Innovations in Fixed Long-Distance Telecommunications:
The Case of Optical Fibres

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Chapter 0

INTRODUCTION

In today's economy, it is difficult to name an industry that has not been either altered or influenced by the technological changes that have occurred in telecommunications during the last two decades. This is because many of the productivity improvements in manufacturing and services depend on the availability of effective and efficient telecommunication systems. An efficient telecommunications system links geographically dispersed markets, thus, allowing producers to realise economies of scale in production. It also enables producers to develop flexible production processes that help them respond quickly to changing markets.

Today's telecommunication systems are the production technology for many industries. Finance is a good example. According to Thurow, " *the financial institution that can bring information from Hong Kong to New York five seconds faster than some other institution does not make some of the arbitrage profits -- it makes all of the arbitrage profits*"[1]. Most of today's industries rely on the availability of effective and efficient telecommunication systems. An efficient telecommunication system makes possible the rapid provision of services, instantaneous transmission of information and news, and the simplifications of social communications. More significantly, it is essential for the widespread communication of prices and other economic data that form the bases for business decisions, which, in the aggregate, guide the behaviour of the economy. Thus, improvements in telecommunications system efficiency and services directly improve the functioning of markets and, therefore, have a direct impact on the performance of the economic system.

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[1] Thurow, Lester : "*Is Telecommunications Truly Revolutionary* ", The telecommunications Revolution; Past, Present, and Future, Edited by Sapolsky et al. (1992), Routledge Chapman and Hall Inc., New York, p.2.

The world telecommunications industry, currently growing at 10% to 15% a year, and reaching $500 billion in revenue in 1990, is one of the largest-and fastest-growing industries in the world economy. Profitability has climbed almost without interruption for a decade, and is still accelerating. According to the Economist." *In 1994, the ten largest telecommunications firms made more profits than the 25 largest commercial banks. Demand is soaring: over 38 million new subscribers were connected to the fixed network 1994 alone, more than twice as many newcomers as in 1986*"[2]. Yet costs continue to fall faster than prices.

The reason for these very high profits lies in the cost-efficient technologies that have been introduced in recent decades. The first cost-efficient technology involves the use of fibre-optic cables. To give an indication of the enormous carrying capacity of fibre, consider the following fact. A single fibre-optic cable thinner than a hair (a single mode fibre) can carry 30,000 simultaneous telephone conversations[3]. This is vastly more information than can be transmitted by a traditional pair of copper wires, which can only carry from 24 to 30 conversations. In addition to efficient high-speed transmission of data and voice over long distances, fibre-optic cables can also carry video signals. The use of optical fibre cables can increase significantly the number and types of services-- television, video programs-- without incurring the additional cost of providing new capacity. Furthermore, their use allows huge reductions in the running cost of a fixed network. Yet, an optical-fibre cable costs the same as copper wire to lay down. The maintenance cost of a fibre optics network is estimated to be around one-fifth that of a wired network -- an important consideration, especially when maintenance accounts for a quarter of the cost of running a network[4]. The second cost-efficient technology involves the installation of computer-driven exchange facilities as new switching devices to

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[2] The Economist, Sept. 30, 1995, p.5

[3] AT&T technical journal September/October, 1992, p.42

[4] The Economist, Sept. 30, 1995, p.7

replace human operators and electromechanical devices. Together, these technologies have reduced the costs of operating a fixed network[5] and increased capacity to the point where the new networks are no longer constrained by capacity. This huge increase in capacity allows the new networks to exhibit large economies of scale and scope. That is, as the new technologies are used more extensively to provide a wider variety of services, the average unit cost of providing a unit of service actually decreases as the capacity of operation increases.

The objectives of this paper are to explain how the new technologies are cutting the cost of operating a fixed telecommunications network, and how the new economies of scale are realised on the new networks. The paper also discusses the industry's market structure, with special reference to the market shares of long-distance carriers in the US. The paper is organised as follows. Chapter one gives a brief history of the innovations in the telecommunication industry from the year 1800 right to the beginning of the fibre optic era in 1970. Chapter two gives a survey of the economics of telecommunication, with emphasis on the literature that dealt with the overall effects of the adoption of optical technology in the telecommunications industry. Chapter three provides an introduction to the basic concepts of telecommunications networks and their key technical and economic aspects. In chapter 4 the technological aspect of the two technologies is discussed, in particular, a technical comparison between the old transmission technology and the new transmission technology is presented to explain how the new technologies have changed the economics of fixed networks. In chapter five we introduce the concept of Tele-traffic engineering. This allows us to develop the Erlang formula, which is then used to measure the new economies of scale (the output aspect) in an optical fibre network. Next, the new economies of scale (the cost aspect) is

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[5] A fixed network is a network intended to be used as fixed ground location, and therefore neither mobile nor portable.

discussed in the context of a case study. Chapter six explains the implications of fibre optics technology for competition, market shares, and welfare. The focus here will be on the market shares and market structure of the long distance carriers in the US market.

Chapter 1

THE DEVELOPMENT OF TELECOMMUNICATIONS TECHNOLOGY

Early Developments

Long distance communications started with a visual telegraph system in late eighteenth century France. Designed by Claude Chappe, an engineer, the first link was 230 kilometres long, connecting Paris with Lille. The system consisted of a series of towers located on hills in sight of one another. Movements of wooden arms mounted on top of a tower represented the letters of the alphabet and the numerals, and these movements could be seen by a telescope at the next tower and transmitted to a succeeding tower by the same means. This early visual telegraph system proved invaluable to France during the revolution because it permitted the rapid deployment of forces in response to any surprise attacks. Other countries, noting the military advantage gained by this visual telegraph system, quickly copied it (McNamara, (1991), p.9).

The use of electricity was next in long distance communication. It began with the invention of the telegraph by Wheatstone and Morse in 1837[6]. The initial system consisted of a pair of stations, each with a telegraph key, connected by two wires. At the sending station, the operator depressed a key to activate a battery to the two wires, causing a pulse of current to flow. The current flowed through the wire to the receiving station, and there it was detected by an electromagnet. The electromagnet, which is a piece of soft iron surrounded by a coil of wire, sounded a click. Communication occurred by using a key to send a pattern of short and long pulses of current to spell out the letters and numerals. The ability to communicate over long distances through the use of the telegraph system was, at the time, considered a scientific marvel, even though only one message at a time could be transmitted and only one letter at a time.

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[6] Bray, 1995, p.37-39

The Electronic Era

Next came the communication of speech over long distances. It began with the invention of the telephone by Alexander Graham Bell in 1876[7]. A telephone is an instrument containing a transmitter for converting the acoustic signals of a person's voice to electrical signals and a receiver for reconverting electrical signals to acoustic signals. The initial telephone system was simply a pair of instruments connected by a wire loop. The microphone in the telephone transformed the speech into signals or current modulations, which was then carried by two wires to the receiving telephone where the current modulations or the signals were transformed back into speech. This system required each caller to use a separate telephone and a separate transmission link (a wire) to reach each individual.

Subsequently, exchanges or switchboards operated by humans were incorporated into telephone systems. This was done by physically connecting the lines of the two locations, thus allowing the caller to reach any other station connected to the exchange or switchboard. With this new central-switching idea, the telephone system improved dramatically and the number of telephones and transmission links required were reduced. However, other problems ensued, such as human errors, slow response, and the high cost of manual connections (McNamara (1991), p.111).

Electronic Switching

In 1889 Almon Strowger, a Chicago undertaker, solved the problems by inventing an automatic switching device. Strowger's device consisted of electrical contacts located inside the device. The contacts inside the device were each connected to a wire passing through the wall of the device. The wires were in turn connected to telephone lines. Strowger's device evolved rapidly into the electromechanical switching system. This

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[7] Bray, 1995, p.49

new switching system replaced many human operators and it also reduced the number of transmission links required in a network. This switching system works in the following way. When the telephone receiver is picked up, a rotary electromechanical switch, called a uniselector, begins to move, looking for a free set of switching equipment among the several thousand that may be available at the local exchange. Each of the sets of the local exchange is based on the Strowger system just described. These systems were used to switch over half the world's telephone lines, and they remained in use until the advent of electronic switching in the late 1960s (McNamara (1991), p.111).

Electronic switching was a great improvement over electromechanical switching. However, both switching systems used analogue signals to transmit speech. This meant that an exclusive circuit had to be connected between each pair of callers. This made the use of a telephone system inefficient. Analogue switching remained in use until the development of the general theory of information by Shanon[8]. He was able to break down the analogue entities into digital bits, which are much easier to manipulate by machines. Thus, the digital era was born.

The Digital Era

Next came the invention of the amplifier by de Frost in 1907[9]. Its use made telephone communication possible over longer distances and enabled underground cables to replace open-wire overhead lines. It also enabled a large number of voice signals to be multiplexed, i.e., to be combined into a single electrical signal, in a single pair of conductors by modulating different carrier frequencies. The art of frequency division multiplex[10] (FDM) carrier made it possible to convey over 10,000 voice channels on a single coaxial-cable pair. As a result, the cost per kilometre of telephone circuits fell

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[8] Bray, 1995, p.200-201

[9] Bray, 1995, p.65

[10] Frequency Division Multiplexing is to derive two or more simultaneous, continuous channels from a propagation medium that connects two points.

dramatically, and national and international telephony became a commercial reality (Flood (1991), p.2).

In 1938 came the invention of Pulse-Code Modulation[11] (PCM) by Reeves[12]. This technology enabled analogue voice signals to be converted into digital signals which could be regenerated at repeaters[13] to make the transmission of signals practically immune to noise, regardless of the distance over which they were transmitted. Also, it made switching a lot more efficient because a digital switch does not require that an exclusive circuit be connected between the caller and the recipient. However, the numerous connections that were required made the PCM uneconomical.

In 1948 Bardeen and Brattain[14] invented the transistor. The invention of the transistor allowed the introduction of integrated circuits, which reduced the number of connections required so it made the equipment much cheaper in PCM than in FDM. It also ushered in the era of digital telephony (Flood (1991), p.2).

Fibre Optics

The use of light or optical communications began with the signal fires in prehistoric times. The ancient Greeks developed and used a system of signal fires to spell words. The next attempt to communicate by light source, using a far more sophisticated technology, was in the year 1888, when Alexander Graham Bell invented the photophone, which was similar in design to the telephone but used optical signals which responded to sound waves instead of electrical signals. The photophone, at the time, proved to be technologically more complicated and much more expensive to develop than the telephone, so the photophone was not developed commercially (Webb (1996), p.134).

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[11] Pulse Code Modulation is multiplexing by deriving a single digital channel from two or more analogue channels by a combination of pulse code modulation and time division multiplexing.

[12] Bray, 1995, p.203-205

[13] A repeater is a device that performs one or more signal functions on input signal, such as to recover, filter, amplify, reshape and retime the signal.

[14] Bray, 1995, p.177-180

Until the 1950s, the idea to communicate by using a light source remained just dormant. Between the year, 1950 and 1970, a series of scientific breakthroughs brought the idea closer to becoming a technological reality. The first breakthrough came in 1955, when Narinder S. Kappany[15], an Indian scientist, discovered that by using glass fibre surrounded by cladding, it is possible to conduct light over long distances, without much loss of the light's intensity. He found that light bounced along inside the fibre and continued to travel towards its destination by the outside cladding. Thus, glass fibre was born.

The second breakthrough came in 1960, when Theodore H. Maiman[16], a physicist with Hughes Aircraft company, built the first working laser--a new light source that can generate a powerful beam.

The third breakthrough came in 1966, when Charles Kao and George Hockhan [17] of England's standard communication laboratories developed a way to use fibre to carry information. At the same time they showed that it could be used to replace the conventional copper wire (Koelsch (1995), p.130).

In the 1970s, the power of lasers began to work their way into the telecommunications industry. Research showed that by rapidly pulsing lasers on and off, it is possible to encode information in the light stream. The only thing that the laser light needed at this point was a road to travel on. Hence, fibre optics was born.

In a fibre optic link, communication is carried out as follows. First, we recall that information is transmitted under the form of an electrical signal. Next with a fibre optics link the electrical signal enters a device called the driver, which controls (modulates) source of light to produce a modulated light signal. The light signal then travels over the

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[15] Koelsch, 1995, p.129
[16] Bray, 1995, p.277
[17] Bray, 1995, p.258

fibre until it reaches a sensor at the far end called a detector. The detector converts the light signal back into an electrical signal.

In 1977, AT&T and its subsidiary telephone companies began to establish the practical value of fibre optics as a communication medium. In that same year, the first working fibre-optics cable was installed beneath the streets of downtown Chicago.

Chapter 2

A SURVEY OF THE ECONOMICS OF TELECOMMUNICATIONS

The Demand Side

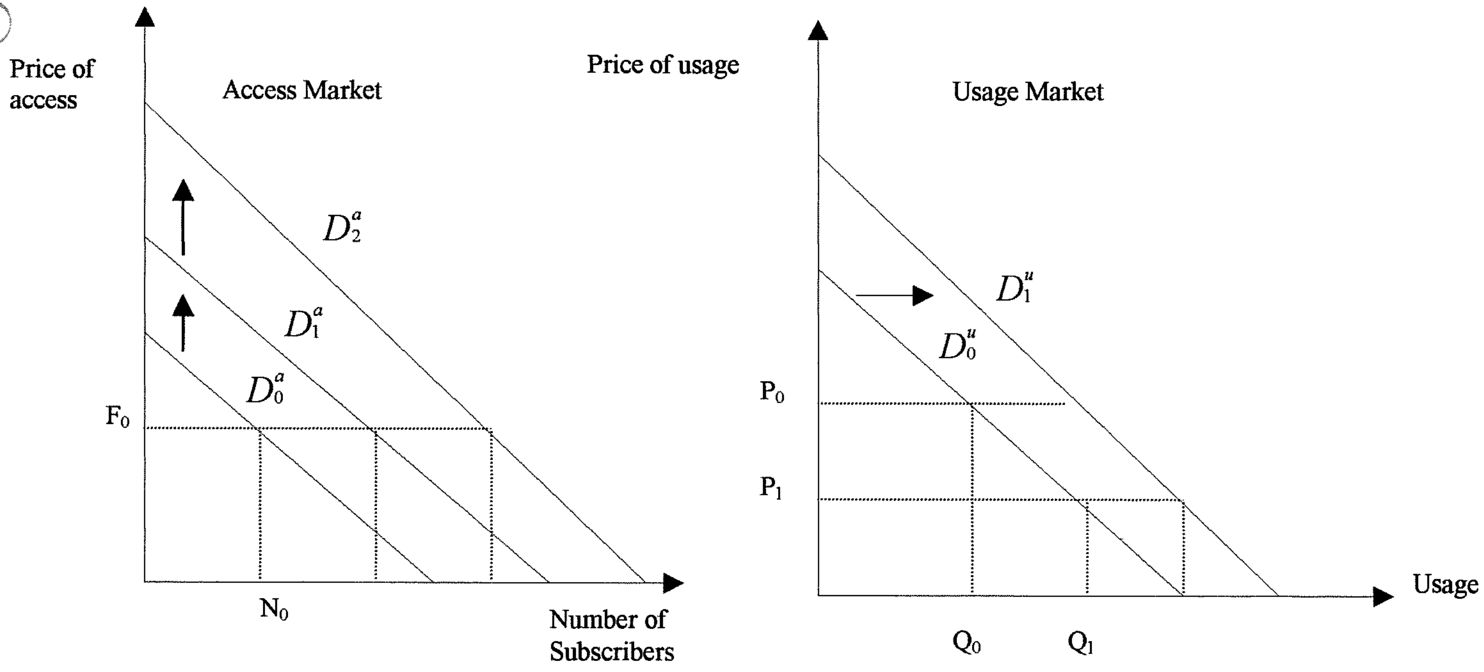
According to the economic literature on telecommunications, the demand for telecommunication services is characterised by demands for access and demands for two-way communication. The most common form of two-way communications is the telephone, and the most common form of access is a twisted pair of copper wires between the user and the local switching office. The method used to supply telephone services is to provide a direct link between each pair of nodes. With such a technology the marginal cost of a link increases directly with the size of the network. Up to the available capacity of the network, additional output can be produced at a small additional cost. However, when the demand exceeds the available capacity many parts of the network become capacity constrained, which means that some of the calls will either be rejected or delayed. This creates a negative externality, because some of the callers will be denied access to the network.

Network Externality

The nature of demand for telecommunications is characterised by the existence of a positive externality. This is due to the benefits derived from use of the network. More precisely, the benefit to an individual user increases as the number of telephone increase; that is, as the number of people who make and receive calls increases, each individual will be able to communicate with more people.

Subscriber's Externality

In addition to the network externality mentioned above there exists a subscriber externality, that is, individual demands for usage and access depend also on the number of other subscribers on the system. To see this consider the Figure below which has two graphs showing the market demand curves for usage D_0^u and access D_0^a. At usage price p_0 and access price F_0, aggregate usage is Q_0 call-seconds and N_0 subscribers join the network. Now suppose the price of local usage is lowered to P_1. Immediately, existing subscribers will increase their usage. However, in addition, the lower price raises the consumer surplus from usage, which in turn causes the demand-for-access curves for both actual and potential subscribers to rise to D_1^a; more subscribers will join the network, causing the demand for usage to rise as a result to D_1^a, but in addition making the network more valuable for all, causing still a further rise in the demand-for-access to D_2^a (Wenders (1987), p.54-55).



Source: (Wenders (1987), p.55)

The Demand for Access and The Demand for Usage

According to Mitchell (1987a) the demand for telephone service is characterised as demand for connection and demand for usage. Both, the demand for connection and the demand for usage can be described under two-part tariff. Under two-part tariff, the consumer pays a fixed monthly charge F and usage charge U. The consumer will therefore subscribe only if $F \leq S$ (S = Consumer's Surplus), that is his/her evaluation of the service is higher than the fixed charge.

The Supply Side

Economies of Scale

For years, the telecommunications industry has been considered a natural monopoly because it exhibits economies of scale in production. That is, telecommunications cost functions appear to exhibit economies of scale and scope over at least initial levels of output. This means up to a certain level of output average cost is decreasing. A large increase in volume (demand) permits the production of services using high capacity technologies and the achievement of economies of scale.

Productivity Gain

The telecommunications industry has experienced a continuous growth of productivity due to technological changes. Reductions in cost, particularly in long-distance transmission, were realised with the help of fibre-optic cables and improved multiplexing. Cost reductions have also been notable in switching, where computer-driven digital equipment has been employed to cut maintenance costs and to expand the variety of services (The Economist, Sept.30, 1995, p.8).

Competition and Price Structure

Gradually competition in the telecommunications industry is being allowed by governments to creep in. Competition has resulted in the expansion of the range of services and has driven down prices, in particular, rates of long-distance services because they were most out of line with cost. In this new economic environment, a number of new pricing structures have been introduced. For example, for years the telecommunications carriers have priced long-distance service based on call and minutes of duration according to its distance and time of day. Today's long-distance rates are no longer distance-sensitive and there is little difference between peak and off peak rates (Mitchell et al. (1991a), p.17).

Regulations

As a result of the new developments, the regulatory bodies almost everywhere have shifted from rate-of-return regulations to price cap regulations. In this way, more control can be exercised over the pricing of services (Mitchell et al. (1991a), p.19).

Benefits of the new technologies

The last ten or fifteen years have seen drastic technological changes in fixed telecommunication networks. The main features of these changes are the transition from analogue to digital switches and the introduction of optical fibre cables. These new features have made the existing services more efficient, reliable, and cheaper.

As a result of this joint adoption of the new technologies, nearly all industry observers forecast a significant glut of transmission capacity. According to Egan (1991, 38), in the United States, fibre optics networks already serve 80% of the market and capacity on many routes is over five times the current demand. This abundance of capacity will allow the traditional network operators to provide new services, such as new voice, data and video, cable television with little or no increase in the marginal capacity cost when compared to the costs that can be achieved with old technologies (Egan 1991,41).

Until now, the economic literature has been concerned mainly with the benefits that can or will result from investments in the telecommunication sector and from the adoption of the new technologies, that is, the demand side of the equation. As a result, many studies have been carried out to highlight these benefits.

According to Cronin et al. (1991, 29), investments in the telecommunications sector from 1963 to 1991 have saved the US economy $102.9 billion dollars in labour and capital expenditures. Improvements in telecommunication infrastructure between 1977 and 1982 have increased US exports by over $50 billion as a result of increased competitiveness. The utilisation of telecommunication technologies in health care services can potentially save the US population $38 billion by the year 2000.

According to Cohen (1992, 4), the utilisation of telecommunication technologies in distance learning can increase efficiency and cut cost. For example, using distance learning allowed one corporate training program to cut training cost by 90%. Furthermore, investments in new telecommunication technologies have a multiplier effect. Investments in broadband networks over the next 16 years could add an additional $321 billion in GNP growth in the US (Cohen (1992), p.1). More precisely, a $1 billion in government commitments in the telecommunications sector could produce $5 to $10 billion or more in additional infrastructure (Stanbury (1996), p.83).

Empirical studies of costs of the new technologies

While analyses of the economic benefits of the new telecommunications technologies are abundant, few analyse the effects of the new technologies on the production structure of the telecommunications industry (Garrone (1996), p.93).

To survey some of the available literature that deals with the effects of the adoption of optical systems on the production and cost structure of telecommunications, we begin with the early literature and then move on to more recent studies.

Cost Estimation Method

Greenwell (1979) carried out an early study on cost estimation. The author used a cost-estimating relationship to evaluate two alternative data transmission systems. The first system used coaxial cables and the second fibre-optic cables. The critical input parameters in estimating the total cost of a data transmission system were distance of the complete system L measured in kilometres, repeater spacing L_r also measured in kilometres, and bandwidth or capacity B measured in mega hertz. For coaxial cable systems, the study found that historical data supported the following relationship. between total costs.

$$C_{coax} = 2350(14.3 - 0.838\,L_r)L\left(\frac{B}{3.1}\right)^{\frac{1}{3}}$$

On the basis of empirical estimates, Greenwell found that for a 100 kilometre system operating at a bandwidth of 83.7 mega hertz per channel, with repeater spacing one kilometre apart, the total system cost was approximately $9.5 million.

For fibre cable systems, the study found that historical data supported the following cost-estimating relationship.

$$C_{fibre} = 425(20 - L_r)L\left(\frac{B}{5}\right)^{\frac{1}{3}}$$

Based on empirical estimates, for a 100-kilometre system operating at a bandwidth of 40 megahertz per channel, with repeater spacing 5 kilometre apart, the total system cost was approximately $1.28 million. Similar results were obtained for long-haul communications, that is, for systems over a 100 kilometres in distance.

The second is by wolff and Gratzer 1988, this study presented a cost model which used the learning curve approach to quantify the economies of scale that are reflected in the production technologies. Based on this study, the installed fixed cost (IFC)[18] of one line (one subscriber) on copper was estimated in 1988 to be approximately $1,300. The study assumed that the technology for copper was mature, meaning it would not experience any reductions in cost during the study period, while the IFC of copper cable would increase at a yearly rate of 5%. This value represented the cost increase in copper cable due to the fact that it was approaching depletion. This led to an IFC of approximately $1,800 in the year 2000.

The installed fixed cost (IFC) of one line (one subscriber) on fibre was estimated to be approximately $3,100 in the year 1988. The cost was also subject to the 5% yearly cost increase. It was assumed that the technology for fibre is in its infancy. Meaning, the cost of providing the voice line on fibre will decrease with increasing volume of production according to the technology learning curve[19], which indicates that every doubling in the cumulative production volume leads to a fractional decrease in the component cost. Historical data for fibre-optics component costs supported the following relationship:

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[18] Installed fixed cost will include components such as: Central office terminal, Remote terminal, Distribution plant, etc.

[19] The basic principle of the learning curve is as follows. Experience has shown that the graph of production labour against the number of units produced is very nearly a straight line when plotted on a log-log paper. This means that labour goes down with every doubling of the quantity produced. A particular learning curve is characterised by a percentage, such as “ the 80% learning curve, each doubling of the production quantity brings the labour required to 80% of its former value. For example the following numbers are applicable to the aeroplane manufacturing industry:

Unit Number	Labour Required (80% Learning Curve
1	100
2	$80 = 100 \times 0.80$
3	70.2
4	$64 = 100 \times 0.80 \times 0.80$
5	59.6
6	56.2
7	53.4
8	$51.2 = 100 \times 0.80 \times 0.80 \times 0.80$

$$P(NV) = P(V) * F^{\log_2^N}$$

where $P(V)$ is the cost at some initial cumulative volume, $P(NV)$ is the cost at N times this volume and $F \leq 1$ is a volume cost factor which expresses the fractional decrease in cost for every doubling in the cumulative volume. The study assumed that the production volume doubled every two years and the fractional decrease in component cost was estimated by the industry to be $F = 0.8$ or 80%. This implied that, the IFC of fibre would fall to 80% of its previous value for every doubling in output. The study lead to the following estimates:

Table 1. Summary of the Study

YEAR	IFC OF COPPER	IFC OF FIBRE
1988	$1,500	$3,100
2000	$1,800	$1,750

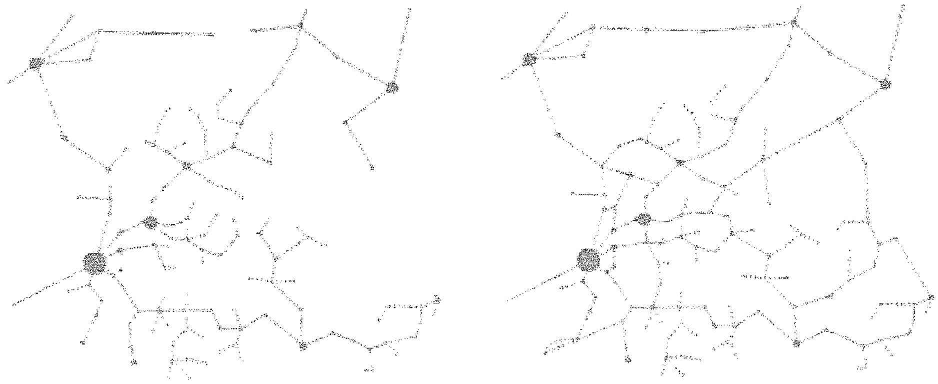
The study concluded that, given a large enough production volume, the IFC of fibre will become comparable to or less than copper for a single line sometime during the 1990's (Wolff and Gratzer (1988), p.1585).

Network Optimisation Method

The third study by Lindberg et al. (1989,1) addressed the following problem. Given a geographical area with a number of nodes and the communication demands between the nodes, between which pair of nodes should transmission plants be constructed? The difficulty of this problem lies in the fact that in the presence of optical fibres the economies of scale for transmission become much larger than the economies of scale that can be achieved with the traditional copper wires. So in the presence of optical fibre cables it becomes feasible to delete some of the transmission links and redirect the traffic flows from those links on to the fibre-optic cables. Thus, it becomes possible to reduce the number of links and therefore reduce the overall cost of the network.

According to Lindberg et al. The general solution to such a problem involves solving complex problems such as the travelling salesman and the Steiner tree problem in graphs. To be able to optimise networks of realistic size one has to begin from an initial network with all the suggested links and then using a heuristic approach reduce them to an optimal number.

Using a computer program, which they developed, the authors optimised an existing network in southern Sweden. The initial network consisted of 143 nodes and 395 transmission links with an initial estimated cost of 262.4 million Swedish Crowns. With the presence of optical fibre cables they were able to delete a number of the original links and reroute the traffic flows from them onto fibre links. As a result, they were able to reduce the cost of the Swedish network, from 262.4 to 157.4 million Swedish Crowns.



□The initial unoptimised fibre network

□The final optimised fibre network

□ Figure 1.

Source: (Lindberg and Sweden (1989), p.377)

Cost Estimation by the Econometric Method

In a recent study, Garrone (1996) concentrated on single-mode optical fibre systems and used the econometric approach to estimate the cost savings that have resulted from the adoption of these systems. For his specifications of the cost function, this researcher used a translog cost function of the following form.

$$
\begin{aligned}
ln\,c &= \alpha_0 + \alpha_y ln\,y + \sum_j^n \alpha_j ln\,w_j + \sum_i^n \alpha_i ln\,f_i \\
&+ \frac{1}{2}\beta_{yy} ln\,y^2 + \frac{1}{2}\sum_i^n \sum_k^m \beta_{ik} ln\,f_i ln\,f_k + \frac{1}{2}\sum_j^n \sum_h^m \beta_{jh} ln\,w_j ln\,w_h \\
&+ \sum_i^m \sum_j^n \beta_{ij} ln\,f_i ln\,w_i \sum_j^n \beta_{iy} ln\,w_j ln\,y + \sum_i^m \beta_{iy} ln\,f_i ln\,y
\end{aligned}
$$

Here *y* denotes output approximated by total revenue from telecommunications; *w* denotes the vector of input prices (capital, labour); *f* denotes a vector of the levels of fibre adoption in the trunk network, and *c* denotes total cost of the network.

Based on the estimated cost function the following hypothesis was tested: " *As we progressively replace the old copper trunk lines with fibre trunk lines, less equipment and less man-hours are expected to be needed by carriers, given the assumption that the same amount of service is provided*" (Garrone (1996), p.96). To conduct the test Garrone used a set of data of 16 European countries over the period from 1980 to 1992. He concluded that carriers' costs were reduced as a result of the adoption of optical systems. More precisely, a one-percent increase in the installed base of optical systems will result in a reduction in the average cost of a carrier by approximately 2 %. The study concluded that as a result of the adoption of optical communications systems, the average European carrier experiences a 4% yearly gain in productivity and the cost reduction is estimated to amount to a yearly gain comprised of between 3.89 and 562.35 million dollars (Garrone (1996), p.99).

Chapter 3

TELECOMMUNICATIONS NETWORKS

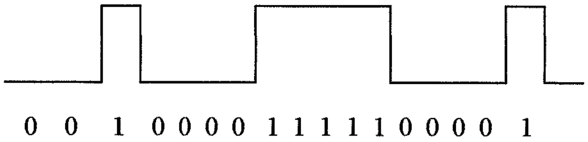
Definition of a Telecommunications Network

A two-way telecommunications network is a system of interconnected facilities designed to transmit and receive information. Information is transmitted in the form of signals under two forms, analogue and digital. An analogue signal is one that has a continuous range of values as a function of time. A digital signal has discrete sets of values as a function of time, such as a binary 1 or 0 (*Figure 1).*

The system also consists of nodes and links. Nodes represent switching offices, facility junction points, or both. Each node is an input device, an output device, or both. Examples are central office (CO), public branch exchange (PBX), local area network (LAN), etc. Their function is to interconnect various locations with one another, route traffic through a network, and, at times, process and store information. Links are transmission facilities designed to carry the traffic-- flow of information--between nodes in the network. In general, transmission facilities consist of a medium (e.g., the atmosphere, twisted copper-wire cables, fibre-optic cables, and coaxial cables) and various types of electronic equipment located at points along the medium. This equipment amplifies or regenerates signals, provides termination functions at points where transmission facilities connect to switching systems, and can combine many separate sets of call information into a single "multiplexed" signal to enhance transmission efficiency.

In a long transmission, signals tend to weaken. If a signal has weakened substantially it becomes hard to recognise its exact frequency or amplitude. This means that the information contained in the signal becomes garbled and difficult to reproduce. Therefore, a repeater or generator is used to restore the original pattern of the signal.

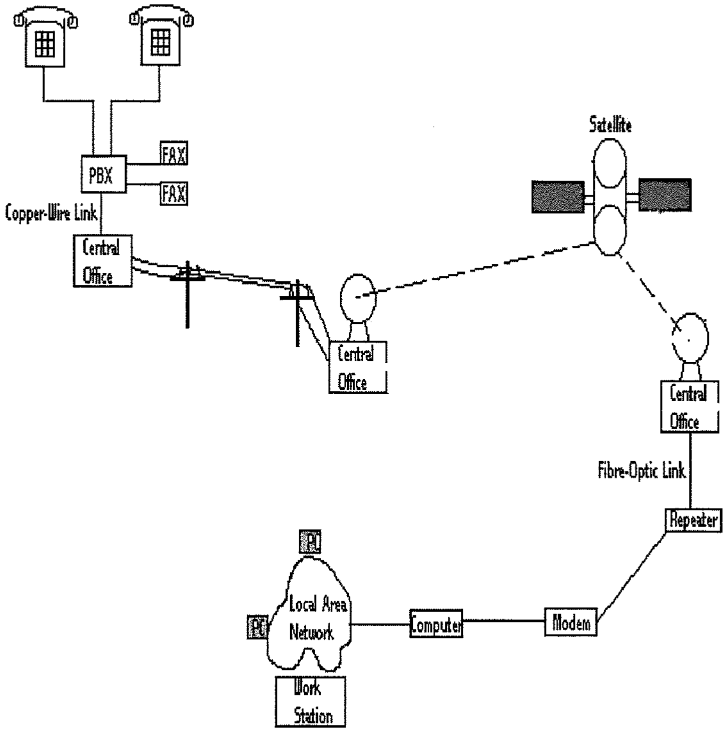
The Analog Voice Signal



A Digital Voice Signal

☐ *Figure 2*

Since signals are transmitted under two forms--analogue and digital-- a device is needed to convert the signals from digital to analogue and vice versa. This device is called a modem--an abbreviation of modulator / demodulator.

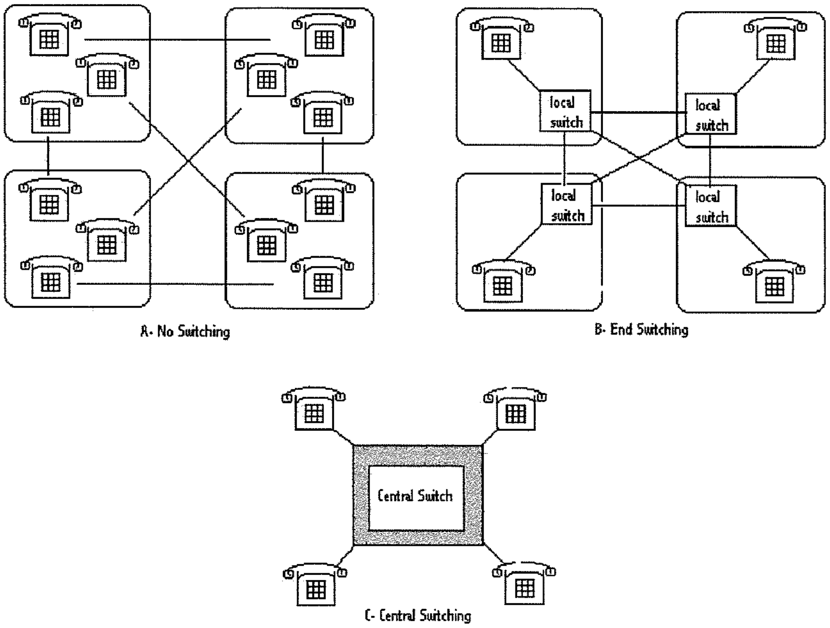


Telecommunication System

- *Figure 3*

The Key Aspects of a Telecommunication System

Three characteristics influence the nature of a network. First, traffic is generated over a large geographic area. Second, traffic is generated at any time. Third, the capacity to exchange information must be available with little or no delays.



❑ *Figure 4*

Figure 3 illustrates the key aspects of a telecommunication network. Part A shows a situation where no switching is used and pairs of telephones at four end points (users) are directly connected by transmission links. To satisfy the need of a single user on this network, three telephones and three transmission links are needed. To provide access to all the users, twelve telephones and six transmission links are needed. Such a network becomes extremely costly, as the number of subscriber increase. Part B shows a network where a switch is being used at each end location. To provide access to a single user on this network, one telephone, one switch, and three transmission links are needed, and to provide access to all the users, a total of four telephones, four switches, and six transmission links are needed. The network here represents an improvement over the network in part A in the sense that it requires fewer telephones to operate. Part C shows a network where a central switching system is used. To provide access to a single user on this network, only one telephone, and one transmission link are needed. To provide service to all the users, a total of four telephones, one switch, and four transmission links are needed.

In general, in a network with no switches, if there are n locations to be served, the number of independent transmission paths required is $[n \times (n-1)] / 2$ and the number of independent telephones is $[n \times (n-1)]$. With central switching, the number of telephones and transmission paths are reduced to n. Two economic facts are made clear in this illustration. First, a network with a central switch reduces the number of end switches and transmission links required as well as the number of telephones. Second, a network without a switch can support simultaneous connections, thereby, increasing the number of simultaneous calls that can be completed to $[n \times (n-1)] / 2$. These are important considerations when building a network, because they determine the level of service and the performance of the network, defined as the probability that a call cannot be completed. Thus, there is a trade-off between network resource sizing and the probability that a call cannot be completed. This performance level is referred to as *grade of service* (GOS). GOS represents a measure of the adequacy of telecommunications equipment, and can also represent a measure of the output. It represents the portion of calls that cannot be completed due to limits in call-handling capacity. For example, a GOS of $p=0.01$ means that only one call in a hundred would be blocked.

As seen from our illustration, the efficient use of resources favours a large aggregation of traffic. That is, at equivalent levels of output or performance, a single large network that can handle a large quantity of traffic is less expensive than several smaller networks that can handle the same amount of traffic.

The Cost Aspects of a Telecommunications System

Two factors influence the cost of a telecommunication transmission system. The first factor is distance. The further apart the locations of a telephone call are, the greater the length of the required cable or wire path, the greater the number of repeaters required, and so the greater is the cost of the system. The second factor is capacity[20] or bandwidth, that is, the amount of information the transmission lines can carry between nodes. Capacity is an increasing function of traffic intensity. Traffic intensity in turn depends on the product of the number of calls and the average length of a call. The higher the number of calls and the longer is their duration, the greater is the traffic intensity, the greater is the required capacity, the greater is the number of required wires, and so the greater the cost of the system.

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[20] Capacity is defined as the amount of information the transmission lines can carry between nodes. A basic measure of capacity is the bit, that is the amount of information conveyed by single binary switch in the on or off position.

Chapter 4

OPTICAL FIBRE VERSUS COPPER: THE TECHNICAL ASPECTS

Fibre versus Copper

Optical fibres are a combination of two complementary technologies: lasers and glass fibres. Lasers are powerful light sources that transmit information through a tiny tube of glass. While this new light source can generate a beam of light powerful enough to cut steel, its importance for communications resides in its ability to transmit information. Since its inception, its uses have included measurements, navigation, and chemical research. Its application has expanded to include the reproduction of music, eye surgery, and the recording of information on compact discs by burning microscopic holes on their surface. But its most significant use to date has been in telecommunication and this is due to the unique properties of laser light. Laser light is quite different from other sources of light. For example, if one shone a flashlight at a distant object one would notice that, the further away the object the larger the diameter of the light and the more area it covers: the light spreads out. Laser light, on the other hand, is very precise and directional. It does not diffuse over distance; no matter how far away the object is, the diameter of the laser beam's spot remains the same size. The other property is coherence. Unlike light from the sun, which contains all the colours of the spectrum, laser light has the same wavelength and a characteristic colour, usually red or green. This coherence property allows for greater receiving sensitivity and longer spans. These properties--directionality and coherence-- are what make laser light relevant and applicable to telecommunication. By rapidly pulsing lasers on and off, it is possible to encode information in the light stream with accuracy and speed. Now the only thing missing is a medium of transmission to bend and guide the laser light.

This is where fibre technology comes into the picture. Fibre which is usually made of glass, does not use electrical signals to carry information but uses short pulses of light. One of its properties is the fact that it is an enclosed transmission medium. This means light does not escape out the sides of the fibre because its walls act like a mirror, reflecting the light back in. Thus, the light is conducted within the fibres right to the end even if the conduit is curved.

Fibre optics communications cables have four key advantages over earlier metallic cables:

1) Quality and quantity of transmissions over fibre optic cables are very high. To achieve the same information carrying capacity as one single-mode optical fibre cable, would require at least 1000 twisted-wire copper cables. Moreover, optical fibres are composed of concentric cylinders made of dielectric material (i.e., non-metallic material that does not conduct electricity), which gives them immunity from outside interference (other signals or noise) and a much greater signal quality.
2) Fibre has a size and weight advantage. The light guide cable is 23 times lighter than copper cable, and its cross sectional area is 36 times smaller. These two advantages make fibre cables easy to handle in the field and allow much more economical use of the duct space, an important consideration when the duct space is already utilised to capacity by copper wire cables.
3) Fibre has a signal transmission cost advantage. Signals can be carried in optical fibre cable up to a 100 kilometres before they need regeneration or amplification, compared to just 3 kilometres for copper. Moreover, each 80-100 kilometre segment of fibre needs only a 2 two-way repeaters, while a copper system of equivalent information capacity would need about 30 two-way repeaters (Heldman (1994), p.12).
4) Fibre has maintenance cost advantage. A break in a fibre strand can be located to within one meter, an important consideration when several kilometres of fibre are buried underground. By contrast, copper wire cables may require extensive trench digging to locate a break.

These advantages-- larger information carrying capacity, smaller size, much greater repeater spacing, improved transmission quality and easier maintenance-- have resulted in major savings for the telephone companies.

To understand the carrying capacity of fibre consider the following fact: In March, 1992, TAT-9, the transatlantic fibre optic system was able to transmit the text from the entire 30-volume *Encyclopaedia Britannica* in less than one second (Heldman (1994), p.13). In addition to efficient high speed transmission of data and voice over long distance, fibre can easily carry video and television signals, so the use of optical fibres could significantly increase the number and type of services without incurring a major additional cost to provide new capacity. Also, their use would allow significant reduction in the running cost of a fixed network. According to *The Economist*[21], The maintenance cost of a fibre optic network is estimated to be around one-fifth that of a wired network.

However fibre also has a number of disadvantages:

1) There is the added cost for Electro-optical transmitters and detectors, because such communications cables require the conversion of the signal from optical to electronic, and from electronic to optical at each regenerator.
2) Higher termination cost (largely manpower for making physical connections and splices).
3) Higher installation costs in short distances such as premises wiring system.

Because optical cable technology is in its infancy, such costs are expected to continue to decline and, therefore, these disadvantages have become less of a cost consideration. Table 2 below provides comparison of the average costs of fibre optic components over time.

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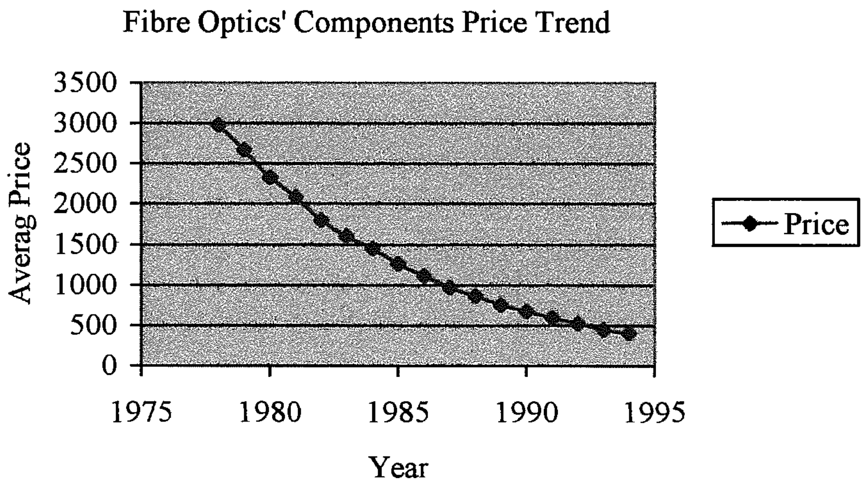
[21] The Economist (1995) Vol. 336, No. 7934, p.8

Table 2. Historic average prices for fibre optics components

Year	*Cable \ Meter*	*Multiplexer*	*Transmitter*	*Receiver*	*Connector*	*Coupler*	*Total*
1978	$5.28	$1665	$390	$397	$44	$480	$2981.28
1979	4.7	1515	335	340	38.8	435	2668.5
1980	4.28	1376	273	275	37.2	360	2325.48
1981	3.49	1282	244	238	32.1	286	2085.59
1982	2.91	1154	202	187	27.6	225	1798.51
1983	2.43	1032	185	171	24.7	184	1599.13
1984	2.25	954	167	154	22.4	148	1447.65
1985	2.01	849	143	121	20.5	120	1255.51
1986	1.74	777	128	89	19.4	94.3	1109.44
1987	1.53	683	113	69	17.5	84.4	968.83
1988	1.27	621	93	57	15.5	75.6	863.37
1989	1.16	549	76	48	13.6	67.7	755.46
1990	1	488	67	41	12	60.4	669.4
1991	0.74	433	62	35	10.5	53.9	595.14
1992	0.58	377	55	31	9.34	48.2	521.12
1993	0.5	316	48	27	8.44	44.1	444.04
1994	0.4	288	42	24.5	7.98	41.8	404.64

Source: (Webb, (1996), p.140)



❑ *Figure 6*

Fibre technology, however, cannot by itself account for all the reductions in cost and increases in output. It is a new and highly efficient medium to transmit information from point A to point B. But it needs a smart piece of technology in a telephone company's network to guide and tell it what to do, like who is placing a call and to whom. That piece of equipment is the phone switch.

Digital versus Electromechanical Switches

Switches/telephone exchanges have moved on from operators and electromechanical devices to become increasingly like computers, their cost falling and their capability (capacity to process and route information) expanding. In order to understand the key economic aspects behind electronic switching one needs to compare it with the old existing electromechanical switches.

An electromechanical switch is a space-division switching system, meaning the speech path is continuous through the exchange and each one of these speech paths is separated physically from all other speech paths. Such a continuous speech path, once set up, remains unchanged for the whole duration of the telephone communication. In other words, a line (wire or trunk) must be dedicated to each call. Therefore, any increase in capacity must be associated by an increase in the number of trunks and changes to the switch's hardware. The switch has a small and fixed capacity, which can only process a fixed number of calls and can only accommodate a fixed number of trunks. The switch has no ability to complete a call on an end-to-end basis without the commitment of trunk and switch resources. So the maximum quantity (number) of trunks must be installed to ensure that the users receive an acceptable grade of service. Hence, as the capacity of operation increases, the cost must also increase. The switch can only process analogue signals, which require more precise tuning and adjustment and greater maintenance. Moreover, transmitting analogue signals over long distances requires expensive signal regeneration equipment. Because an analogue signal needs to be regenerated more frequently, the repeated regeneration required results in poor sound quality in direct proportion to the distance travelled. So the further apart the parties to a call are, the greater the length of required wire path, and so the greater the number of repeaters.

Modern electronic switches on the other hand, are fundamentally different from electromechanical switches and other earlier versions of electronic switches. The new switch employs modern integrated circuitry and digital capabilities, which means it can provide new features with software changes, reduce space and power requirements by approximately 60%. The system grows in terms of call-handling capacity and features through increases in memory capacity, expansion of office database, and addition of peripheral equipment. Also, the manner in which modern electronic switches switch telephone calls is different from the method used in other large switching systems that switch calls along separate physical paths. Here, calls are switched over a single physical path, separated from each other by microsecond time. The calls are switched by shifting their position in time on the path. The time position helps determine where the call is routed. An example of a modern expandable switch is the 4ESS. Currently, the switch has the capacity to process more than 680,000 calls per hour, accommodate more than a 100,000 trunks, and handles signals from both analogue and digital circuits. The economic advantages are:

1) The switch can process a large number of calls and accommodate a large number of trunks.
2) The switch has a large and expandable memory and operates under the control of a stored computer program, which means that the software can be written to do many tasks and can also be changed without having to change the hardware. Any required increase in capacity can be obtained through increases in memory and software changes. Therefore, the cost associated with capacity increases is small in comparison with older switches.
3) The switch is equipped with common channel signalling so that the ability to complete a call on an end-to-end basis can be determined prior to the commitment of trunk and switch resources.

4) The switch handles both digital and analogue signals. Therefore, the signal can be transformed into whatever is optimal (cheaper) for transmission or processing.

There is an intimate relationship between fibre optics cables and electronic switches. They both share the same language ones and zeros (i.e., digital signals). This enables the two technologies to communicate with each other at very high speeds over long distances and at the same time reduce cost. Moreover, by digitising voice calls at the central office (CO), the calls could be treated as data, using digital routing and signal regeneration. Digital error detection and correction techniques mean that a digitised voice signal can be regenerated perfectly. When the digitised voice is converted back to an analogue signal at the destination, it is clear, as it was when it arrived at the central office from the subscriber. The cost savings here result from the fact that digital transmission signal are less susceptible to transmission impairments than are analogue signals. Digital signals transmission facilities require less expensive repeaters and amplifiers, less precise tuning and adjustment, and much less maintenance.

Another important aspect of this relationship is that digital technology can easily handle video signals. This allows telephone companies to provide a wider range of services without having to incur the additional cost of providing new capacity. In summary, the new technologies have created an excess capacity in both the processing and transmission of information. This new and unused capacity changes the economics of fixed networks, since many parts of the new networks will no longer be constrained by capacity. Economically speaking, this means the marginal operating costs will be falling as the number of subscribers increase, and the marginal capacity costs will be very low in comparison with the cost of the older technologies.

Chapter 5

OPTICAL FIBRE VERSUS COPPER: THE ECONOMIC ASPECTS

Tele-Traffic Engineering

Traffic engineering of voice and data networks involves the determination of the number of circuits needed to keep delays below a specified level. The task of making this determination is known as the sizing problem.

Consider a group of trunks consisting of N circuits, where N is a positive integer and a circuit represents a single talking path. The use made of such a group of trunks depends on the rate at which calls arrive and the length of time for which they are held. The term "traffic" takes into account these two factors.

Consider a circuit for which only one call can be handled at any instant. If a call on such a system lasts for one hour, the circuit is said to carry *1* erlang[22] of traffic. If during an hour the circuit carries two calls, each lasting 20 minutes, then the traffic carried by the circuit is [(20+20)/60] = 2/3 erlang. In general, if k circuits are busy continuously for 1 hour, then the group of trunks under consideration carries traffic of k Erlangs.

The volume of telephone traffic passing through a given exchange depends on the nature of the subscribers-- business, residents, or mixed-- the time of the day, the month of the year, holidays and catastrophes, and the rates at which calls are priced. The following figure depicts a typical evolution of the traffic on a weekday for an exchange with a preponderance of business subscribers.

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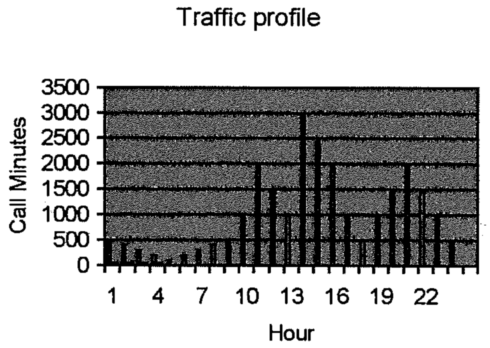
[22] Two units of traffic measurements are used: the Erlang and the CCS (hundred call- seconds). The CCS is used in the United States, while the erlang is used in Europe and other parts of the world. One Erlang is equivalent to 360 CCS.

We observe that the night-time traffic is low and that there is a morning peak between 9h30 and noon. In the afternoon, the traffic reaches a peak between 14h00 and 16h30. There is a slight increase between 18h00 and 22h00 due to discounted tariffs on trunk calls for residential subscribers. In designing a telephone exchange, knowledge of traffic volume is required. The traffic volume often used for this purpose is an average, taken over several days of the month, more specifically, the average traffic of the five busiest days of the month.



A Statistical Model of Tele-traffic

Suppose the telephone exchange under consideration is a group of trunks consisting of N lines linking two cities. Calls arrive at the exchange in a random manner and a call that arrives when all the N lines are busy is blocked and assumed to be lost. In developing a mathematical model for tele-traffic volume generated, we make the following assumptions.

First, the calls arrive at the exchange independently and during an infinitesimal time interval $[t, t + dt)$ at most one call arrives. We assume that the probability of one call arriving is $\lambda dt + o(dt)$ while the probability of no call arriving is $1 - \lambda dt + o(dt)$. Here λ is a positive constant representing the average number of calls arriving during the busiest period of the day and $o(dt)$ is a generic remainder term of order less than dt. That is, $o(dt)$ represents any term for which the $\lim_{dt \to 0} \frac{o(dt)}{dt} = 0$.

Second, the duration of a call on a line is assumed to follow a negative exponential distribution with mean *h*, where *h* is a positive constant. In designing a telecommunication network the average duration *h* is often taken to be 120 seconds or 180 seconds. More precisely, if a call arrives at time zero and is terminated at time $t > 0$, then the density function of *t* is $f(t) = \frac{1}{h} e^{\frac{-t}{h}}$. It follows from this specification of the density function that if the call is still going on at time t, then it will be terminated by time $t + dt$ with a probability $\frac{1}{h} dt$. In general, if *i* lines are busy at time t, then the probability that one call is terminated by time $t + dt$ is $\frac{i}{h}\ dt$. This last result follows if we assume that the duration of busy calls are independent and identically distributed and at most one call is terminated during the infinitesimal time interval $[t,\ t + dt)$.

Now let $X\,(t)$ be the number of busy lines at time *t*. We observe that $X\,(t)$ is a continuos-time stochastic process that takes on discrete values. More precisely, $X\,(t)$ might assume one of the following values $0,1\ldots,N$. When $X\,(t) = N$, all the lines are busy and any new call arriving will be blocked and presumed lost. The random variable $X\,(t)$ represents the state of the system at time *t*.

For each $i = 1,\ldots,N$, let $p_i(t)$ denote the probability that the system is in state *i*. Next consider an infinitesimal time interval $[t,\ t + dt)$. We want to compute $p_i(t + dt)$, to this end we write

$$
\begin{aligned}
(1)\qquad p_i(t + dt) &= prob[X(t + dt) = i] \\
&= prob[X(t + dt) = i \,/\, X(t) = i] \\
&+ prob[X(t + dt) = i \,/\, X(t) = i - 1] \\
&+ prob[X(t + dt) = i \,/\, X(t) = i + 1]
\end{aligned}
$$

In the above expression, we have used the assumption that during the infinitesimal time interval only one of the following three disjoint events can take place: a) No new call arrives and no on-going call is terminated; b) exactly one new call arrives and no on-going call is terminated; c) no new call arrives and exactly one on-going call is terminated. The probabilities of a), b), and c) are given, respectively, by

$$(2)\qquad \begin{aligned} prob\left[X(t+dt)=i\,/\,X(t)=i\right] &= p_i(t)\left(1-\lambda dt-\frac{i}{h}dt\right)\\ prob\left[X(t+dt)=i\,/\,X(t)=i-1\right] &= p_{i-1}(t)\lambda\, dt\\ prob\left[X(t+dt)=i\,/\,X(t)=i+1\right] &= p_{i+1}(t)\left(\frac{i+1}{h}\,dt\right) \end{aligned}$$

Using (2) in (1), we can write

$$(3)\qquad p(t+dt)=p_i(t)\left(1-\lambda\, dt-\frac{i}{h}dt\right)+p_{i-1}(t)\lambda\, dt+p_{i+1}(t)\frac{i+1}{h}\,dt$$

It follows from (3) that

$$(4)\qquad \frac{\lfloor p_i(t+dt)-p_i(t)\rfloor}{dt}=-\left(\lambda+\frac{i}{h}\right)p_i(t)+\lambda\, p_{i-1}(t)+\frac{i+1}{h}\,p_{i+1}(t)$$

Letting $dt\to 0$ in (4), we obtain the following differential equation.

$$(5)\qquad \frac{dp_i}{dt}=-\left(\lambda+\frac{i}{h}\right)p_i(t)+\lambda\, p_{i-1}(t)+\frac{i+1}{h}\,p_{i+1}(t)$$

For $i = 0$, $P_{i-1}(t) = Prob.[X(t) = -1] = 0$ because $X(t)$ cannot take on negative values.

In this case, (5) becomes

$$(6)\qquad \frac{dp_0}{dt}=-\lambda\, p_0(t)+p_1(t)\frac{1}{h}$$

For $i=1,\ldots,N$, (5) has the following form

$$(7)\qquad \frac{dp_i}{dt}=-\left(\lambda+\frac{i}{h}\right)p_i(t)+\lambda\, p_{i-1}(t)+\frac{i+1}{h}\,p_{i+1}(t),\quad i=1,\ldots,n$$

Observe that when $i = N$, $i+1 = N+1$ and $P_{i+1}(t) = Prob.[\,X(t) = N+1] = 0$.

When the system is in statistical equilibrium the probability distribution that characterises the state of the system is stationary, i.e., $P_i(t)$, $i=1,\ldots,N$ does not vary with time, say $P_i(t) = P_i =$ constant, $i=1,\ldots,N$. In this case, $\frac{dp_0}{dt}=0$ and (6) allows us to write

$$(8)\qquad \lambda\, p_0=\frac{1}{h}p_1$$

For $i = 1$, (7) allows us to write

(9) $\left(\lambda+\frac{1}{h}\right)p_1=\lambda p_0+\frac{2}{h}p_2$

Using (8), we can write (9) as

(10) $\lambda\ p_1 = \frac{1}{h}p_2$

The above procedure can be repeated for $i = 2,\ldots,N-1$ to obtain the following results

$$\lambda p_0=\frac{1}{h}p_1$$

$$\lambda p_1=\frac{1}{h}p_2$$

$$\vdots$$

(11) $\lambda p_i=\frac{i+1}{h}p_{i+1}$

$$\vdots$$

$$\lambda p_{N-1}=\frac{N}{h}p_N,$$

If we let $E = \lambda h$, then it follows from (11) that

$$p_1=Ep_0$$

$$p_2=\frac{Ep_1}{2}=\frac{E^2 p_0}{2!}$$

$$p_3=\frac{Ep_2}{3}=\frac{E^3 p_0}{3!}$$

(12) $\vdots$

$$p_{i+1}=\frac{Ep_i}{i+1}=\frac{E^{i+1}p_0}{(i+1)!}$$

$$\vdots$$

$$p_N=\frac{Ep_{n-1}}{N}=\frac{E^N p_0}{N!}$$

Now using the fact that, $P_0+P_1+\ldots+P_N=1$ and (12), we have

$$1=p_0+p_1+\cdots+p_N=p_0+Ep_0+\cdots+\frac{E^i p_0}{i!}+\cdots+\frac{E^N p_0}{N!}=p_0\sum_{i=0}^{N}\frac{E^i}{i!}$$

Hence,

$$p_N = \frac{E^N p_0}{N!} = \frac{E^N p_0 / N!}{p_0 \sum_{i=0}^{N} \frac{E^i}{i!}}$$

(13) $$p_N = \frac{E^N / N!}{\sum_{i=0}^{N} \frac{E^i}{i!}}$$

Equation (13) is known as the Erlang formula. It gives the probability of a new call being blocked, i.e., the probability that all the lines are busy. This probability depends on the number of lines N and E, the traffic carried by the system during one unit of time. Recall that $E = \lambda h$ = the product of the average number of calls arriving per unit of time and the mean of the duration of a call.

Interpretation of the Erlang Formula

The volume of traffic carried by a circuit -as measured in Erlang--is random. However, at the system level, when a telephone exchange consists of a large number of circuits, the traffic carried by the system as a whole exhibit a high degree of regularity. For a telephone exchange, $E = \lambda h$ can be considered as being known with little variation. In the Erlang formula, as represented by (13), if P_N is taken as given, then E can be considered as the output of the system as the grade of service P_N.

Now in (13), if P_N is fixed, then an increase in N will result in a more than proportional increase in E if equality continues to hold. That is, if we double the number of lines N, the output, given the grade of service P_N, will more than double. This property is at the source of the economies of scale in telecommunications.

With the technological progress in optical fibres, a certain level of expenditures can result in more optical fibre cables, with each cable supporting many more lines than a copper cable. These facts are at the source of the economies of scale in optical fibres.

Economies of Scale

Today, after years of conversion from coaxial cable and microwave by inter-exchange carriers, long distance phone service in the United States is mostly carried on single mode optical fibre. Conversion to fibre began in 1983 as a result of competition between the inter-exchange carriers on the basis of capacity and quality. For competitive reasons, long-distance carriers began installing fibre in their networks and began marketing their services as providing connections with clarity and quality superior to older technologies. This competitive environment resulted in significant capital expenditures, more than $5 billion as of 1986, by the leading long distance companies. By 1987, the major US carriers had converted the bulk of their long-distance transmission lines fibre. Today, Sprint has a 23,000 miles all fibre network. Most of MCI's network is fibre. And by December 1991, AT&T had installed 31,400 miles of fibre routes.

To illustrate the new economies of scale and scope that will result from substituting copper with optical fibre cables, use will be made of the data available on domestic long-distance telephone service in the United States. Since voice calls make up the largest component of demand as assessed by AT&T's the world's telephones and the federal communications commission's statistics of communications common carriers[23].

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[23] AT&T 1981-1990 and the FCC 1989/1990.

Table 3. Data on domestic long distance in the US

Domestic Long-Distance Calls Per Year (Billions)			
Year	Calls Completed	Year	Calls Completed
1965	4.7	1979	17.2
1966	5.2	1980	19.783
1967	5.6	1981	18.77
1968	6.2	1982	36.5316
1969	6.8	1983	N/A
1970	7.2	1984	30.4915
1971	8.0	1985	37.5253
1972	9.2	1986	42.3208
1973	9.9	1987	51.744
1974	10.6	1988	48.4569
1975	11.5	1989	48.9726
1976	12.2	1990	N/A
1977	13.5	1991	66
1978	15.233		

Source: (Adamson et al. 1995, p.12)

To describe a realistic case, consider the traffic demand for the domestic long-distance market in the United States Table 3. Suppose in this market, call origination times occur at random during the hour and suppose that enough trunks are provided to carry all the long-distance calls. Then given a blocking probability of $P = 0.01$ (industry standard) we can calculate the number of cables required for each technology and hence show the new economies of scale as a result of switching from copper to fibre.

We recall from chapter 3 that the volume of traffic demand--denoted by E--is measured by Erlangs and is obtained by multiplying the arrival rate of calls λ by the holding time of a call h, that is, $E = \lambda h$.

According to AT&T and the FCC the average holding time for a call is estimated to be $h = 5.6$ minutes. Given the data in table 3 and the average holding time we can calculate the total traffic intensity (or offered load) per second for each year follows.

Number of long distance calls × holding time × number of seconds in a minute, λ is given by total traffic in seconds divided by (number days per year multiplied by the number of hours per day multiplied by the number of seconds per hour).

So the total traffic load is given by the average number of calls per second multiplied by the average holding time per second. That is,

$$E = \lambda h.$$

Now we can use the Erlang formula to calculate the number of circuits N required to achieve a blocking probability of say $P = 0.01$ (industry standard).

Now suppose all the long-distance traffic was carried on copper wires. Then the number of cables required given that, the maximum attainable number of circuits from a twisted copper cable are 30 will be.

$$N_{copper} = \frac{N}{30}$$

On the other hand, if all the long-distance traffic were carried on single-mode fibre-optics. Then the number of cables required given that the minimum number of circuits attainable from single-mood fibre cables are 30000 will be.

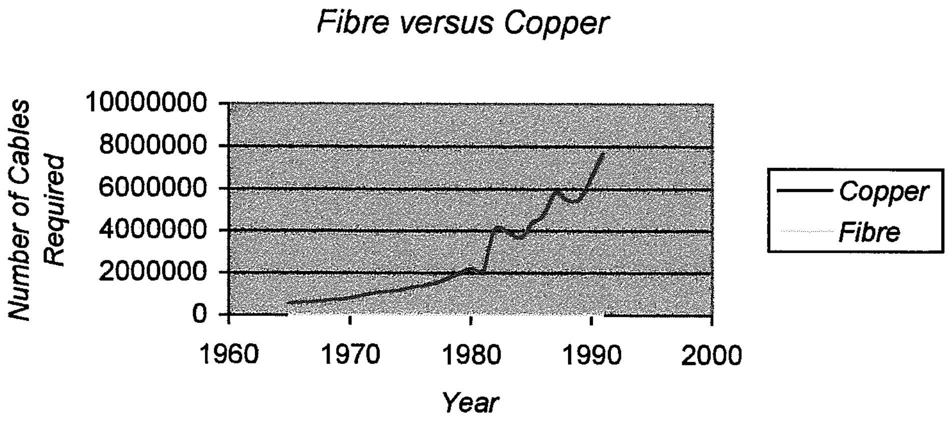
$$N_{fibre} = \frac{N}{30,000}$$

Using the above logic we can produce the following table of values.

Table 4. Calculated values using the data in table 3

Year	$P \le 0.01$	$E = \lambda h$	$N_{circuits}$	N_{copper}	N_{fibre}
1965	0.01	1.683×10^7	16×10^6	5.333×10^5	533
1966	0.01	1.862×10^7	18×10^6	6×10^5	600
1967	0.01	2.005×10^7	19×10^6	6.333×10^5	633
1968	0.01	2.220×10^7	21×10^6	7×10^5	700
1969	0.01	2.434×10^7	23×10^6	7.667×10^5	766
1970	0.01	2.578×10^7	25×10^6	8.333×10^5	933
1971	0.01	2.864×10^7	28×10^6	9.333×10^5	833
1972	0.01	3.294×10^7	32×10^6	1.067×10^6	1067
1973	0.01	3.544×10^7	34×10^6	1.133×10^6	1133
1974	0.01	3.795×10^7	36×10^6	1.2×10^6	1200
1975	0.01	4.117×10^7	39×10^6	1.3×10^6	1300
1976	0.01	4.367×10^7	42×10^6	1.4×10^6	1400
1977	0.01	4.833×10^7	46×10^6	1.533×10^6	1533
1978	0.01	5.453×10^7	52×10^6	1.733×10^6	1733
1979	0.01	6.157×10^7	59×10^6	1.967×10^6	1967
1980	0.01	7.082×10^7	67×10^6	2.233×10^6	2233
1981	0.01	6.719×10^7	64×10^6	2.133×10^6	2133
1982	0.01	1.308×10^8	124×10^6	4.133×10^6	4133
1983	N/A	N/A	N/A	N/A	N/A
1984	0.01	1.092×10^8	11×10^7	3.667×10^6	3667
1985	0.01	1.343×10^8	13×10^7	4.333×10^6	4333
1986	0.01	1.515×10^8	14.3×10^7	4.767×10^6	4767
1987	0.01	1.852×10^8	17.5×10^7	5.833×10^6	5833
1988	0.01	1.735×10^8	16.4×10^7	5.467×10^6	5467
1989	0.01	1.753×10^8	16.6×10^7	5.533×10^6	5533
1990	N/A	N/A	N/A	N/A	N/A
1991	0.01	2.363×10^8	23×10^7	7.667×10^6	7667

* p = *Probability of blockage or the Grade of Service*
* h = *duration of the call in minutes*
* λ = *Rate of calls or Traffic Intensity in seconds*
* N = *Number of circuits required to satisfy the constraint P=0.01*
* N_c = *Number of copper cables required to satisfy the blockage constraint*
* N_f = *Number of fibre cables required to satisfy the blockage constraint*
* E = *Offered load or Traffic load*



It is evident from the calculations in the table, that, as we double the capacity, the number of circuits required does not need to double, hence, there are economies of scale in transmission with both technologies. That is, as we aggregate more traffic greater resource efficiency can be achieved while providing acceptable grade of service levels. Now in the case of copper at low levels of output, efficiency can be achieved with little or no increase in the number of cables installed but at high levels of output the number of cables required starts to increase at an increasing rate. Similarly, with fibre great resource efficiency can be achieved at low levels, but as output begins to increase greater resource efficiencies are achieved and the number of cables start to increase at a decreasing rate.

In other words, the economies of scale that results from the use of fibre-optic are equal to 1000 times the economies of scale that result from the use of copper, since every single mode fibre-optic cable replaced a minimum of approximately one thousand copper-wires. So, by replacing copper with fibre to maintain the same level of service one of two things must happen. Either capacity must increase to account for the difference or the number of cables must fall, hence, both scenarios zero in on the new huge economies of scale in transmission.

Cost Analysis: A Case Study

Consider two long-distance networks that have equal link length and capacity, one installed with fibre-optic transmission technologies and the other installed twisted copper wire transmission technologies. Suppose that, both networks are a point-to-point long distance link between two cities. The link length is 100 kilometres and the link capacity is 672 voice channels or 45 MB/s. To simplify the analysis, observe that many cost elements that are either common or unavailable to the two networks are not included. For example, digital switching is common to both, but data on the maintenance of both systems is not available. Even though maintenance cost estimates are not available, we do know that the maintenance cost of a fibre optic system is estimated to be one-fifth the cost of a copper wire network (The Economist, Sep. 30, (1995), p.7).

Copper Network

According to 1990 prices, (Esty (1987), p. 44), the components cost of a copper, digital T1 toll carrier line[24], where two copper-wire pairs are required for every 24 voice channels are as follows:

☐ Cable cost:

$49/km/pair

☐ Cable installation costs:

$200/km + $44.50 /km/pair for splicing

$1,250/km + $2 /km/pair for placing

Total installations cost per km is

$200+$44.5+$1250+$2 = $1,496.5

☐ Repeaters:

$130 per unit, one required every mile on each T-1 line

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[24] T1 line represents a measure of capacity = 1.544 MB\s =24 circuits or voice lines

- ☐ Digital transmit and receive units:

$750 per unit, one for each set of 24 voice channels at each end

For 672 voice channels with 24 channels per line we have:

672/24= 28 cable runs or lines

Table 7. Cost Summary

	No. of Km	No. of Runs	No. of Units	Price / Unit	Total Unit Cost
Cable	100	28		$ 49	$137,200
Installation	100	28		$1,496.5	$ 4,190,200
Repeaters		28	63	$130	$ 229,320
Multiplexers			48	$ 750	$ 36,000
Total System Cost					$ 4,592,720

Fibre Network

According to 1990 prices, (Esty, (1987), p. 44), the components costs of a single mode fibre optics network are as follows:

- ☐ cabled optical fibre cost:

$1,100 / km for each fibre cable (normally four are installed two for active service and two for protection or back up.

- ☐ Cable installation costs:

$600/km + $16/km/fibre for splicing

$1,000/km for placing

Total installation cost/km

$600 + $16 + $1,000 = $1,616

- ☐ Optical repeaters cost:

$1,000 per unit, one is required 70-100 km

- ☐ Digital transmit and receive, Multiplexer / demultiplexer units:

$8,000 per unit one for each end, for systems up to 672 voice channels.

Table 8. Cost Summary

	No. of Km	No. of Runs	No. of Units	Price / Unit	Total Unit Cost
Cable	100	4		$1,100	$ 440,000
Installation	100	4		$1,616	$ 646,400
Repeaters			4	$1,000	$ 4,000
Multiplexers			2	$8,000	$ 16,000
Total System Cost					$ 1,106,400

It is clear from the calculations that the fibre optic system has an installation cost advantage over the copper wire system, given equivalent link length and capacity. Now the only thing that remains to be shown is the fact that the new network will exhibit large economies of scale in terms of cost. Suppose now we double the capacity or output to 1,344 voice channels or 90 MB/s. What happens to the cost in the two networks?

For case one, the technology is such that when we double output, the cost will double ($4,592,720 × 2 = $9,185,440) because we will need twice the inputs. For example, to increase the amount of information carried by a copper network it is necessary to increase the diameter of the copper or increase the number of copper cables (Loube, (1991), p.1006).

For case two, the technology is more flexible. When we double output we will incur two additional costs. The first one involves the cost of splicing the cables further. The second one involves the cost of upgrading the end units, i.e. the transmitting and the receiving units. Given that the cost of splicing is $50 a unit or voice, the total cost of splicing becomes (672 ×$50=$33,600). Given that, upgrading the end units from 672 voice channels to 1,344 voice channels costs $4,000 more. That is, the price of a unit for systems up to 90 MB/s is $12,000. Therefore, the additional cost incurred is ($33,600 + $12,000 = $45,600).

Hence, as the capacity of operation increased on the new network, i.e. the network is used more extensively, the average unit cost of providing service actually decreased.

Chapter 6

THE IMPLICATIONS OF FIBRE OPTIC TECHNOLOGIES

The developments in optical fibre communications, which have taken place to date, have used only a fraction of the inherent capability of optical fibre. It is expected that there will be further progress during the coming years which will take the maximum capacity of the fibre from the current 1-2 Gbits/s[25] (gigabit per second) region into the 10-100 Gbits/s through the use of wave length division multiplexing. These new developments in transmission will also lead to rapid reductions in transmission costs, especially if existing fibres can be used for higher bit rates by only replacing the transmitters, repeaters and receivers. It is also expected that switching costs will decrease steadily but not as rapidly. These changes will have series implications for the industry of telecommunications, in particular the telephone industry and the cable industry.

Competition

The telephone companies introduced fibre-optics because it has the potential to carry not only vastly more voice and data communications but also video programs and services. As for cable companies, they have reinforced their coaxial systems with fibre backbones to improve the quality of cable television services and to enhance the two-way communications abilities of the cable system. Thus, the new technology is bringing these two industries into direct competition. A glimpse of this evidence has already appeared in Vancouver. According to the Vancouver Sun[26]. " *British Colombia Telecommunications and Concorde Pacific Development in Vancouver created a joint venture to bypass Rogers Cable and deliver at least as many channels over fibre-optic*

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[25] Gigabits per second: A unit of data signalling rate i.e., one billion bytes per second or 10^9 BPS.

[26] *The Vancouver Sun*, September 21, 1995, p.A1; and September 23, 1995, pp.B4, B13

lines from a receiving dish in the suburbs to 13,000 units in a number of apartment towers with inside fibre-optic wiring. The CRTC, however, has severely constrained this lower cost alternative to Rogers".

Market Shares

In 1984, the Federal Communications Commission ended AT&T's long distance monopoly in America. As a result, competition began to spread and the new technologies started translating into lower tariffs mainly because of excess fibre capacity on the long distance routes. During the following years, long distance rates fell by approximately 40%, and AT&T's long distance market share dropped from 84% in mid 1984 to 60% by mid 1993. MCI and US Sprint picked up the majority of those lost shares.

This section will be mainly concerned with the market shares of the big three carriers in the US, namely AT&T, MCI, and US Sprint and the future effect on them. We begin by identifying the likely factors that will influence their market shares in the future, and then we make use of a simple game model to predict the future distribution of their market shares.

As companies and consumers begin to get used to the savings that resulted from the new technologies and competition, they will choose their carriers based on the capacity of their lines and the quality of their service. According to industry observers, since a price war between the big carriers is not likely to occur in the future, marketing and advertising will be the new method of competition. According to Competitive Media Reporting of New York, the big three American Carriers (AT&T, MCI, & Sprint) dumped at least $800 million into the advertising battle. Sprint Corporation applied $131 million of its $11 billion revenues towards its image. Given this evidence, it is fairly safe to assume that the competitive strategy set by each firm will be associated with marketing strategies, quality improvements, advertising, and differentiation efforts.

The Model:

Suppose that there are n firms, which are sharing a market of fixed volume $\bar{v}$, the number of domestic long-distance calls. The strategy set for each firm will be associated with marketing expenditure costs such as quality improvements and advertising. One of the characteristics of these costs is that they are recurrent at each period. The other characteristic is that they are critical to preserve market shares[27].

Assume that market shares are the advertising expenditure shares. Let σ_i denote firm $i's$ market share, x_i its level of market share by expenditure, m_i its profit margin on variable cost, π_i its profit level, and f_i its fixed costs. We have

$$\sigma_i = \frac{x_i}{\sum_{j=1}^{n} x_j}, \quad i = 1, \cdots, n \text{ and} \tag{1}$$

$$\begin{aligned} \pi_i(x_1, \ldots, x_n) &= \sigma_i m_i \bar{v} - x_i - f_i \\ &= \frac{x_i}{\sum_{j=1}^{n} x_j} m_i \bar{v} - x_i - f_i, \quad \textit{for } i = 1, \ldots, n \end{aligned} \tag{2}$$

At the Nash Equilibrium, for each $i = 1, \ldots, n$, we have, $\frac{\partial \pi_i}{\partial x_i} = 0$, i.e.,

$$\begin{aligned} \frac{\partial \pi_i}{\partial x_i} &= \frac{\sum_{j=1}^{n} x_j - x_i}{\left(\sum_{j=1}^{n} x_j \right)^2} m_i \bar{v} - 1 = 0 \\ \textit{or} \quad \frac{\sum_{j=1}^{n} x_j - x_i}{\left(\sum_{j=1}^{n} x_j \right)^2} &= \frac{1}{m_i \bar{v}} \end{aligned} \tag{3}$$

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[27] Ponsard, (1981), p.81-85

$$\sum_{j=1}^{n} x_j - x_i = \frac{\left(\sum\limits_{j=1}^{n} x_j\right)^2}{m_i \bar{v}}$$

$$(4) \qquad x_i = \sum_{j=1}^{n} x_j - \frac{\left(\sum\limits_{j=1}^{n} x_j\right)^2}{m_i \bar{v}}$$

Here x_i is the market equilibrium level of expenditure for each firm i. Given $\bar{v}$, m_i, $i = 1,\ldots,n$, the parameters of the model, equation (4) can be used to compute the equilibrium market share for each firm. Now if we know the value of x_i for each firm in period one then we can use the values of m_i for each firm to calculate the new $x_i's$, $i = 1,\ldots,n$.

Because of lack of access to the data specific to each firm, m_i and f_i, $i = 1,\ldots,n$, are not available. So we have to compute m_i and f_i indirectly through a technique known as calibration. Thus assuming that the data for the year 1995 represent a Nash equilibrium-- called the benchmark equilibrium--we can compute the profit margin over variable cost for each firm as follows. Given $\bar{v}, \sigma_i$, and m_i we can compute the present Nash equilibrium.

Case Study:

According to the Federal Communications Commission and CanComm reports in 1995 we have the following data.

Table 9: Initial data

Associated with 1995 Market Size of $\bar{v} = 50\times10^9$ Calls / Year			
Firm	Marketing expenditure $\$10^6$	Market share	Profit $\$10^6$
i	x_i	σ_i	π_i
AT&T	695	53 %	15.2
MCI	234	17.8 %	5.2
SPRINT	131	10 %	2.9
OTHERS	250	19.1 %	3.5

Using the above data we solve for the present Nash Equilibrium values.

Table 10: 1995 Nash Equilibrium

Present Nash Equilibrium Point associated with a market size of $\bar{v} = 50\times10^9$ calls / year					
Firm	Fixed cost $\$10^9$	Profit margin on variable costs	Market share	Marketing expenditure $\$10^9$	Profit $\$10^9$
i	f_i	m_i	σ_i	x_i	π_i
AT&T	7.9	0.9	53.1 %	0.695	15.2
MCI	2.6	0.9	17.8 %	0.234	5.2
SPRINT	1.5	0.9	10 %	0.131	2.9
OTHERS	1.4	0.45	19.1 %	0.250	2.6

Now to predict the future Nash Equilibrium in the year 2001, we proceed as follows. With the deployment of fibre optics the carriers will experience a reduction in their costs. To capture this cost reduction we make use of the following relationship.

$$m_i = p_i - mc_i$$

or

$$mc_i = p_i - m_i$$

Now if we assume that there will be no further reductions in price, that is, p is constant, then the new $m_i's$ become solely determined by the change in the mc_i's.

Based on CallNet (Sprint Canada) 1996 annual report, the average cost of operation per billed minute falls by approximately 11 % a year due to increased efficiency. It means that the $m_i's$ will increase by the same rate. Now, given p the average price of a one minute long distance call and the benchmark values of the $m_i's$ we can compute the $m_i's$ for the year 2001. Based on a selected sample of AT&T long distance charges per minute p =0.26, the average holding time for a long distance call is 5.6 minutes and the average cost per minute is $AC = 0.10$. Therefore, the average price of a call is 1.44 and the average cost of a call is 0.54. So we have

$$m_{1995} = 1.44 - 0.54 = 0.9$$

$$mc_{2001} = \frac{mc_{1995}}{1.11^6} = \frac{0.54}{1.87} = 0.288$$

Therefore,

$$m_{2001} = 1.44 - 0.29 = 1.15$$

Since all three big carriers have access to the new technologies we would expect the $m_i's$ to be almost the same with the exception that the small carriers do not have the same costs and will not likely experience any cost reductions in the future for the following reason. Analysis of the data on revenue given their market share does produce the same price for a long distance call and since they cannot charge less for a long distance call than the big carriers by assumption. We conclude that their average costs per minute must be higher than the other carriers. Since, after all they buy capacity from the big carriers and resell it for a profit.

Now suppose that AT&T the dominant firm in the industry decides to increase competitive pressures on its competitors by increasing its level of advertising, such as marketing its service as providing connections with clarity and quality superior to its competitors. According to our model, The new Nash Equilibrium points will be as follows.

Table 11: Predicted values for the year 2001

Nash Equilibrium Point associated with a market size of $\bar{v}$ = 103×10^9 calls / year					
Firm	Fixed cost \$$10^9$	Profit margin on variable costs	Market share	Marketing expenditure \$$10^9$	Profit \$$10^9$
i	f_i	m_i	σ_i	x_i	π_i
AT&T	7.9	1.15	28.5	1.1	25
MCI	2.6	1.15	28.5	1.1	30
SPRINT	1.5	1.15	28.5	1.1	31
OTHERS	1.4	0.45	14.5	0.56	4.7

Based on the model's predicted values one may conclude that the three big carriers will continue to be the big winners in the industry. As for the other smaller firms in the industry they will be vulnerable firms in the sense that, they could easily be pushed out of the market, and their vulnerability comes both from their fixed costs and profit margins. If they are unable to adopt the new given the huge investments required they will not likely be able to adopt the new technologies. Moreover, presently most of the smaller firms purchase capacity from the big carriers and if the price of capacity is not reduced they will continue to be vulnerable. In another word, if the savings that have been achieved by the big carriers through the use of the new technologies are not passed on to the new smaller firms they will be pushed out of the market through mergers or by take-overs.

Market structure

To predict the market structure of this industry we use equation (3) of the model. First we sum over $i = 1,\ldots,n$, we have

$$\frac{n\sum_{j=1}^{n}x_j - x_i}{\left(\sum_{j=1}^{n} x_j\right)^2} = \frac{n}{m_i \bar{v}}$$

$$(5) \qquad \frac{\sum_{j=1}^{n}x_j(n-1)}{\left(\sum_{j=1}^{n} x_j\right)^2} = \frac{n}{m_i \bar{v}}$$

$$\frac{(n-1)}{\sum_{j=1}^{n}x_j} = \frac{n}{m_i \bar{v}}$$

Substitute equation (5) into equation (4) we have

$$x_i = \frac{(n-1)m_i\bar{v}}{n} - \frac{\left(\frac{(n-1)m_i\bar{v}}{n}\right)^2}{m_i v_0}$$

$$= \left(\frac{n-1}{n}\right)m_i\bar{v} - \left(\frac{n-1}{n}\right)^2\left(\frac{(m_i\bar{v})^2}{m_i\bar{v}}\right)$$

$$(6) \qquad = \left(\frac{n-1}{n}\right)m_i\bar{v}\left[1-\left(\frac{n-1}{n}\right)\right]$$

$$= \left(\frac{n-1}{n}\right)m_i\bar{v}\left[\frac{1}{n}\right]$$

$$= \left(\frac{n-1}{n^2}\right)m_i\bar{v}$$

Substitute equation (5) and (6) into equation (2) we have

$$\pi_i = \frac{m_i \bar{v}}{n} - \left(\frac{n-1}{n^2}\right) m_i \bar{v} - f_i \geq 0$$

$$\text{or} \quad \frac{m_i \bar{v}}{n}\left[1 - \frac{n-1}{n}\right] - f_i \geq 0$$

$$\text{(7)} \qquad \text{or} \quad \frac{m_i \bar{v}}{n}\left(\frac{1}{n}\right) - f_i \geq 0$$

$$\text{or} \quad \frac{m_i \bar{v}}{n^2} - f_i \geq 0 \Rightarrow \frac{m_i \bar{v}}{n^2} \geq f_i \Rightarrow n^2 \leq \frac{m_i \bar{v}}{f_i} \Rightarrow$$

$$n \leq \sqrt{\frac{m_i \bar{v}}{f_i}}$$

The justification here is that, as long as there are positive profits in this market, entry into this market will continue and will only stop when the profits of the *n+1* firm becomes negative.

$$\bar{v} = 103 \times 10^9$$

$$f_i = 3.35 \times 10^9$$

$$m_i = 0.98$$

$$n \leq \sqrt{\frac{0.98 \times 103 \times 10^9}{3.35 \times 10^9}} \approx 5$$

According to the model the number of firms in the industry will be approximately 5, that is, a form of oligopoly, and AT&T the leading firm in the industry loses its dominance status. It is interesting to note that currently there is an influx of new entrants to the long distance market lured by the big profits that can be made. However, the current situation is not likely to continue because the big long-distance carriers are starting to get aggressive in their advertising and price reduction campaigns, something the smaller companies will not be able to afford specially when they start seeing their profit margins shrink.

Chapter 7

CONCLUSION

According to our analysis, as a result of technology and competition, the telecommunications industry in the US will experience major changes in the next decade, particularly, its market structure. It will likely converge to a form of oligopoly with 4-5 firms in the industry. This means that all the smaller firms that are currently operating fixed networks or those that are in the resale business in the US market will either disappear or merge. The evidence in that regard is strong. Based on the Federal Communication Commission 1996 report, the following mergers and take-overs have occurred.

1. In 1985, ALLNET merged with LEXITEL.
2. In July 1986, GTE SPRINT and US TELECOM merged into US SPRINT.
3. In 1988, METROMEDIA COMMUNICATIONS merged with ITT COMMUNICATIONS.
4. In 1989 MCI telecommunications and TELECOM USA merged.
5. In 1992, LDDS COMMUNICATIONS merged with ADVANCED TELECOMMUNINATIOS.
6. In August 7, 1995 AT&T acquired ALASCOM.
7. In August 16, 1995 FRONTIER CORPORATION acquired WCT COMMUNICATIONS.

The implications for the Canadian telecommunications market will likely be similar to those of the US telecommunication market with one exception. Full long distance competition did not begin in Canada until July 1994 when a decision by the Canadian Radio and Television Commission (CRTC) allowed companies equal access to the public telephone system. Therefore the Canadian telecommunications market lags behind that of the US by ten years. So the full effect of competition and technology is yet to be seen. But as result of competition in the last two years long-distance rates have dropped 30-40 %.

While competition since 1992 created an influx of new entrants, industry consolidation followed between 1993 and 1995 and only four major long distance companies have survived to compete nationally against the Stentor group, an alliance of 9 provincial and regional telephone companies. Although the Stentor alliance still dominates the long-distance sector with 70 % market share, they have been loosing market shares steadily since their monopoly ended in 1990.

Unlike the United States, where the regional local companies are entering the long-distance sector, no major new competitors are expected to enter the Canadian long-distance market. Therefore we will not likely see major changes in the current oligopolistic market structure, but what we will likely see is a marketing war and further price reduction once the full effect from competition and technology sets in. The new economic environment in the Canadian telecommunications market will likely change the distribution of market shares in the long-distance market. Already, a glimpse of this evidence is starting to surface. Bell Canada, the leading firm in the industry, has lost approximately 3% of its long-distance market share to smaller firms in the market who mostly buy capacity and resell it. It is interesting to note here that the major competitor to the Stentor group in the long-distance sector has been Sprint Canada. It happens to have fibre-optic circuits on most of its major routes[28] and DMS-250 switches, which are the highest standard, used by major telephone companies. Those switches are 100 percent digital and can easily be enhanced to add both new capacity and new technological features.

According to (Telephony 1990, p.12) " *Northern predicted savings of up to 21% in annual network operating costs, based on deployment of fibre and conversion of current electronic central offices to all fibre centres*".

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[28] In 1994, Sprint Canada activated the fibre optic link between Toronto and the US. In 1995, They activated a fibre optic link between Ottawa, Montreal, and Toronto with interconnections between

Based on Northern Telecom predictions, it is safe to assume that Sprint Canada has a cost advantage and therefore a higher profit margin than others do. This is the reason why they have been leading the way in price reductions for the last two years.

The economic implications of fibre optics technologies both for the producers and consumers of telecommunication services will be enormous. For the producers it means that the telecommunications firms will be able to offer a better product at a fraction of its former cost. Already first glimpses of this evidence are beginning to appear. According to the Economist[29], "*carrying a call from London to New York costs virtually the same as carrying it from one house to the next.*"

In the presence of true competition it means that the prices of long distance services will become a fraction of today's prices, which according to our analysis, are ways out of line with cost. Again first glimpses of the lower prices are beginning to appear. US Sprint now offers long distance calls in the US for 10 cents a minute, which happens to be exactly, equal to the average cost of one minute of long distance in the year 1995. It is interesting to note here that, US Sprint was the first long distance carrier to adopt fibre optic technologies and currently its entire network is cabled up with fibre optics.

For consumers the lower prices of long distance communications will mean lower transaction costs. In the presence of lower transaction costs it is known that consumer welfare improves. For example, any activity that relies on a screen or telephone can be carried out anywhere in the world for very little; thus, location and geography will cease to be a barrier for communication. This implies that, many services now provided by local markets would be made easier to carry out by people who live in different geographic areas. This will offer workers who lives in remote areas, the chance to attain

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Belleville and Oshawa. Later in 1995, they activated a fibre optic link between Montreal and Vermont in the US (CallNet,1996, p.20).

[29] The Economist, Sept. 30, 1995, p.1

a standard of living that they can only get by moving to big cities. Furthermore, workers who sell information for living will experience the same competition from abroad as they do in their domestic markets.

Glossary

1. **Twisted Copper-Wire Cable**: A cable that is made up of one or more separately insulated twisted pair of copper conductors.
2. **4ESS**: The first time-division digital switching system with stored program control, capable of handling both digital and analogue signals. It was made by AT&T in 1976.
3. **Common Channel Signalling**: A system developed for use between stored program control switching systems, in which all of the signalling information for one or more trunk groups is transmitted over a dedicated signalling channel, separate from the user traffic-bearing channel.
4. **Optical Repeater**: A device that is designed to receive and amplify an optical signal.
5. **Multiplexer / Demultiplexer**: A device that combines different electrical signals into a single electrical signals then converts the signal to an optical signal.
6. **Coaxial Cable**: A cable that is made up of one insulated copper conductor.
7. **Cable**: A group of metallic conductors or optical fibers that are bound together, with a protective sheath.
8. **Channel**: A single communication path in a transmission medium connecting two or more points in a network.
9. **Digital transmission**: Transmission in which information is sent in discrete bit form (i.e., as a stream of 0s and 1s).
10. **Digital signal**: An electrical signal in which information is carried in a limited number (two or more) discrete status. The most fundamental and widely used form of digital signal is the binary (i.e., 0s and 1s).
11. **Fiber optic**: Extruded glass fibbers that carry light waves over extended distances.
12. **Analogue transmission**: Transmission in which the native discrete valued data processing digital signals are converted back into continuos valued waveforms for transmission.
13. **Analogue signal**: Continuous Variations in some characteristic of the flow, a change in the frequency or amplitude.

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