Alpha units – VistaNet Prime/Multilink Prime
- Build Beta prototypes – NPI Prime
- Execute verification test cases on Betas – Verification Prime.
- Manufacturing documentation and factory tests – NPI Prime.
- Write product documentation and training manuals. – Product Management Prime.

		WEEK												
TASKS	PERSON	1	2	3	4	5	6	7	8	9	10	11	12	13
Data point definition	VistaNet / Multilink	*	*											
H7 parser & wrapper	Multilink prime			*	*	*	*	*	*	*				
CLI interface	Multilink prime										*	*	*	*
Custom control	VistaNet prime										*	*	*	*
Verification test plan	Verification prime			*	*									

Table 6-1: Part 1 of Implementation Plan

		WEEK							
TASKS	PERSON	13	14	15	16	17	18	19	20
Build alpha units	NPI prime	*							
Alpha testing	VistaNet / Multilink		*	*					
Build beta units	NPI prime				*				
Beta testing	Verification prime					*	*	*	*
Manufacturing doc	NPI prime						*	*	*
Product doc	Product mgmt prime						*	*	*

Table 6-2: Part 2 of Implementation Plan

7 CONCLUSION

7.1 Reflections

The competitive landscape for Lentronics is undergoing a revolutionary change. Packet switched technology and the Ethernet standard are now disrupting established circuit switched technologies in utility communications market as they have in the telephone long distance carrier market. The changes bring new competitors, marketing challenges, and technology hurdles. To address these requires a unified organizational effort as it is a significant shift in the business and cannot be championed by a few individuals or a single department.

Although technology is driving the changes to the market, the key choices facing Lentronics are not technology based. Lentronics enjoys a majority share of the market currently but this position cannot be defended with the same strategy as the landscape is undergoing change. The choice is not whether they can afford a new strategy but whether they can afford not to. As the new strategy takes shape, the organization will move downwards from their current position before ascending to a new higher position. The resulting decline in performance is temporary and should not be construed as failure of the strategy.

Our investigation and strategic analysis was conducted under challenging circumstances. Information regarding market sizes and sales information was difficult to obtain. During the internal analysis, we discovered that GE Multilin

already had developed a product very similar to the project that GE Lentronics was considering. We found that an ineffective organizational structure allowed for communication gaps between the to business units. Our recommendation of working together with GE Multilin would help the two organizations recognized the gaps that exist and find a more effective way of providing the best product possible to their customers.

7.2 Further Areas of Research

We had planned on performing a detailed survey of the existing customer base but due to time constraints and procedural restrictions, this did not take place. The purpose of the survey was to gather information about the extent of their substation LAN development plans: timeline, number of ports to be purchased, vendors in consideration and such. This would be a worthwhile avenue for further investigation. In addition, interviews with the product manager and other senior staff at Multilin about the Multilink switch product strategy would greatly enhance the competitor analysis.

APPENDIX A – ETHERNET TECHNOLOGY

A Brief History

Robert Metcalfe developed Ethernet technology in 1973, while at Xerox's Palo Alto Research Centre, for interconnecting advanced computer workstations for data exchange and to high-speed laser printers. The networking system was based on a radio networking system called Aloha, which was developed in the 1960s by Norman Abramson et al at the University of Hawaii. The Aloha radio system was an experiment for communicating among the Hawaiian Islands using a protocol that allowed sharing of a common radio channel. Ethernet was based on this very premise of a shared communications channel but its medium would be copper cabling rather than radio waves.

To enable multiple users to share a common channel, Aloha made use of a very simple collision detection and retransmission protocol. In the Aloha system any user could send whenever it liked and waited for an acknowledgement from the recipient. If an acknowledgement wasn't returned within a specified amount of time then it is assumed that another user had also sent a simultaneous transmission, causing a collision with the original, and destroying the integrity of both transmissions. The end user cannot receive the damaged transmissions and no acknowledgment will be sent. Upon detecting a collision, the user will backoff for a random period of time and then retransmit the message again. The random backoff time provides a good probability of

retransmitting the original message successfully. A limitation with the Aloha protocol was that as traffic usage increase so would the number of collisions and hence the number of retransmissions, which results in lower user utilization. Abramson calculated that the Aloha system could achieve a maximum theoretical utilization of 18 percent.

Metcalfe made several innovations to improve the Aloha system in his Ethernet implementation. Mechanisms were developed to actually detect when a collision occurred (collision detect), to listen for activity before transmitting (carrier sense), and for supporting access to a shared channel by multiple users (multiple access). The combination of these mechanisms formed the Ethernet channel access protocol called Carrier Sense Multiple Access with Collision Detect (CSMA/CD). The access protocol was a vast improvement over the Aloha scheme and is capable of functioning at up to 100 percent load. Systems that can send and receive but not simultaneously are also referred to as half-duplex in communications terminology.

The Ethernet protocol soon began to draw the attention of large technology corporations and in 1980 DEC, Xerox, and Intel formed the first vendor consortium to establish a 10 Mbps standard. Thereafter, the Institute of Electrical and Electronics Engineers (IEEE) began development of an open network standard. By 1985 the IEEE Local and Metropolitan Networks Standards committee published the IEEE 802.3 Carrier Sense Multiple Access with Collision Detection Access Method and Physical Layer Specifications. The IEEE 802.3 standard has since been adopted by the International Standards

Organisation, making Ethernet now a worldwide standard. There have been several supplemental releases subsequent to the original 802.3 standard that added different types of cable media, full duplex (send and receive simultaneously), 100Mbps speed, and 1000Mbps speed.

Ethernet has become by far the most widely used local area networking (LAN) technology in use today. It is estimated that over several hundred million Ethernet based ports have been sold to date. Virtually every computer built today comes equipped with and Ethernet connection.

The Ethernet Frame

All data in an Ethernet system is transported between devices in an Ethernet Frame. The frame is defined as follows (Spurgeon, 2000, p.24):

8 bytes	6 bytes	6 bytes	2 bytes	46 to 1500 bytes	4 bytes
Preamble	Destination address	Source address	Type/ length	Data	Frame check Sequence (CRC)

- **Preamble (PRE)**. The frame begins with 8 bytes of an alternating pattern of ones and zeros that tells receiving stations that a frame is coming, and that provides a means to synchronize the frame-reception portions of receiving physical layers with the incoming bit stream.
- **Destination Address (DA).** Following the PRE is the address for the receiver(s) of the frame. The DA format specifies whether everyone on the network should receive the frame (broadcast), a specified group (multicast), or an individual station on the network. Individual

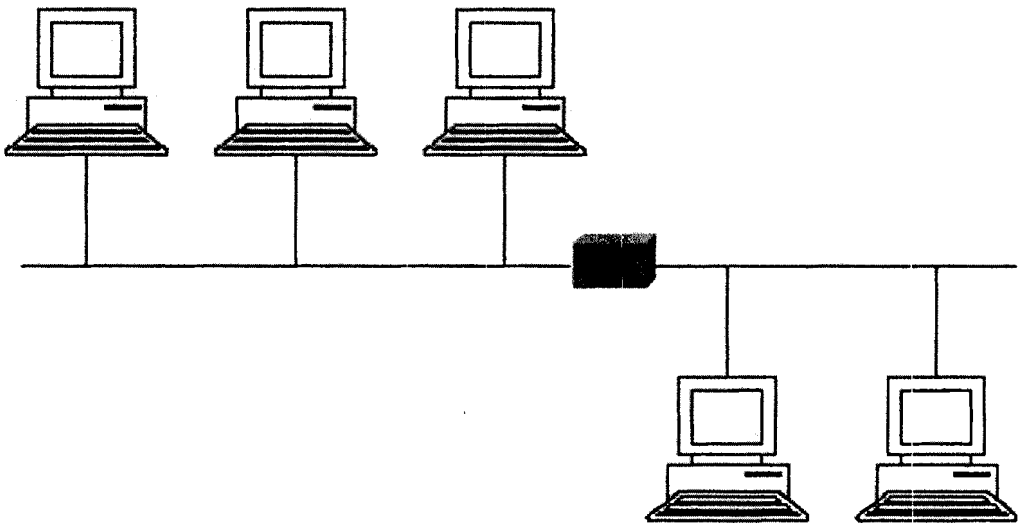
addresses are globally unique. Manufacturers are assigned an Organizationally Unique Identifier (OUI) by the IEEE Standards Association. The OUI makes up the first 3 bytes of the DA and the remaining are uniquely assigned by the manufacturer to identify every piece of hardware produced.

- **Source Address (SA).** The address of the frame sender follows the DA. Similar in format to the DA except it is always the address of a unique station.
- **Type/Length:** The 2 bytes following the SA define either the type of higher protocol used or the length of the data in the following Data section.
- **Data:** This is the actual data from the sender. The data cannot be less than 1500 bytes in length. If the data is less then 46 bytes then it is padded achieve a 46 byte minimum.
- **Frame Check Sequence (FCS).** The 4 bytes following the Data sequence contain a 32-bit cyclic redundancy check (CRC) value, which is created by the sender and is recalculated by the receiver to check for damaged frames. The FCS is generated over the DA, SA, Length/Type, and Data fields.

Ethernet Networks

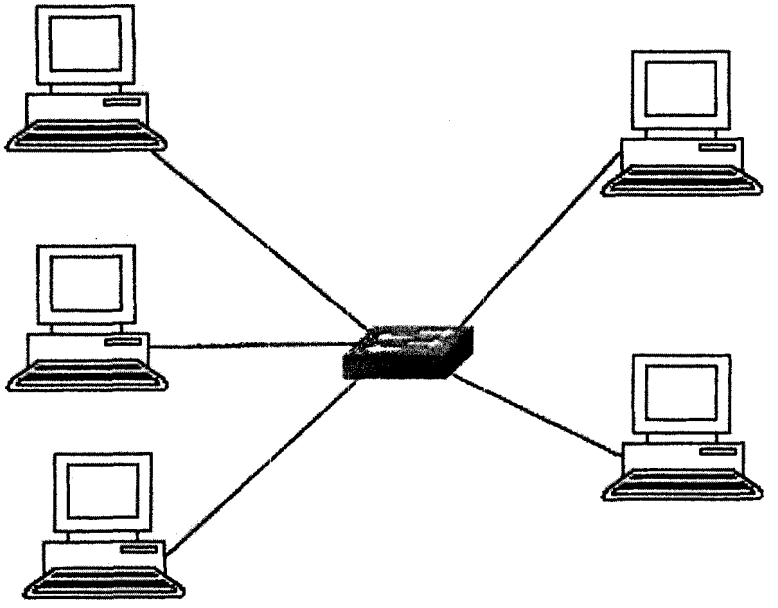
Ethernet LANs consist of network nodes and interconnecting media. LANs take on many topological configurations, but regardless of their size or complexity, all are a combinations of bus and star structures.

The original Ethernet standard specified a copper coaxial cable media for interconnection. Stations or users would connect to the network via tap into the cable. The resultant networks took the form of a bus structure. While the structure provided great advances in computer networking, it did have some drawbacks with difficulty of installation and maintenance. This structure is not as prevalent today but some still do exist. (TRA, 1998, p.2)



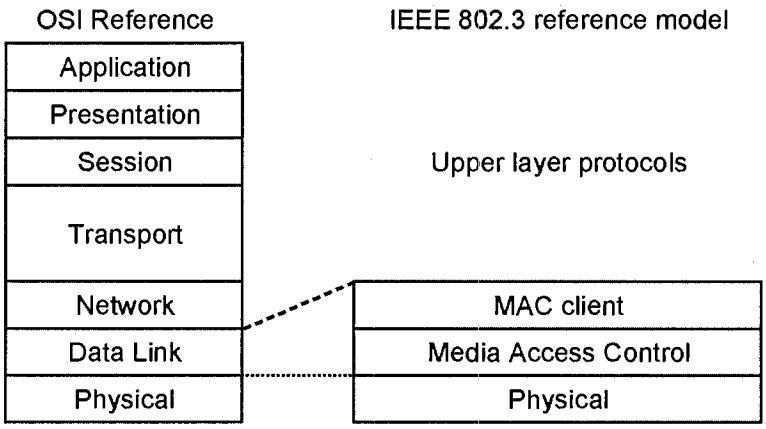
With the invention of twisted-pair (similar to cabling used for telephones) Ethernet in the late 1980s and then the IEEE 802.i specification for 10BaseT twisted-pair in 1990, networks shifted to the use of central network units such as hubs or switches, which led to the use of star-connected topologies. All

connections in a star network are point-to-point links implemented with twisted-pair or optical fibre cable, which was developed later on. (TRA, 1998, p.2)



Relationship to the OSI Model

The OSI reference model reduces the complexity of open systems interconnection and communications by organizing the system into a series of well-defined functional layers. The OSI model is recognized internationally and virtually all communications systems and protocol stacks make reference to it in some form



The above diagram shows (Spurgeon, 2002, p.13) that the IEEE 802.3 physical layer corresponds to the ISO physical layer. This layers deals with electrical signals, connectors, and cabling. The second OSI layer, the Data Link layer, corresponds to 2 sublayers of the Ethernet standard: Media Access Control (MAC) and MAC client. The MAC layer defines the protocol used to arbitrate access to the Ethernet system. The MAC client layer is an interface between the MAC layer and upper layer protocols of the end device and helps identify the data carried in the Ethernet frame. The end purpose of the second layer is to transmit packets from node to node to the specified addresses.

Since the Ethernet standard corresponds to the first layers of the OSI model it is also referred to as the Link Layer standard or a Layer 2 standard.

Protocol Encapsulation

Layer 2 capabilities ensure network compatibility and operation but transporting useful data across the network normally requires the use of higher

layer protocols and functions. For example, downloading a file from the Internet or sending a job to the network printer requires the use of the TCP/IP protocol, which is a layer 4/layer 3 function. Higher-level protocol packets are carried in the Data field of the Ethernet frame. This is known as encapsulation. This allows independent systems to work together by treating the entire protocol packet as just so much unknown data stuffed inside the data field of the Ethernet frame. The receiving station's system deals with the extracted protocol packets.

The IEC61850 standard used in substation LAN applications, utilizes the Generic Object Oriented System-wide Event (GOOSE) model, which uses multicast on TCP/IP.

APPENDIX B – ETHERNET SWITCHES OVERVIEW

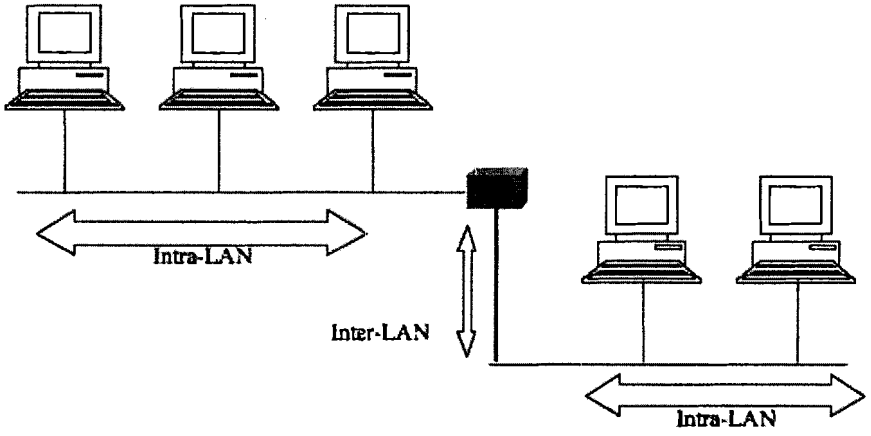
Ethernet switches function on the MAC layer hence are also known as layer 2 switches or Link layer switches. They perform the following functions:

1. **Build large Ethernet systems by connecting smaller LAN segments together.** Switches operate transparently with Ethernet systems at the MAC layer and seamlessly connect LAN segments together to form larger networks. This is also known as "bridging" LANs.

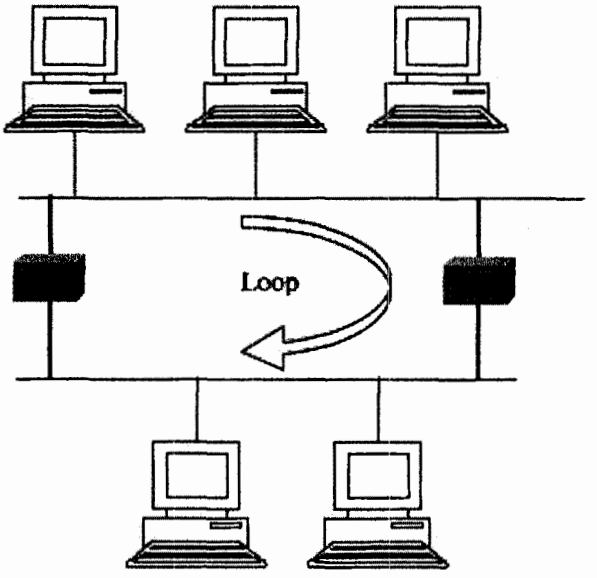
2. **Link Ethernet segments that operate at different speeds.** Each segment connected to a switch port, although logically connected, are physically isolated from other segments by the hardware. This isolation provides several advantages, one being bit rate independency between segments. For example, the switch can bridge packets from segments operating at 10Mbps to and from ones at 100Mbps or even 1000Mbps.

3. **Terminates collision domains.** A collision domain is defined as a single Ethernet system in which two or more stations transmitting simultaneously will encounter a collision. Having on collision domain on a large network greatly reduces the available bandwidth. A switch terminates the collision domains for each segment, effectively creating separate collision domains for each segment.

4. **Control the flow of traffic through the system.** Switches learn the inter-LAN (segment) traffic by building table information of the Destination MAC addresses of packets. Once learned, the switch only forwards the packets destined for other LAN segments, greatly reducing unnecessary transmissions.



5. **Spanning Tree Algorithm.** As Ethernet systems get larger and larger, many switches are used and it is possible that two switches in parallel connect some segments or stations. (Spurgeon, 2000, p.305) This creates a loop path that causes packets to circulate in the loop indefinitely. The spanning tree algorithm is to allow switches to dynamically create a loop free set of paths. The algorithm uses configuration messages sent with a special multicast address by every switch. The configuration messages allow switches to determine which ports to use and which ports to shut off for a loop-free path.



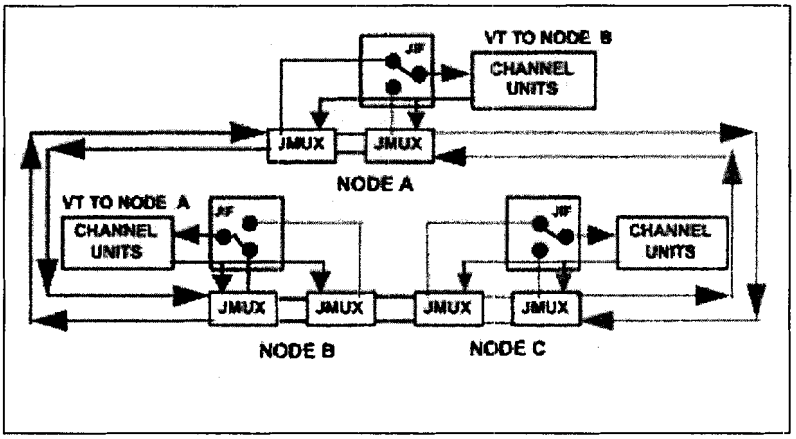
The aggregate of these benefits serve to improve the reliability of the systems and increase the amount of bandwidth available for use.

APPENDIX C – COMMUNICATIONS NETWORK TOPOLOGIES

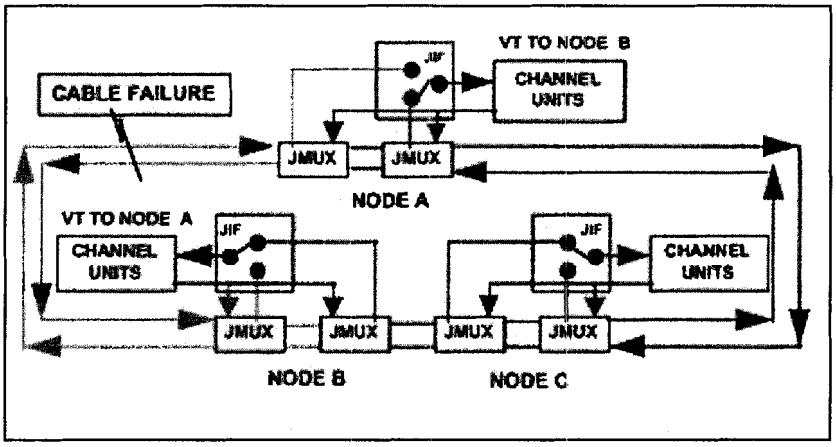
One of the key considerations of systems engineers when designing a communications network is fault tolerance – the ability of the network to maintain all traffic under a fault condition. To achieve this requires a combination of protection switching equipment and topologies that provide an alternative or backup path. The most common topology that provides an alternate path is the ring structure. Normal traffic between any two nodes travels in one direction of the ring. If there is a fault within the normal path then traffic is rerouted to the opposite direction. The following example provides a detailed explanation of the Lentronics Multiplexer implementation.

Under normal conditions, a VT (traffic) is assigned between Node A and Node B. The shortest path between two nodes is usually assigned as priority path. Traffic is transmitted along both paths but is only received in one direction. Since VT path switching takes place in the JIF units, the JIF units are shown above as one unit. There are in effect two JIF units; one for the Left/East JMUX unit and one for the Right/West JMUX unit.

Normal Configuration: (GE, 1998, p. 9)



Fibre Failure: (GE, 1998, p. 9)



When a failure occurs, the traffic is rerouted to the stand-by or back-up path. Traffic is passed through all nodes on the back-up path and all circuit communications are maintained. This node-through-delay is 14 μs per node. The system reverts back to the priority path when the abnormal condition has been corrected. This is known as reverted protection switching.

APPENDIX D – FINANCIAL SCENARIOS

For a clearer view of allocation the project costs were grouped into three classifications: variable costs, expenses, and capital expenditures.

Rail Switch Development Cost Model

The variable costs for this project consists primarily of employee wages required for the development efforts, with the bulk of the costs spent in hardware development. Since a variety of different staff may be involved with each development effort, the labour rate used in the model was estimated using an average burden cost of the business unit that includes allocated fixed overhead costs. This method achieves a reasonable rate estimate before assigning specific staff to the project and their individual charge rates.

The main expenses for the project relate to building prototypes and purchased services. Electronic components and devices and mechanical parts are included in the expense category while any labour is accounted for in NPI effort. Mould design and casting services to produce the unit case are purchased from external vendors. An external software developer performs the embedded firmware development.

The capital investments for the project include test equipment, instrumentation, and customized equipment. These are normally depreciated over 4 years.

Variable Costs

Effort	Man-Months	Extended Cost (@ $7.5k USD/month)
Hardware Development - Hardware layout - Programmable Logic Development - Printed circuit board layout	22	160k
Software Development (NMS)	1	7.5k
Verification	2	15k
NPI - Building prototypes - Manufacturing transfer	1	7.5k
Documentation	1	7.5k
Total Variable Costs	27	$202.5k

Expenses

Type	Cost (USD)
Prototype Expenses	30k
Molds and Castings	30k
Firmware development	30k
Total Expenses	$90k

Capital Expenditures

Type	Cost (USD)
Test and Measurement equipment	50k
Total Capital Expenditures	$50k

TOTAL PROJECT EXPENITURE $342.5k

Multilink-VistaNet Development Cost Model

Considerably less development effort is required to enhance the VistaNet NMS feature for the ML1600 in comparison to the Rail Switch. The same monthly rate that was derived for the Rail Switch project was used.

Expenses incurred relate to prototyping only and no additional purchased services are required. Prototyping expenses are estimated to be slightly higher since the base cost of the ML1600 is higher than the rail switch.

No additional capital investment is expected since the hardware of the ML1600 is not expected to be modified in this project.

Variable Costs

Effort	Man-Months	Extended Cost (@ $7.5k USD/month)
Multilink Development - H7 Parser and Wrapper - CLI interface for VistaNet local access	8	60k
Vistanet Development - Units XML encoding - Custom control for the ML1600	4	30k
Verification	1.5	11.2k
NPI - Building prototypes - Manufacturing transfer	1.25	9.3k
Documentation	1	7.5k
Total Variable Costs	15.75	$118k

Expenses

Type	Cost (USD)
Prototype Expenses	30k
Total Expenses	45k

TOTAL PROJECT EXPENITURE $163k

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