The Canadian Computer/Communications Task Force

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The Canadian Computer/Communications Task Force

Background Papers

11 Local Facility Study

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June, 1972

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Introduction

The objective of this study is to identify and evaluate the various methods of extending digital communications to and from terminating equipment at the users' locations in Canada to the point of interconnection with a general computer/communications network.

Study Outline: The local distribution network provides the communications link between the user's equipment and the peripheral node of a general computer/communications network. The distance between user's and peripheral nodes will reflect the optimization of the total system, but distances of up to 500 miles may be expected. The following study examines the users' requirements and the conditions at the peripheral node of the general computer/communications network in order to establish the parameters that the local distribution network must meet. The various instrumentalities that will meet these parameters are then identified and their characteristics outlined to indicate their respective merits in meeting the varied circumstances and environments which may be encountered in the Canadian situation.

1. Users' Terminal Requirements

The range of speeds at which existing computer terminal devices operate is in the region of 100 b/s to 50 kb/s, with the majority operating below 2.4 kb/s. Future requirements are uncertain in degree, but increasing volumes and speeds can be considered a likely requirement. Speeds as high as 50 Mb/s are required to handle colour television signals and it is possible that a future general computer/communications system will need to accommodate this. For completeness then, requirements for speeds up to 50 Mb/s will be considered, but emphasis will be placed on below 50 kb/s requirements which are expected to generate the greatest need within the next decade.

In addition to the users' speed requirements other terminal characteristics which affect the selection of a suitable local communications medium are:

- Distance from peripheral node
- Need for security
- Need for bi-directional operation
- Need for synchronization
- Need for rapid response time
- Traffic volume and time distribution
- Length of messages or transactions

The last three are of concern where shared usage of the same local distribution medium is envisaged.

2. The General Computer/Communications Network

The nature of the general computer/communications network that will evolve is currently not known and the alternatives available are many. However, in examining the function of a peripheral node on any communications network, it is possible to identify the likely effect that its characteristics will have on the local distribution network.

By definition, the peripheral node is the first interconnection point at which the various network users have the capability of interacting. In order to determine how the user's information is to be acted upon, the node has to record and examine at least some part of the originating user's message in the form that it was dispatched.

In general then, the local network must be capable of reproducing the user's signal at the peripheral node in its original format. Possible exceptions to this occur when separate signalling channels are employed and where, at the same time, it may be desirable to switch and distribute a signal in a coded format and translate back to its original form at the destination location. The need for this type of arrangement appears limited, and in general it will be assumed that the peripheral node will require the user's signal to appear there with the same characteristics that it exhibits at the user's terminal. When the architecture of a proposed computer/communications network, or networks, has been determined it will be necessary to review this assumption for validity and modify the local distribution network considerations if appropriate.

3. Local Facility Instrumentalities

The local distribution network must be capable of accepting a signal at the input interface and reproducing it at the output interface within a prescribed time-frame. By this definition the signal becomes any digital bit rate up to 50 Mb/s and the interfaces become the user's equipment and the peripheral node of the general computer/communications network, in any sequence.

The intermediate transmission process may be accomplished by simple conditioning of the media to maintain as closely as possible the original input signal state throughout. Alternatively, it could include any or all of the various methods of conversion such as regeneration, digital/analogue, analogue/digital, time-division multiplexing, frequency-division multiplexing, as well as store-and-forward features. Similarly, the transmission media could include anything from a simple pair of wires, through coaxial cable and microwave radio carrier systems to sub-optical and optical systems.

If the initial premise is accepted and criteria are established with respect to the faithfulness and transit time of the signal transmitted, then the distance, signal rate, traffic volume, directionality and security required by a specific user will dictate the feasible instrumentality options. In developing a specific design, the most economic method of handling this requirement would then be determined by considering these options in relation to both the individual user's and other users' specific current and expected future needs. A more general approach to this is required in order to develop a meaningful overall view.

In reviewing the many variations that may be expected in the several parameters involved, it is appropriate to effect some simplification of variables in order to focus attention on the more significant considerations. Accordingly, it is proposed to consider bi-directional transmission, synchronization, and a rapid response time to be the general requirements, and the alternatives to be exceptional cases. Similarly, it is not considered necessary to compound the analysis of each instrumentality with assessments of the security that it affords. Improved security can generally be obtained from non-radiating versus radiating media and from multiplexed versus non-multiplexed systems, but all can be supplemented by the provision of additional security devices as the needs dictate. Faithful reproduction of the input signal can also be considered separately, since all instrumentalities considered may be engineered to meet whatever practical standards are established.

The remaining criteria may significantly affect the choice of instrumentality to meet a particular need. These criteria are signal rate, traffic volume and the distance between the interfaces. In examining the possible users' requirements it was determined that signal rates could be up to 50 Mb/s and that distances and volumes were really not known. It is therefore proposed to review the various instrumentalities which are capable of transmitting digital signals at various bit rates up to 50 Mb/s and over distances of up to 500 miles. The Appendix provides a general outline of the various systems which fit this category. The several configurations shown may be applied singly or serially as required. All the instrumentalities are currently available, or will be available within four years with the exception, perhaps, of some very high capacity regenerative microwave systems and some of the high-speed regenerative line access units. However, the existing state of the art has the capability to produce these devices and may be expected to do so if there is sufficient need. In addition to the functional units shown, interface devices will generally be required at the terminal locations to provide the standard data equipment/communications system interface conditions.

Since, with multiplexing devices, the bit rate and volume are interrelated, the maximum bit rate within each system is shown and this can then be equated to a multiple of lower bit rates, as required. Similarly, any required traffic volumes may be accommodated by multiplying the number of transmission systems provided. Frequently there are economies of scale involved and where these are significant and are generally obtainable in combination with other requirements for whatever purpose, this is identified (asterisked) – examples of this are shared use of multiple-capacity cable, cable carrier and microwave carrier structures.

The other important characteristic of any instrumentality is its cost (costs will be considered in terms of annual charges, since they are more indicative of the overall financial burden than first costs). Given any particular instrumentality, it will be subject to a range of annual charges dependent upon the particular environment encountered, in terms of both geography and getting started, versus incremental provisioning. This may be further compounded by variations in the provisioning and maintenance capabilities of the various organizations which may be involved. In any proposed Canadian network, extreme situations in each environmental condition may well be encountered. More meaningful information may then result from establishing some general cost perspective between the respective instrumentalities involved and then identifying the more common variations in environment which are likely to distort the cost perspective between instrumentalities. Section 5 and Figures 11 and 12 in the Appendix provide information on the general relationship between annual charges per unit of bit rate in relation to distance and capacity for the several transmission system types involved.

In interpreting the capability and cost information provided in Section 5 and the Appendix, the relative merits of the various instrumentalities for moving different volumes of various bit rates over various distances may be assessed in general terms. However, as discussed previously, some environmental conditions will distort this perspective significantly and not infrequently. The following outlines some of the more sensitive conditions which must be considered in order to meet any specific requirement in an optimum manner.

The cost of carrying a circuit unit (4.8 kb/s data, voice circuit or whatever) over any transmission medium is inversely related to the volume of units being carried by that same medium. This is particularly true at the lower end of the volume scale where specific provisioning for a unique low volume requirement will almost certainly be considerably more costly than incrementally adding it to other existing requirements or combining it with other new requirements. All options for the combining of requirements should therefore be considered.

Allied to this first consideration is the recognition of the growth-rate situation expected to evolve. Everything else being equal, systems with low getting-started costs will generally be more advantageous for low growth-rate situations and *vice versa.*

The terrain to be traversed will influence the cost of the various instrumentalities. The cost of placing physical cable facilities in unfavourable terrain between cities may be high in some instances. This can be significant even between locations as close as thirty miles, where the change in terrain from sand to rock may double costs. Cable system provisioning within Canadian cities does not seem to present any real problems. However, radiating systems may incur higher costs in metropolitan areas due to path-blockage situations.

The availability of frequency allocations for radiating systems will differ between environments and, where this inhibits the optimum development of a structure, it will have some adverse cost effects.

Specific reliability needs will also have an effect on costs, particularly with radiating systems where path lengths and the provision of protection channels are subject to trade-offs with respect to costs. Also related to this is the need to reduce the path lengths of radiating systems above 10 GHz in environments subject to heavy rain, snow or fog.

The need for asymmetric transmission also has to be considered. The optimum transmission facility may not be the same in both directions and the objective will generally be to optimize the whole system.

Not directly related to costs, but of some value, is the survivability benefit obtained from the diversity of circuitry and instrumentalities. Where the volume of requirements is sufficiently large, both space and instrumentality diversity may be obtained relatively inexpensively. This provides for greater protection against catastrophic failures that may occur in any one environment or instrumentality.

4. Summary

Each of the instrumentalities identified may expect to have some economic advantage in meeting a particular combination of bit speed, volume, distance and environmental conditions. The one factor which has the most marked and universally applicable effect on the cost of providing transmission facilities relates to the degree to which the volume of usage of the facility can be increased. Transmission facilities are more economic in volume, and the more usage that can be applied to a particular structure, the lower the cost of each circuit unit carried.

Instrumentalities have been identified which may be expected to cover the whole range of bit speed, volume and distance requirements and, as indicated, there may be some specific need for each. However, it is reasonable to assume that the most common requirement will likely be for bit rates below 50 kb/s at distances of less than ten miles with still some doubt with respect to the likely volumes in each transmission route cross-section. Even under these more specific conditions, paired cable, coaxial cable, microwave and optical systems may all be feasible. However, paired cable systems are expected to be more economic in meeting the majority of requirements.

The advantage of coaxial cable distribution systems lies in their high capacity and for point-to-point requirements above 6.3 Mb/s they may well prove in over microwave and optical systems. The establishment of a high-capacity multipoint distribution system on coaxial cable is worthy of consideration where individual requirements above 6.3 Mb/s are to be met. Multipoint use of coaxial cable systems providing users with wide flexibility in bit rate and volume usage will be dependent on future reductions in control hardware and software costs. In the interim, paired cable systems appear generally more economic for the majority of requirements below 6.3 Mb/s.

Radiating systems will undoubtedly have a role to play in moving high-traffic volumes. Short-distance, high-volume requirements will, in some environments, be most economically met with optical systems. Microwave systems will most certainly fill a need for longer-haul, high-capacity systems.

Further generalization would serve no useful purpose, since it would tend to obscure the importance of reviewing the capabilities of all available instrumentalities to meet each specific situation and provide system-wide optimization. The one universally applicable guide is that the combination of requirements to develop volume traffic leads to more economic and survivable circuit provisioning and should be considered wherever feasible.

5. Instrumentality Costs — Associated Notes

Multiplexing costs have not been identified because of the very wide ranges which apply for various configurations. For very rough approximations, annual charges of $5,200 per terminal may be reasonable.

Costs have not been developed for Figures 2C and 8 because of the absence of Canadian experience with these systems. However, they may be roughly considered to approximate to Figures 2B and 7 respectively, but providing higher capacities at corresponding reductions in circuit unit costs.

The costs outlined reflect an average of Canadian situations. Although not necessarily typical of the whole Canadian position they do serve to establish the general perspective which applies. Some value may be gained from an appreciation of a number of the variations which can apply and a summary of some of the more significant ones is provided.

The contribution of local cable plant to the costs shown has been obtained by averaging the respective contributions of aerial, buried and ducted cable in the local network plant today, together with a consideration for their respective average capacities. The costs per pair mile will be as much as five times more for a small capacity cable than for a larger one (say eleven pair versus 600 pair).

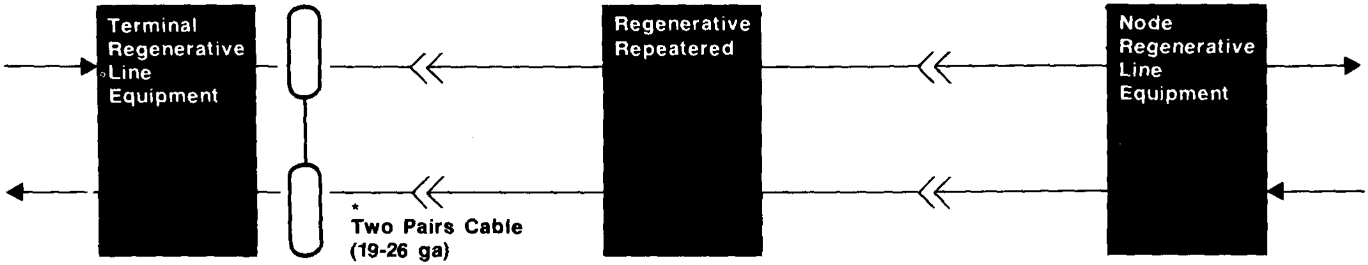
Similarly, in the provisioning of longer-haul circuits, the costs are arrived at on an average basis. The costs per circuit unit may vary by as much as a factor of ten, depending upon whether the circuit unit is provided by incrementally adding to an established cross-section or by a new route configuration.

There is also a great deal of significance in the capacities that are provided by the various instrumentalities. For instance, the higher capacity systems reflect a much lower circuit unit per mile cost. However, unless all the available circuit unit capacity is utilized the actual cost per circuit unit in use may be very costly in relation to other alternatives.

Appendix

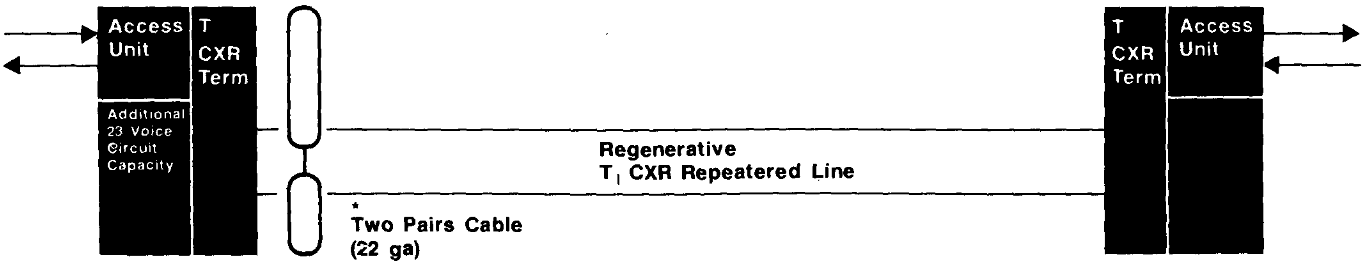
Instrumentality Configurations

Figure 1
Local Distribution Network — Instrumentalities
Regenerative Transmission Systems, Short Haul — Cable



Speeds: up to 48 kb/s
Distance: 10-15 miles at 4.8 kb/s
Repeater Spacing: approx. 6-mile intervals at 4.8 kb/s

Figure 2A
Medium Haul — Cable

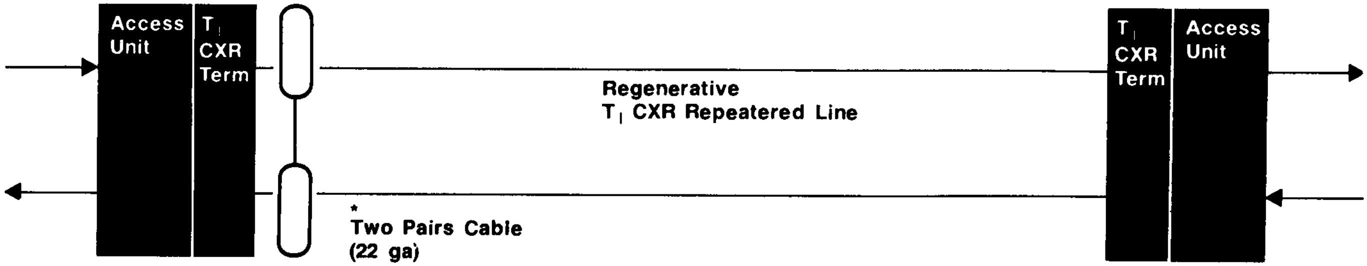


Speeds: up to 48 kb/s
Distance: up to 200 miles
Repeater Spacing: 1.14 miles

* Asterisks denote the potential for significant economies of scale by combining requirements

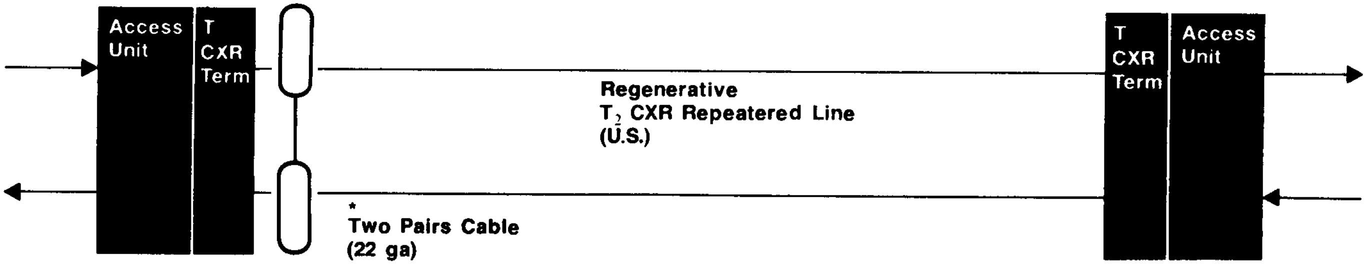
Figure 2B

Medium Haul — Cable



Speeds: up to 1.54 Mb/s
Distance: up to 200 miles
Repeater Spacing: 1.14 miles

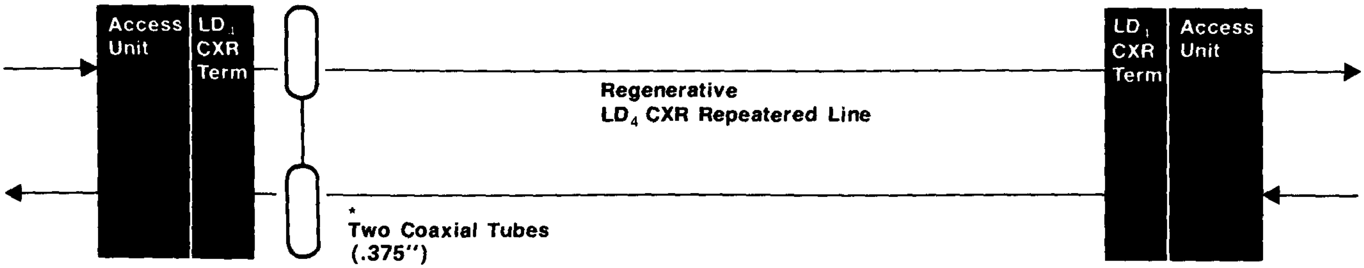
Figure 2C



Speeds: up to 6.3 Mb/s
Distance: up to 500 miles
Repeater Spacing: 1 mile

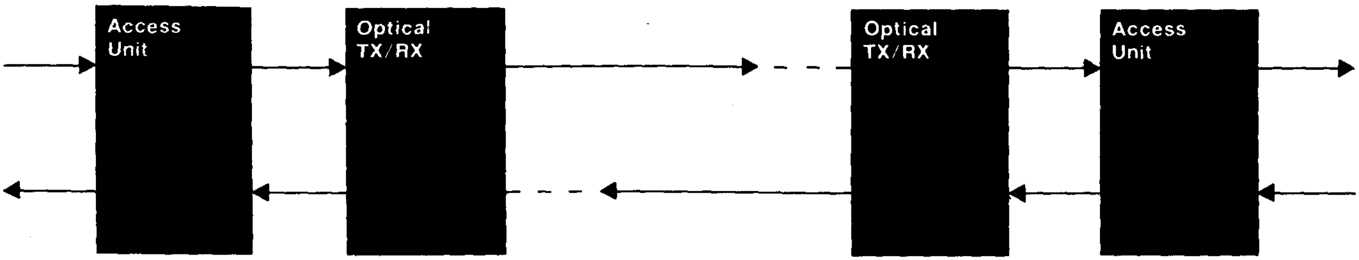
* Asterisks denote the potential for significant economies of scale by combining requirements

Figure 3
Long Haul — Cable



Speeds:	up to 280 Mb/s
Distance:	up to 4000 miles
Repeater Spacing:	1.15 miles

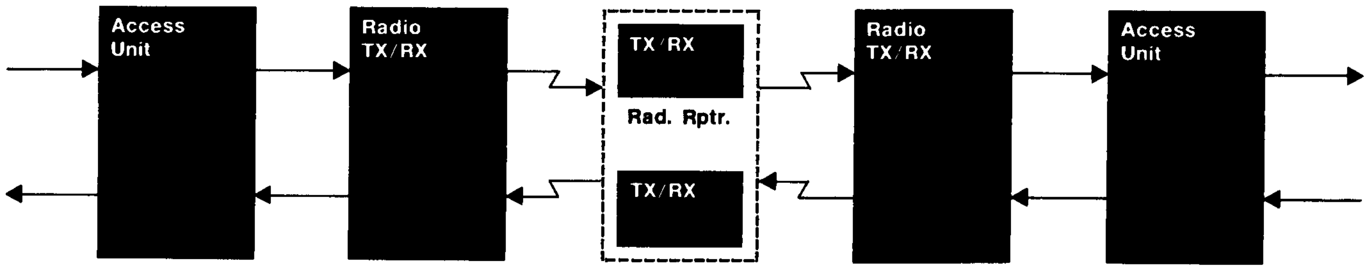
Figure 4
Short Haul — Optical (non-coherent)



Speeds:	up to 250 kb/s
Distance:	approx. .5 mile
Repeater Spacing:	not generally feasible to repeater

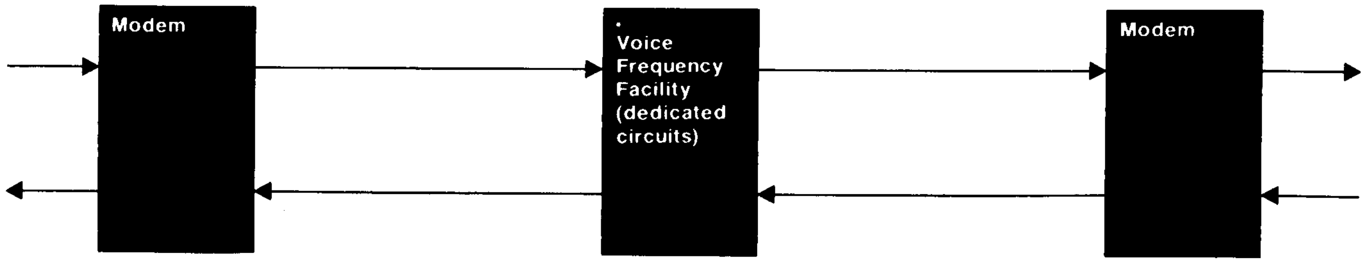
* Asterisk denotes the potential for significant economies of scale by combining requirements.

Figure 5
Short-, Medium- and Long-Haul — Radio



	2-10 GHz	above 10 GHz
Speeds:	up to 20 Mb/s	up to 300 Mb/s
Distance:	up to 4000 miles	up to 4000 miles
Repeater Spacing:	up to 25 miles	up to 6 miles

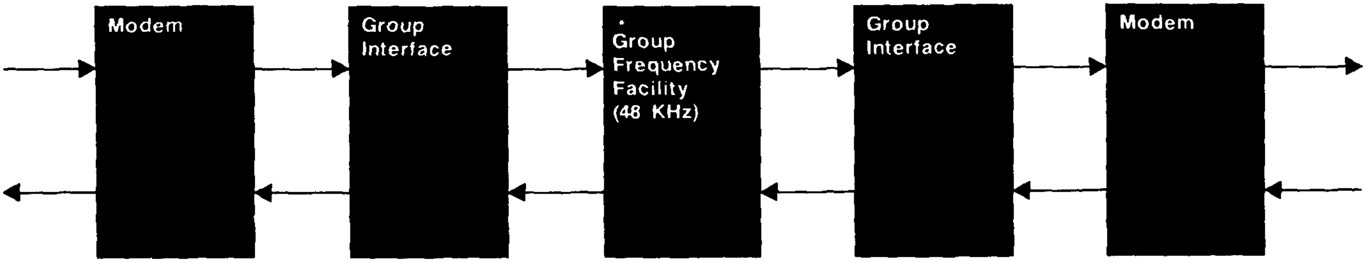
Figure 6
Non-Regenerative Transmission Systems
(regenerative capabilities may be inserted, if required)
Low-Speed Systems



Speeds: up to 7.2 kb/s
Distance: up to 4000 miles

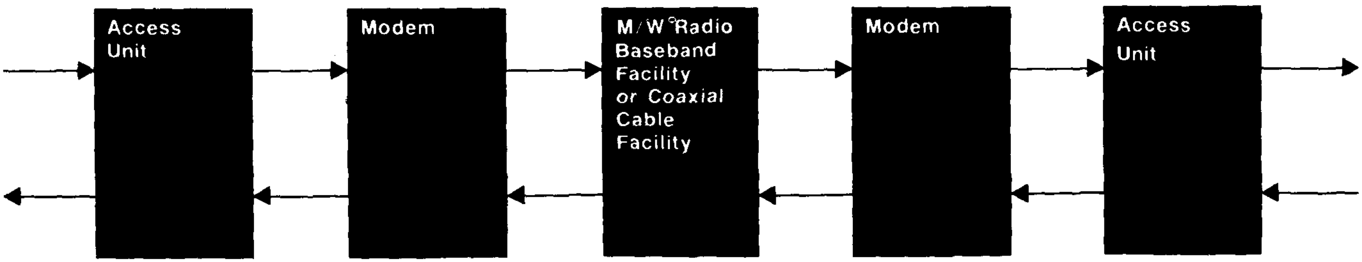
•
Asterisk denotes the potential for significant economies of scale by combining requirements.

Figure 7
Medium-Speed Systems



Speeds: up to 48 kb/s (a similar supergroup arrangement can handle approximately 300 kb/s)
Distance: up to 4000 miles

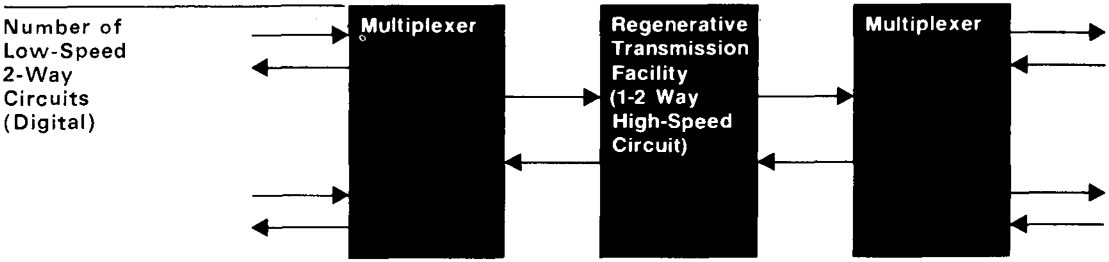
Figure 8
High-Speed Systems



Speeds: up to 19 Mb/s
Distance: up to 4000 miles

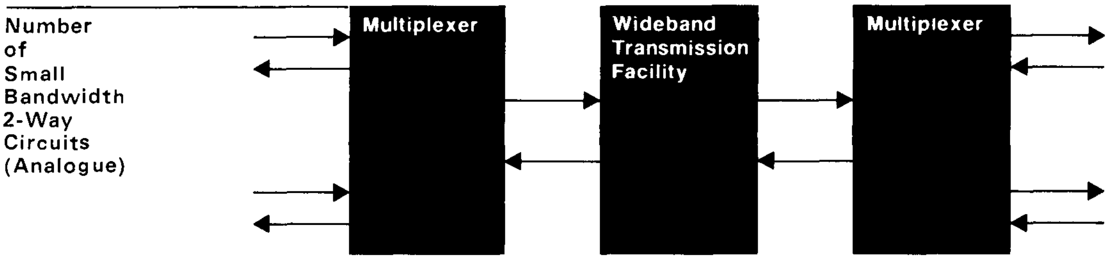
* Asterisk denotes the potential for significant economies of scale by combining requirements.

Figure 9
Time-Division Multiplex Systems



Operating Speeds:
Can be configured to provide any combination required and is considered a pure multiplexer when the higher speed section can accommodate all the low-speed ports operating simultaneously at their maximum speeds. If some blocking occurs under these conditions the device becomes a concentrator rather than a pure multiplexer. Alternatively, the ability to store input information until output capability is available gives it the characteristics of a store-and-forward device.

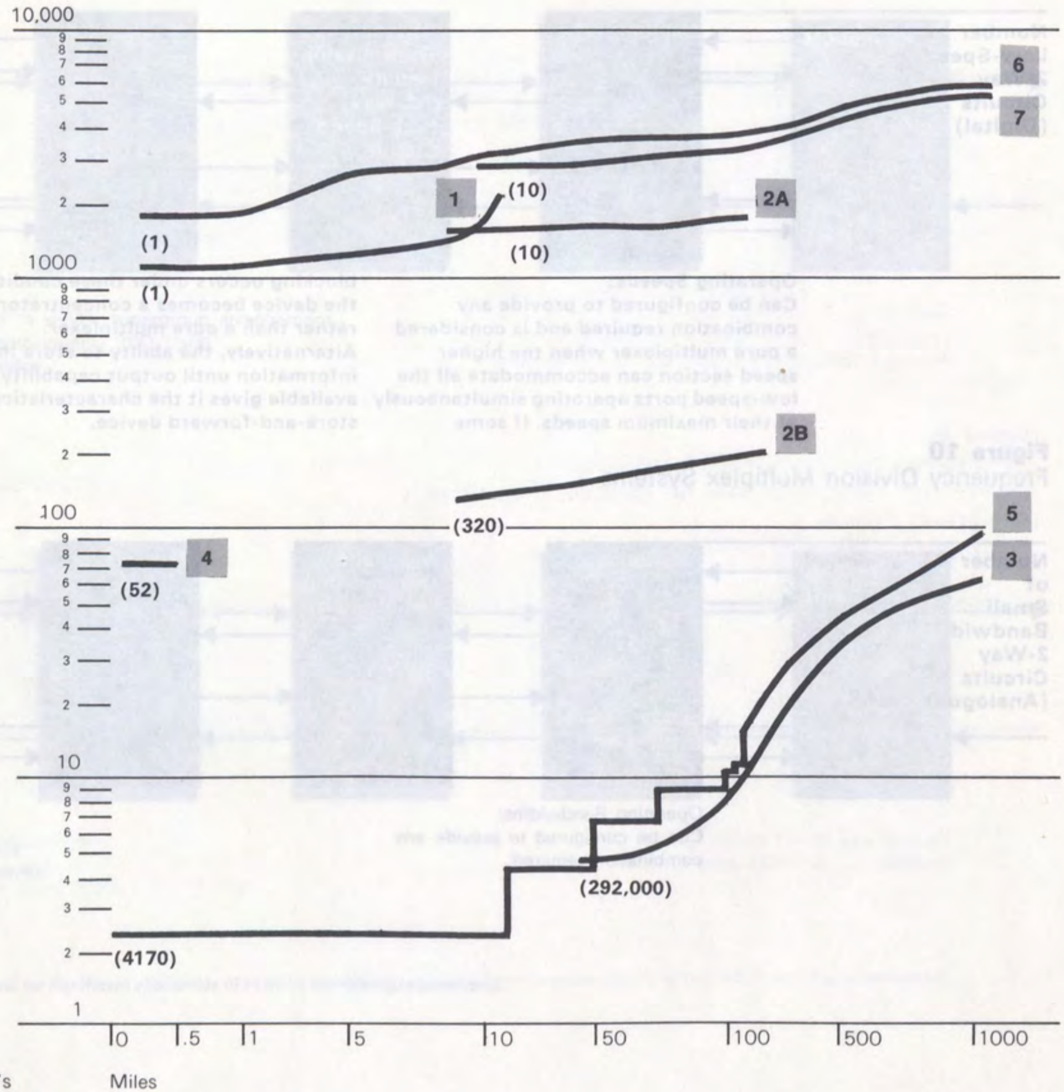
Figure 10
Frequency Division Multiplex Systems



Operating Bandwidths:
Can be configured to provide any combination required

Figure 11
Instrumentality Costs

See Section 5 for interpretation and identification of figures



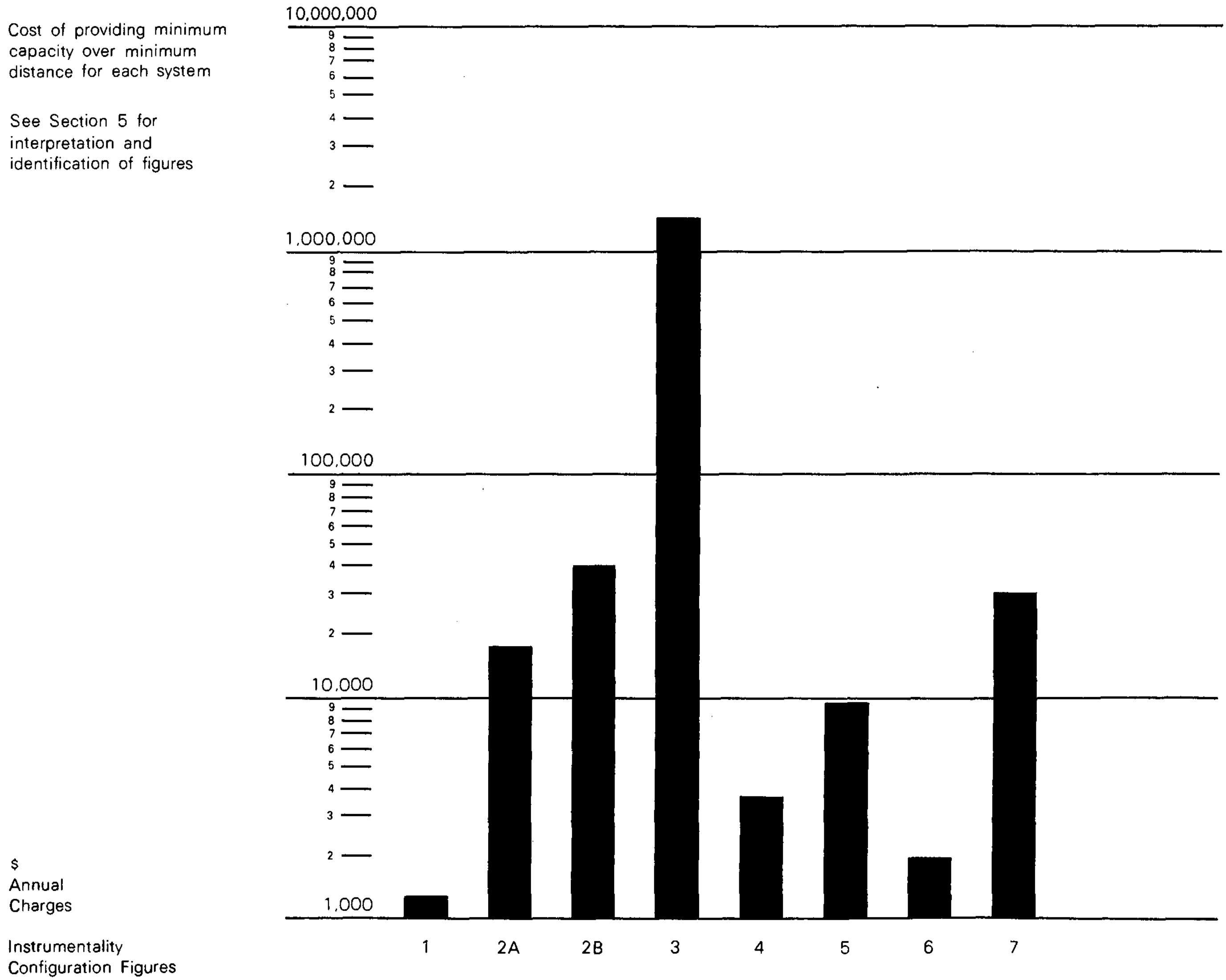
$/48 kb/s Annual Charges

Legend
☐ Configuration Fig #
( ) Capacity of system in 48 kb/s

Figure 12
Minimum System Costs

Cost of providing minimum capacity over minimum distance for each system

See Section 5 for interpretation and identification of figures



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12 Computer/Communications Network Study

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June, 1972

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Introduction

Data communications in Canada are in their infancy. There are indications, however, that requirements for their services will increase rapidly in the near future.

Among the many problems to be faced in Canada is the choice or choices of the form of the network interconnecting the customers. This report reviews the most commonly used (or proposed) types of network, and compares the merits of each. A proposal is made regarding the form of network best suited to such peculiar constraints existing in Canada as geography, computer/communications needs, traffic growth, and traffic patterns.

The need for compatibility with external networks is considered. In general, precise recommendations are not possible because data network plans are evolving rapidly. The report does include, however, a review of the present plans for networks in North America and in Europe.

For the orderly evolution of an integrated data network, agreement between business machine manufacturers, and their co-operation with the common carriers will be required. This hopefully will establish a uniform communications protocol suitable to the user.

This standardization process, combined with decreasing cost of digital logic and memory components will produce less expensive data communications services and more cost effective and cheaper data terminals. Thus, wider user acceptance is assured.

1. The (Canadian) Environment for Computer/Communications

To give the background for the other parts of this report, this section will attempt to define the external parameters. Since such things as economics, geography, and traffic volume influence the shape of communications networks, an attempt will be made to develop information in this section.

(a) What is Computer/Communications?

For the context of this report, computer/communications has been understood to mean business-machine-to-business-machine communications. The business machine may have stored program control (*i.e.*, a computer) or it may be a hard-wired terminal (*e.g.*, a remote printer, or a keyboard terminal).

(b) Who Needs Computer/Communications?

Before 1960, data communications were mainly between keyboard devices. The 1960's saw a rise in communications between this type of terminal and business data processing systems. The first systems were private in-house systems in universities and large research establishments; lately the public systems, serving a variety of interests, have become more and more important. The shift from the private to public system also brought about the increased use of the voice communications network for data communications.(2,35)*

Most of the terminal equipment used in these systems was either previously available (*e.g.*, Teletypes) or was an adaptation of the existing equipment to user's communications requirements. The 1970's will probably require user terminal equipment which cannot be satisfactorily driven at low terminal speeds such as thirty characters per second; data terminals like graphic Cathode Ray Tube (CRT) displays need equivalent data burst speeds of 50 kb/s or possibly higher. With decreasing costs of logic components and data storage modules, special-purpose processors are conceivable within the user data terminals.

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* Boldface numbers in parentheses refer to items in Bibliography.

These tend to reduce the upper bound on line capability requirement *so that most likely the preferred bit transmission speeds will be within the 100 to 10,000 b/s range*. Especially at the upper limit, traffic from any one terminal will be very "bursty" because of the human response time to the information presented by the terminal.

In addition to the low-speed keyboard terminals currently used mainly for time-sharing applications, the business machines and the network will therefore also have to be capable of handling this higher-speed bursty traffic efficiently. Applications which fall into this latter category are defined as "transaction" oriented since each exchange of data bursts between the business machine and a terminal is similar to a business transaction.(4,5,34)

The preliminary growth-rates on Canadian data communications, as compiled by the Canadian Computer/Communications Task Force of the Department of Communications, also seem to indicate that the highest growth-rates for data communications are within the above-mentioned areas. Data transfer in medium-speed remote batch applications and other similar services is usually reasonably continuous at rates of 2.4 to 10 kb/s. The growth-rate in this area is less spectacular, mainly because of higher relative unit costs of mechanical devices like printers, etc. associated with such stations. It also is often cheaper and more versatile (for the incremental benefit to cost ratio is very high) to use a small local stand-alone data processor instead of the station controller plus associated facilities and data communications equipment. This obviously has a negative effect on the growth-rate of data communications in the area of remote batch-processing.

(c) Geographical and Other Considerations

Most of Canada's population is concentrated along a fairly narrow corridor of land along the U.S. border. Most trade, transportation, and communications are therefore along an east/west axis with access routes from north and south wherever the need exists.

Because of the trend to cheaper small-scale digital computing equipment, the super-large data processing system stretching its low-speed data communications tentacles across the land will probably not evolve. Rather the growth pattern for the data communications system will follow these three steps:

- As the data processing penetration increases there will be nodal concentration of low-speed traffic through multiplexing — concentrating techniques.
- Load increases at specific nodes will then cause a swing to more efficient software concentration or paralleled multiplexing arrangements. In particular, the growth of distributed data bases will force the development of software-controlled nodal processors which do most of the local data base management falling back on the main processor only occasionally (as, *e.g.*, when there is a need for vast amounts of data processing).
- Finally, the small nodal processor will be replaced by a full-size main processor able to handle much greater traffic volumes while retaining the capability for shared data base management.

At present, few standards on computer services exist; hence initially the communications network may become a collection of sub-networks in the various stages of evolution outlined above. Standardization of external and internal software characteristics, software communications procedures, data-base formats, etc. will permit development of a single homogeneous network. Thus with an increase in the number of users a Canadian data communications network could emerge by the late 1970's similar to the voice network. As with the present voice network, the major costs of the data network will be in the local distribution and switching functions.

Forecasts of expected growth suggest that by 1980, between 3 and 5 percent of the total communications network terminals in Canada will be used for data communications. A similar forecast for the United Kingdom indicates that in 1983 the data transmission requirement (on a bits/second basis) will be about 5 percent of the voice transmission need.

2. Communications Network Considerations

This section deals with the network elements as they are currently available, or planned for the future. Emphasis is placed on those elements which have significant bearing on data communications.

(a) Topology

Communications networks in their simplest form are either of the star or the ring type. The present-day communications plant layout is of the star type, with dedicated wire facilities between the subscriber (*e.g.*, telephone) and the serving communications centre (*e.g.*, central office). The main advantages of this layout are its reliability (a break in any one loop affects only a single subscriber) and the concentration of the more complex equipment (*e.g.*, voice switcher) at the node (see Appendix, Figure 5a).

In the ring type of network,(8,9,10,33) the switching or multiplexing of all users on the ring is of the distributed form. Each user has sufficient logic associated with his terminal equipment to extract information destined for him, from the common bus. Obviously, logic or power failure at a user terminal, or a break in the ring, can have serious effects on all other users of this ring. Because of the higher complexity, the user terminals in the ring structure presumably also have higher associated maintenance costs (or they must be of higher reliability and thus higher initial cost) than a terminal in the star structure (see Appendix, Figure 5b).

In the case of the star used in modern communications, most transmission circuits are usually laid out with both directions of transmission on the same route, *e.g.*, under the same cable sheath. The ring type of topology would have propagated probably an unidirectional mode for transmission between nodes.

At the higher levels of the voice communications network, where carrier systems are normally used for transmisssion between nodes, the fundamental star structure is maintained, but with modifications.

Interconnections are permitted between nodes at the same level or, between different levels in the network according to certain algorithms or rules. The star configuration therefore becomes partially converted to a third functional type of configuration called the distributed network (or interconnected grid) (see Appendix, Figure 5c).(18)

These cross-connection links prevent failure or congestion at nodes and provide for alternative routing of traffic. By choice of the appropriate algorithm, the introduction of cross-links according to this algorithm, the general network or appropriate sub-networks (such as private networks) may be configured to cater to almost any need. Sub-networks are usually operated in an optimal mode when all links are designed to the same standard of performance.

Hardware implementation of the nodes adds a further dimension to the configuration of the network. This aspect will be discussed later.

(b) Transmission

The baseband signals and the facilities over which they are transmitted can both be classified either continuously variable (*i.e.*, analogue) or finite n-state (*i.e.*, digital). If the baseband signal is classified differently from the transmission facility, then the signal must be encoded. The Pulse Coded Modulation (PCM) encoder, for example, encodes an analogue signal, converting it to a digital format. The usual data modem encodes a digital baseband signal (usually two-state or binary) into an analogue form.

When the distance to be traversed by the signals becomes appreciable it becomes more economic to multiplex a number of baseband signals onto one carrier facility usually by frequency-division or by time-division techniques.

Most multiplex transmission systems used today are of the analogue type. This comes about for two historic reasons. First, the signals to be transmitted were mostly analogue (*i.e.*, voice). Second, up to recent times digital technology was more expensive. However, with the advent of large-scale integration of non-linear semiconductor switching devices, digital technology became a viable entity. Digital techniques promise cheaper and more reliable transmission of data. Savings appear to be possible for both voice and data by integrating the multiplex and switching capabilities into a common digital processor.

Figure 1 shows the digital hierarchy proposed by the Bell System. The transmission rate of 1.544 Mb/s at the lowest level of interconnection (*i.e.*, DSX-1) has been accepted as a standard within North America. The second level (DSX-2) has been accepted in the United States but has not been adopted in Canada. The higher levels (DSX-3 and DSX-4) are currently being discussed.

Also shown in Figure 1 are the various types of services which the digital systems are planned to support and the manner in which they are fitted into the digital scheme.

Digital channel availability in Canada is currently restricted to the T1 PCM type facility. However, other facilities are planned or are at the prototype stage. These will become available in the 1973/75 time frame. A coaxial cable facility at the DSX-4 level is under development (Northern Electric Company Ltd.'s LD-4 Facility). Digital radio terminals operating at 20 and 30 Mb/s are also available (*e.g.*, Collins and Marconi terminals) but have not yet been approved for licensing. Exploratory work is also underway at Bell.Northern Research to investigate the capacity and propagation characteristics of digital systems operating at frequencies higher than 10 GHz.

At the present time, data is transmitted over digital facilities of the T1 type only. The following transmission modes are used:

- (i) By use of an analogue voice band data modem, digital data are first transformed into an analogue signal which is then sampled and transmitted over the ordinary message channel bank (this can be used for data rates up to 4800 b/s). The ratio of data bits to bits transmitted over the T1 facility equivalent voice channel (or the "bit efficiency") is therefore in the order of 8 percent.
- (ii) The digital signal is sampled directly at a high rate, before transmission. To limit distortion, each bit is sampled at least ten times. An example of this is the Philips/Lynch B310/B317 PCM channel bank which has a maximum data rate capacity of 800 b/s per data channel, with seven of these data channels per equivalent voice channel. The "bit efficiency" for this type of process is in the order of 9 percent.
- (iii) The digital signal is encoded. Each data bit is encoded into three to five line bits, to eliminate the need for absolute timing throughout the system. Encoding is more efficient, but considerably more expensive than sampling. "Bit efficiency" for this encoding is in the order of 30 percent.

Neither of these three transmission modes makes use of the full bit transmission capacity of the facility. Obviously, maximum use of the facility would occur, if each data bit could be encoded into a single bit on the digital transmission facility (T1 line). We can, therefore, postulate a further option for the transmission of data over digital transmission lines:

- (iv) If each data bit corresponds to a single bit on the digital facility, then timing information for the data bit stream has to be implicit, or in other words, the whole system has to be synchronous, since there exists no capability to encode data stream timing information onto the digital facility.

In terms of an equivalent voice channel in a PCM system this means that seven bits out of each eight-bit PCM word, 8000 times per second, are used for data. This gives an aggregate line rate of 56 kb/s. The "bit efficiency" as defined above is now in the order of 85 percent. In this data environment the eighth bit in the PCM word is used for supervision internal to the transmission system. Lower data rates (*e.g.*, 2.4, 4.8, or 9.6 kb/s), which are more common in today's environment, can be accommodated by use of a synchronous sub-multiplexer. Thus, for example, a single equivalent voice channel would be able to carry twenty channels at 2.4 kb/s instead of one at present in the analogue environment. Since this sub-multiplexer requires some bit capacity for housekeeping, "bit efficiency" in this instance drops to 75 percent.

Synchronism between the digital lines will also be required if data is transmitted in this mode over a number of these digital links in tandem. As this is the case in a general environment, the whole digital network must then be a synchronous one.

(c) Switching

Switching is generally required at a network node. Today this function is accomplished through a space-division switch. All channels are normally switched at an analogue baseband level, and the same channel is used for both internode communication signalling and information flow.

At present, connection times on the voice switched-network can be up to thirty seconds. This should be improved, especially when one considers the use of the switched-network for data. Maximum end-to-end connection times in the order of three seconds are aimed at for the voice network. One technique to accomplish this is to separate the internode switching control and supervisory signals from the information channels and place them on a common channel. This mode of operation is normally referred to as CCIS (Common Channel Interoffice Signalling); CCITT No. 6 signalling is a special example of CCIS. Unfortunately, however, switching machines with this capability will not be available until 1975.

One of the main disadvantages of the telephone switched-network from the standpoint of data, is the inefficient use of the channel where the actual data load is light, but the connection is held for long periods. This aspect can be overcome by using a store-and-forward type of switching at the nodal points. A large number of logical channels are derived from a smaller number of real channels. Channel blocking is resolved by storing the digital information until a channel becomes available. This mode of switching assumes that a variable time delay can be tolerated. It should be noted that blocking in the switching system can still occur because of a lack of storage space. This only occurs when the outgoing channels cannot absorb all the information which the switch receives from its incoming channels. For a properly designed switch this is a phenomenon which is extremely rare, and it occurs usually only when outgoing channels are blocked (for reasons such as channel failure).

A store-and-forward switch may operate in either of two ways. The total message may be stored-and-forwarded or the message may be broken down into discrete fixed length packets with packet switching. In the latter case, the information is both time and space limited; the switch passes the message segment at the expiry of a short time interval (stuffing the unused spaces) or when the pre-assigned storage space is full. The total-message switch, on the other hand, is only space-limited.

As indicated earlier, the digital multiplexing of channels leads to hardware development programs in the direction of the fully integrated digital switch. In an analogue voice environment, this unit is expected to do A/D and D/A conversion for each channel, signal extraction, and multiplexing of channels to the T1 level, as well as switching.

In a digital environment, digital switching will switch equivalent digitized voice channels without A/D or D/A conversion. Hence, such systems will be very well suited to digital data circuit switching.

These digital switches will be interconnected through digital transmission facilities and will operate under CCIS. Although exploratory development of these machines is currently taking place, they will not become operational before 1975, and will probably not be in service in significant numbers before 1980.

(d) Distribution

Present local distribution plant is reliable and relatively inexpensive on a per-unit basis. From an overall communications system point of view, the highest percentage of investment is in this area. A variety of other schemes, such as rings, are therefore under study to set up a cheaper and more versatile distribution system which would also easily cater to such wideband signals which visual services, for example, require. The present wire-pair plant has sufficient capability to support data services up to the 20 to 50 kb/s range, and if care is taken in the engineering of the service, much higher rates can be accommodated at higher cost. No conclusions in these studies on alternate forms of the distribution plant have been reached, and effects of any changes from the present mode of distribution will not be widely felt before at least 1980.

e) Data Transmission Considerations

Modems are currently used to transform the digital data signal from a data terminal into analogue form suitable for transmission over the analogue voice communications network. At the receiving end, conversion from the analogue signal to the digital signal is again made by the modem.

The most significant impairments to voice-grade transmission channels are known and they are used to specify the quality of the voice-grade transmission channel:

- Attenuation distortion (amplitude characteristic)
- Envelope delay distortion
- Signal-to-noise ratio
- Impluse noise.

Network design, maintenance, and tariff among others are all based on these specifications. However, other parameters, which on existing equipment are normally insignificant for voice transmission, and are therefore not incorporated in the voice channel specification, may have significant influence on data transmission. Some of the major ones are:

- Phase jitter
- Non-linear distortion
- Time variations in the impulse response
- Phase hits (abrupt changes in phase)
- Impulse noise
- Carrier frequency error.

Although a specification for impulse noise exists, it is somewhat incomplete in that nothing is stated about the relationship between impulse energy and the duration of the pulses. Also, no commonly agreed upon method of introducing specified impulse noise parameters into a channel model exists. For these reasons it has also been included in this second set of parameters.

Most of the latter impairments are due to equipment of older design; specifically, phase jitter, phase hits and impulse noise are very much lower in equipment designed and built since 1965. However, replacement of equipment in the field from the pre-data transmission period will require time and capital.

Because of the large number of channels in the network and the statistical nature of these channels, performance specifications are normally expressed in terms of a statistical distribution. There exists an intimate relationship between all of these channel impairments and modem performance parameters, such as modem speed, error rate, and price. Any modem design is therefore a compromise, to minimize the influence of impairments. (For this reason, the common carriers specify such things as error performance only on common-carrier supplied modems.) The preferred modulation method in relation to data rate and other parameters is shown in Table 1.

North American Bell System standards and/or CCITT recommendations exist for modems with data rates up to 2400 b/s such that modems of different manufacturers can interwork. Above 2400 b/s standardization has not yet occurred and modem users may run the risk of having non-compatible modems at both ends of a data circuit in a switched-network environment. This can be a severe problem to both common carriers and users.

In contrast to the above prices, the four-wire digital subscriber loop, where the digital data signal is transmitted as a baseband signal, can accommodate rates up to 10,000 b/s at a projected price of $1,000 to $1,500. The digital loop must work into a fully digital network to be fully cost effective. If loop lengths are greater than four to six miles then digital repeaters must be used.

(f) Error Measurements on Present Networks

As the effect of impairments on digital data is quite different than on voice channels, several telephone and telegraph administrations have made measurements to evaluate error performance on their networks. Results of tests on the Telex network have been documented in the Bibliography (35,67,68) and the most probable error rate is one in 10^5 bits (or equivalently five in 10^5 characters using CCITT No. 2 alphabet).

For error rates on the public telephone network the results indicated below were obtained by several administrations based on measurements procedures as close as possible to the CCITT guide-lines(17). Results are summarized in Table 2.

Table 1
Data Transmission on Voice-Band Analogue Channels

Data Rate b/s	Mode	Modulation Method	Use	Ease	Approximate Market Price (U.S.) $	Comments
1200	2-wire	frequency shift keyed	switched network	easy	$ 440–1,200	full duplex to 300 b/s half-duplex to 1200 b/s
2400	2-wire	phase shift keyed	switched network	easy	$2,500	4-level, half-duplex (or full duplex or 4-wire private line)
4800	4-wire	PSK or VSB-AM	private line	generally workable	$ 6,500–10,000	4–8 level with adaptive equalizer
9600	4-wire	VSB-AM or PSK	private line	some difficulty	$10,000–15,000	8–16 level with adaptive equalizer

Table 2
Summary of Error Performance

Source	Rate kb/s	Bit Errors	Block Length Bits	Block Errors	Circuit Length	Remarks	Reference
U.S. Military	4.8 9.6	$1 * 10^{-5}$ $1 * 10^{-5}$			1000 to 5300 miles	Private line, some links troposcatter	31
Bell System	0.3 1.2 2.0 3.6 4.8	$1 * 10^{-5}$, 95% of time $1 * 10^{-5}$, 82% of time $1 * 10^{-5}$, 82% of time lower lower	 1000 1000 1000 1000	better than $1 * 10^{-2}$		Switched-network	11 12
Federal Republic of Germany	0.2 1.2 2.4	$1.5 * 10^{-5}$ $8 * 10^{-5}$ $8 * 10^{-5}$	1024 1025 1024	$4 * 10^{-2}$ $2 * 10^{-2}$ $1 * 10^{-2}$		Switched-network	47
Italy	40.8	10^{-5} to 10^{-6}	500	10^{-4} to 10^{-5}	≤1500 km	Private line; report shows dependence of error rate on time of day	65
U.S.S.R.	72	$2.4 * 10^{-3}$ to $8.1 * 10^{-6}$ average $4.6 * 10^{-4}$			1000 km	Private line	66

3. Existing and Planned Networks

The initial demand for public data services was met by extending the Telex network and the telephone switched-network. These networks, however, were primarily designed for the written and spoken language with its inherent high redundancy, and therefore, could not sufficiently meet the requirements for error performance in data transmission. The set-up time to connect two subscribers, which is insignificant for the original purpose, becomes very large if compared to the time needed to transmit a limited block of data. Hence system operation becomes inefficient. Also, because of the limited bandwidth of the above services, the highest speed available is 2000 b/s. To meet some of these demands, newer services have been introduced in Canada, *e.g.*, Broadband, Multicom and Message-Switching Data System (MSDS). However, since the volume of data traffic is steadily increasing — the growth-rate of 20 percent to 100 percent per annum has been forecast in various countries — new networks are planned to meet the future needs of data traffic.

A brief description of the present state of the newer data networks in Canada and other countries, as well as plans for the future networks, is given below. Further information on some of the networks may be found in the Appendix.

Canada

(a) Trans-Canada Telephone System (TCTS)$_{(1,3)}$:

TCTS offers, or has announced for service, the following data transmission services:

- Dataphone — a data transmission service over regular voice communications channels using modems.
- TWX — the teletypewriter exchange service between low-speed keyboard terminals.
- Multicom is the generic name used to describe three classes of service:
  - (i) Low-speed Multicom provides switched channels with bit rates less than 1200 b/s multiplexed over *dedicated* voice-band inter-city trunks.
  - (ii) Medium-speed Multicom is a four-wire switched and metered service offering, using specially conditioned analogue channels of 4 kHz bandwidth.
  - (iii) High-speed Multicom provides switched wide-band channels of 44 kHz bandwidth. An additional 4 kHz voice co-ordination channel is included in the service.

- Message-switching is available on the Message-Switching Data System (MSDS) to customers on multi-drop private lines or on the TWX network. Maximum data rate is 300 b/s.
- A small-scale private-line digital synchronous network has been announced. Data rates will be 2.4, 4.8, and 9.6 kb/s.
- A variety of other services, such as DATA-FX and private-line service, is also available.

(b) CN/CP Telecommunications: (6)

- Switched and metered service for low-speed keyboard terminals is provided on the Telex network.
- The generic name Broadband is used to describe a service offering four-wire switched and metered analogue channels of 4 kHz bandwidth up to 48 kHz, including a voice co-ordinator channel.
- The TeleNet network provides a store-and-forward message-switching service mainly for low-speed keyboard terminals.
- Private-line service is also available.

U.S.

(a) American Telephone and Telegraph (AT&T): (97)

- Dataphone is the generic name used to describe all data services over the switched analogue system. Data rates up to 50 kb/s are available.
- A nation-wide private-line digital data system will be introduced in 1974. Data rates of 2.4, 4.8, 9.6 and 56 kb/s will be offered on this network.

(b) Western Union: (24,25)

All current Western Union data services such as Telex, Broadband, and the Information Services Computer System will be integrated into the COMMPLANT system. The COMMPLANT system will offer both digital and analogue channels.

(c) Datran: (28,32)

Datran plans to have digital data services available in 1974. Transmission speeds will be 4.8, 9.6, or 14.4 kb/s. Private-line and switched services are planned.

(d) ARPA: (19,20,21,22,23)

The Advanced Research Project Agency (ARPA) has installed an experimental ten-node system using wide-band circuits for transmission, and small computers at the nodes for message-switching of traffic between computers at the ten nodes. This is essentially a private network.

(e) Microwave Communications Inc. (MCI): (28,29)

Private-line inter-city services over analogue channels will be provided by MCI. Various bandwidths are available. MCI does not provide local distribution.

United Kingdom (36,37,43,44,45,55)

- The British Post Office offers data transmission services over the Telex and voice communications networks. Both private-line and switched services are available. Maximum data rates are 2.4 and 1.2 kb/s respectively.
- Because of phenomenal growth predictions, a synchronous digital data network, integrated with current facilities, is planned. Data rates will be 200, 2400, 9600 and 48,000 b/s. It is anticipated that digital switches will provide connect times in the order of 100 msec. Packet switching may be made available on this network if it proves itself to be acceptable.

Germany (48,49,55)

- Currently data services are available on both the Telex and the voice communications network. Maximum data rate offered on the switched-network by the Bundespost is 1200 b/s.
- The Bundespost will introduce Electronic Data Switching (EDS) (50,51,52,53) Exchanges in 1973 in the Telex network. These exchanges will also be used for switched data services at rates of 200, 2400, and 9600 b/s.

France (64,55)

- A switched-network using conditioned channels is used for data transmission at 2.4 and 4.8 kb/s. Data rates up to 200 b/s are supported on the Telex network.
- Hermes is a digital data network planned for 1976. It probably will be integrated with the PCM voice network.

Computer/Communications Network Study

Sweden (54,63)

- At present data traffic is over public telephone and leased lines, using modems with speeds of 200, 600, 1200, 2400 b/s and 40 kb/s.
- A separate future data network with three data switching exchanges is being studied. Concentrators, remotely controlled by these exchanges, will act as feeders between subscribers and exchanges. Isochronous transmission at bit rates of 1200, 2400, 4800 and 9600 b/s will be available, as well as asynchronous at rates up to 300 b/s. Because of the expected under-utilization of the trunk lines in the initial period, only circuit switching was proposed. However, when the number of terminals has increased, and also for interworking on long international data links, packet switching might be introduced.

The synchronization of the network and the envelope structure proposed are the same as the U.K. proposals.

Italy (55)

Data services are available up to 2400 b/s over public telephone-type circuits and up to 200 b/s over the Telex network. Private leased Telex wide-band circuits for 48,000 b/s are also available.

Japan (55)

- A switched data service separated from the public telephone network was to be introduced in June, 1971 with a maximum speed of 1200 b/s.
- Additionally, a calculating service was recently introduced in Tokyo using touch-tone dialling telephones to access a pre-programmed computer. Output from the computer is via a voice answer-back unit.

4. Constraints and Limitations

Because of increasing world trade, and Canada's economic dependence on trade, business communications will become more important during the 1970's. Increases in manpower costs throughout the industrialized world tend to introduce business machines into this environment. Data traffic between business machines will therefore match the national trading pattern.

Consequently, Canada must consider the U.S. as her most important "data communicator", with the European economic bloc second, and other areas of lesser importance.

At present, a number of proposals have been submitted to the CCITT for recommendation for a new world-wide data network. An asynchronous network has been proposed by Germany[48], while France[64], Britain[45], and the AT&T[7] in the U.S. all advocate slightly different forms of a synchronous network. Additionally, in the U.S. a number of other communications networks like Datran[32,28] and MCI[28,29] are in the planning stages.

Since it is highly desirable, from a user's point of view, to access all foreign networks automatically, and through the same network protocol as for the Canadian network, Canada's common carriers will have a major interfacing task with these other networks. From a data communications point of view it therefore seems safest to wait until some of these plans will actually materialize. Since equipment design and data communications network implementation take in the order of five years minimally, waiting at this time may not be acceptable. However, the penalty for immediate action may be an internationally non-compatible network. The proper approach in this matter therefore seems to be to act carefully, and with one's eyes open.

If incompatibilities in the data network are unavoidable, then the choice for the Canadian carriers must be first to satisfy Canadian needs, and second to be as compatible as possible with the U.S. networks, since most international data traffic from Canada will be directed toward these networks.

If the new data networks will be digital in their switching and transmission, and at present this seems to be the direction that most system planners tend towards, then incompatibility is already assured on the basis of the preferred time-division multiplex hierarchy in North America and in Europe.

It is estimated that within the current communications network more capital is invested in local distribution than in either switching or long-haul transmission. Especially for data traffic, digital switching and transmission will make cost savings possible in those areas; a general solution for cost-reduction in the distribution plant is as yet not in sight.

5. Conclusions

Following is a set of conclusions as to the direction in which data communications are headed, due to communications facilities available during the 1970's:

- In a local (non-toll) environment, data rates up to 1200 b/s can probably be transmitted no more cheaply in the future than at present. Present data modem costs, and therefore transmission costs in this data speed range, can only be reduced through increased volume production of these modems. If volume warrants it, the modem in an Integrated Circuit (IC) package may well be feasible during the 1970's. Modem cost reductions in an approximate order of magnitude appear indicated in this case.
- Above data-rates of 2400 b/s a fully digital transmission and distribution scheme seems to offer maximum advantage. Such a network does not exist today. The planning for this network will have to take into consideration the shortcomings of the present mode for data transfer, like high installation and maintenance costs, long circuit connect times, etc. Additional services, like message-switching, will also have to be accommodated easily in this digital network.
- Because of decreasing digital logic costs, the network terminal at the subscriber will be capable of more complex logic functions (*i.e.*, it will be more intelligent). The terminal itself will also become less expensive.
- Small digital communications processors will fulfill specialized control functions within the network, and interfacing functions to the network.
- Data provided by the Canadian Computer/Communications Task Force indicates that data transmission is projected to amount to only 3 to 5 percent of the total of all communications traffic by 1980. Maximum economies of scale can thus only be realized by sharing communications facilities wherever possible.
- Agreement and co-operation will be required in the area of communications protocol between business machine manufacturers, and the business machine manufacturer and communications equipment supplier. An interface processor, specially engineered and programmed, should *not* be required for two business machines of different manufacture to communicate, as it is today. Early standardization of protocol and codes appears to solve this dilemma.
- Field trials, such as the ARPA network and associated theoretical investigations, must be carried out to prove the economic viability of packet switching.
- A trip to Europe (1971) indicated clearly that high growth-rates of data terminals, additional service requirements foreseen in the 1970's, and an over-loaded telephone network exert great pressures towards building new

data networks. Since alternate solutions of data transmission are available in North America today (Dataphone, Multicom, Broadband Exchange), pressures in North America are moving in the direction of providing more economical and reliable networks, rather than meeting many basic needs for the first time.

- This report has examined the technological capabilities of the future and not the array of customer services that will develop when these capabilities become available. Conversely, it has not explored new types of services that can be developed with existing capabilities (*i.e.*, the ARPA network is designed using today's technology). Exploration of future service concepts using existing and developing data network technology is certainly required before a network design is finalized.

In summing up, it appears there exists a chicken-and-egg situation in the data communications area: because of a lack of volume *both* telecommunications services for data from the common carriers, as well as computer user hardware and software needed for telecommunications, are still very expensive. Undoubtedly, with an increase in use the costs per terminal and per connection to the network will decrease. In order to provide a shared-use network, and to reduce costly special arrangements, the common carriers must interface with teleprocessing equipment through a standardized communications interface. The interface protocol may be different for a *finite* number of classes of traffic (*e.g.*, transaction, bulk data transfer, time-sharing); but terminals for similar use must use the same protocol. Early standardization in this area should be the major current goal of the International Standards Organization (ISO) and its associated national standards groups.

Appendix

This appendix includes further information on existing and planned data networks.

1. Canada

(a) Trans-Canada Telephone System (1,2)

In addition to the Dataphone and TWX services, the Trans-Canada Telephone System offers two additional measured-rate data services; High-speed and Medium-speed Multicom, introduced in June, 1970, offer full-duplex four-wire data transmission at speeds of 19.2, 40.8 or 50 kb/s with a separate channel for voice co-ordination. Coast-to-coast connect time is 3.5 seconds maximum.

High-speed Multicom is a six-wire system with three switching centres across Canada: Montreal, Toronto and Calgary. The two-wire voice channel terminates on a No. 5 cross-bar switching machine that in turn controls a slave matrix to connect the four-wire data channel. The wideband subscriber lines are repeatered and the cable pairs equalized. Inter-office transmission uses T1 lines with specialized terminals or wide-band carrier facilities. The transmission is synchronous, although non-synchronous operation can be provided on the basis of a special assembly, *e.g.*, for facsimile.

Medium-speed Multicom, which began operation in December, 1970 is a combination *voice/data* communications system and permits duplex data transmission at speeds of 2400 or 4800 b/s. Higher speeds will become available with the availability of reliable and economical data sets. The maximum coast-to-coast connect time is three seconds.

Medium-speed Multicom is a four-wire service using specially conditioned voice frequency access lines and trunks. To meet Schedule 4B (2), the maximum number of intermediate trunks in tandem is limited to three. There are five switching centres: Vancouver, Calgary, Winnipeg, Toronto and Montreal (see Figure 3). These centres use a modified Western Electric 758C cross-bar switch with common control. Calls will be rerouted automatically, if all trunks between two centres are busy. All 758C switching machines are designed to operate in a polygrid network with all centres being of equal status within the network. Although the highest speed now available is 4.8 kb/s, the system could be adapted to handle 9.6 kb/s. Multicom offers optional features such as: automatic answer in data mode, business machine disconnect, automatic calling, hot-line, etc.

Low-speed Multicom provides low-speed switched channels which are multiplexed over dedicated voice-band inter-city trunks. It will supplement existing special service offerings such as DATA-FX.

Status: Available in 1971.

For low-speed data traffic with signalling rates of less than 300 b/s TCTS offers a private-line data network, which operates on a store-and-forward principle and is called the Message-Switching Data System (MSDS). Groups of terminals are connected via common bus lines in multi-drop configuration to the switching computer. Traffic flows on the principle of polling and is controlled by the central computer, which stores the messages and then forwards them at a suitable time. Priority in handling the message can be provided. At present the average delay for all messages is ninety seconds. Several facilities are provided with the MSDS, such as multiple and group addressing, direct intra-line traffic, etc. A TWX subscriber can also be connected to MSDS multi-station private-line terminals through "accredition". This will also let him use the store-and-forward facility of MSDS to reach other TWX subscribers.

Status: Introduced in 1968.

TCTS plans to introduce a small-scale private-line digital data system in 1971. This will form the basis for evaluating techniques which could be used for a future digital data network in the mid 1970's. The system will provide an isochronous data rate of 2.4, 4.8, or 9.6 kb/s at the customer interface. Circuits will be full duplex with a target bit error rate of one in 10^7 for 95 percent of the time. To achieve the system error objective regenerative repeaters will be used to reshape and retime the signals. The local loop will employ a four-wire digital transmission technique, with loop regenerative repeaters for distances of more than six miles. Long-haul transmission is provided through regenerative facilities on the present radio system.

Status: Initial phase end 1971.

(b) CN/CP Telecommunications(6)

In November, 1967 CN/CP Telecommunications introduced a service called Broadband Exchange Service for handling the transmission of digital data as well as analogue signals. It is designed to enable a subscriber to choose on a call-up basis a four-wire voice co-ordinated channel of 4, 8, 16 or 48 kHz bandwidth. The target connect time on a coast-to-coast call is two seconds (a CN/CP brochure announced a figure of 3.5 seconds).

''Broadband'' is a measured rate circuit switched system, and uses solid-state common control, with dry reed switches making the necessary circuit connections.

Local circuits to subscribers are four-wire circuits, designed for the maximum bandwidth requirement of the subscriber, *e.g.*, a customer with a requirement of 4 kHz will be provided with a circuit with a bandwidth not exceeding 4 kHz. If the customer inadvertently dials a wider bandwidth circuit than that for which his or the called party's circuit is conditioned, then the call is blocked and the customer is advised of his error.

The system consists of four main switching centres located in Montreal, Toronto, Winnipeg and Vancouver (see Figure 2). Subscribers are either connected directly to the switching centre, or via concentrators if located a long distance from a switching centre.

The system provides extra facilities like ''abbreviated kaying'', ''Hot-Line Service'', preset conference service (*i.e.*, preset multiaddressing) and limited access.

Status: Service announced in 1967.
Service introduced in 1968.

CN/CP Telecommunications introduced in the first quarter of 1971 a TeleNet service. This is a computer-controlled store-and-forward message-switching service, and like the MSDS of TCTS provides essentially a private network. The system uses Philips DS-714 computers(56,58,59), located in Toronto and in Montreal.

Subscriber network stations are of three types, depending on the volume of traffic or the grade of service required:

- Class A is a heavy-volume station provided with a dedicated circuit and a dedicated computer port. However, a class A circuit may be shared by more than one station belonging to the same network.
- Class B is a medium-volume station. Computer ports are shared by several subscribers with access via the Telex (50 b/s) or the Data Telex (180 b/s) networks.
- Class C is a light-volume station similar to Class B.

Speed conversion, code translation, multiple addressing, etc. are also provided.

Status: Introduced in 1971.

2. United States of America

(a) American Telephone And Telegraph(7)

AT&T plans to introduce a nation-wide private-line Digital Data System in 1974 independent of the existing private-line and Dataphone services. The data-rates offered will be 2.4, 4.8, 9.6 and 56 kb/s. Unlike Multicom or Dataphone no alternate voice or voice co-ordination channel will be provided. This point-to-point connection will be synchronous. Provision for multi-point service is planned. For the 2.4, 4.8 and 9.6 kb/s channels the byte structure for multiplexing is (6 + 2), *i.e.*, 6 bits customer data + 1 control bit + 1 framing bit, thus the 64 kb/s PCM channel could accommodate twenty channels of 2.4 kb/s or ten channels of 4.8 kb/s or five channels of 9.6 kb/s. The framing bit is needed for sub-multiplexing, while the control bit indicates whether the byte contains customer data or signalling. For the 56 kb/s channel no sub-multiplexer framing bit is needed, and the byte thus consists of 7 bits customer data + 1 control bit. Transmission facilities employed will be digital. The synchronization of this digital system will be accomplished by secondary, highly stable, yet electronically variable crystal clocks. These clocks are controlled by primary timing sources which in turn are phase locked to a single master timing source.

Studies are in progress of various forms of switched data services based on the digital channels with byte structures as described above.

Status: Private-line digital system to be introduced in 1974.

(b) Western Union (24,25,26,27)

Western Union plans to integrate the existing data networks in a new network, the COMMPLANT System. This will accommodate the Telex and TWX networks, as well as the present Western Union's Hot-Line and Broadband services, and the Information Services Computer System (ISCS). Digital asynchronous transmission will be limited to 300 b/s. Above 300 b/s transmission will be synchronous. There will be two kinds of switching networks, one digital and the other analogue. The digital switching network will carry both synchronous up to 9600 b/s and asynchronous traffic, and will be transparent in code and speed. The analogue switching network will be space division and hence can also carry signals of the digital switching network. This analogue switching network will accommodate the Hot-Line and Broadband Services and all higher-speed data. The switching centres will be stored program controlled, and signalling and supervision between centres will be done on separate channels with a modified CCITT No. 6 signalling. The data from local and remote subscribers will be collected via concentrators, which are under the control of the switching centre. The concentrators in conjunction with the switching centre can accept in-band or separate signalling from the subscriber, handle analogue or digital signals, and provide connections through both analogue or digital trunk facilities to the switching centre. This concentrator which has to handle the various types of subscriber terminal employs a space-division matrix.

Status: End of 1971: initial 20 Mb/s digital line New York to Washington, D.C.
1974: digital transmission network, New York to Chicago.

(c) ARPA Network (19,20,21,22,23,18)

The Advanced Research Project Agency or ARPA of the U.S. Department of Defence has an experimental network installed connecting ten ARPA-supported research centres across the U.S. Phase 1 of this project involves ten centres and started in the fall of 1969. This ARPA network is a private network dedicated to scientific information exchange, *i.e.*, mutual access to computer facilities between the ARPA-sponsored research centres (Figure 4). These centres' autonomous computer systems do not communicate directly with one another, but do this via independent switching centres. The initial design idea was for these switching centres, called Interface Message Processors (IMP), to serve one or more computers, the Host-computer(s), as a gateway to access the ARPA transmission network and hence other computers. Local terminals, *e.g.*, teletypes wishing access into the ARPA-net, have to do so via their local Host-computer, hence unnecessary loading of the Host-computer. To overcome this a new node processor was designed; a terminal IMP or Terminal Interface Processor (TIP), which in addition to being an IMP, will provide direct access for up to sixty-four terminals to the ARPA network and any remote Host-computer without the necessity of going through the local Host.

The method of switching is store-and-forward packet switching. A packet consists of a 1000-bit block of data and a twenty-four-bit cyclic checksum. Since the IMP/TIP has to provide temporary storage for a message, the message length per transmission that any Host can send to an IMP/TIP is limited to eight packets. The IMP/TIP's are connected together on a distributed network principle via 50 kb/s common-carrier leased lines (AT&T) by means of modems. The transmission of data from and to the local terminals and the Host-computer takes place in a start-stop mode. The transmission of a message in the network itself is completely under the control of the IMP/TIP's. The Host-computer has no control at all over it. Thus the IMP/TIP network operates autonomously.

The system is speed transparent and uses ASCII eight-bit code. By special use of the ASCII DLE-character it is also made code transparent. The existing nodes use IMP's; the first TIP will be in use around 1971/72. Work on higher-level Host-Host protocol which will provide among others a direct computer-computer exchange of information is still going on.

Status: Phase 1 (experimental) started in 1969.

(d) Datran (28,32)

Data Transmission Company (Datran) is planning to provide switched end-to-end or private-line digital data service. Voice co-ordination if required will be handled through the regular telephone network. Transmission is over digital lines, thus requiring no modems, with error rate of less than 10^{-7} and connect time less than three seconds. The system is circuit-switched, although store-and-forward message-switching might be added at a later date. The transmission speeds offered are 4.8, 9.6, and 14.4 kb/s synchronous and 150 b/s asynchronous. The backbone of the network will be a microwave "pipe" across the U.S. consisting of 4432 channels of 4.8 kb/s each. Channels requiring more than the 4.8 kb/s capacity will be forced by paralleling the appropriate number of 4.8 kb/s channels. At present the plan calls for the network to be fully synchronous. As initially the planned transmission facilities will be under-utilized, Datran will start by installing just one switcher. This will be a time-division switch, with a time-division matrix supplied by Stromberg Carlson and common control equipment by COMTEN. As traffic builds up, more switching centres will be added. In the beginning the same basic 4.8 kb/s synchronous channel facility will be extended to the subscribers' premises and will be used to sample the lower-speed asynchronous subscriber.

Status: FCC Application filed November, 1969.
Pending FCC approval, service is planned to be offered April, 1974.

(e) MCI Network (28,29)

Microwave Communications, Inc. (MCI) will lease private-line point-to-point analogue communications channels to subscribers. Transmission will take place over microwave carrier systems with frequency-division multiplex equipment supplied by Northern Electric Company Ltd. A wide variety of channel bandwidths is available from 200 Hz to 960 kHz and also channels for video and broadcast. Since channels are leased on a one-way basis, two-way asymmetrical transmission is available. However, MCI will not provide local loops, but will give technical assistance to the customer in renting from the local carrier or in providing his own loops, and in connecting and maintaining them. Specially designed carrier channels for data are also available at bit rates of 75 b/s to 19.2 kb/s and error rates of one in 10^7.

Status: FCC approved initial link St-Louis-Chicago in August, 1969 and its modification in January, 1971.

Applications for other routes by MCI and MCI-affiliated companies were filed with the FCC. In view of the FCC ruling in May, 1971, there will be fewer obstacles to obtaining a license. The start of service offerings is indeterminate.

3. United Kingdom (36,37,43,44,45,46,55)

The British Post Office has at present 30,000 data subscribers, and in the next few years is expecting a subscribers' growth-rate of between 50 to 100 percent per annum. The British Post Office proposed a new data network to accommodate this growth-rate, and to support additional data service requirements which they foresee in the 1970's, and which they cannot support on the currently over-loaded voice network. The network will be a synchronous network with either a common clock, or clocks, operating on mutual correlation.

The Post Office will offer the following service bit rates: 600, 2400, 9600 and 48000 b/s; the latter three having an isochronous mode of transmission require a duplex four-wire transmission facility even at the local loops. For low speeds up to 600 b/s the local loop is two-wire and the loop transmission uses the normal mode of modulation, *e.g.*, Frequency Shift Keying (FSK). However, the transmission mode within the system will be isochronous and adjusted to that for the 600 b/s service at the first multiplexer with speed alignment by insertion of idle "envelopes" (see later). This seeming inefficiency in usage is tolerated because of the short distances involved in the U.K. For anisochronous transmission up to 1.2 kb/s (or up to 2.4 kb/s) transition encoding will be used over the 9.6 kb/s service. The connect time within the U.K. is planned to be in the order of 100 msec from customer to customer.

To satisfy the requirement for bit sequence-independence, in-band signalling and speed alignment, the data envelope structure of ten bits is proposed. This envelope consists of 1 synchronizing bit + 1 status bit + 8 bits of customer data. The status bit will be "one" to indicate customer data and "zero" for signalling.

Since the economies offered by packet switching appeared to be small in a network of the size of the U.K., the proposal envisaged a network for circuit switching with provision for packet switching. The switch could be a synchronous time-division switch combined with space-division switch, *e.g.*, at a concentrator. The time-division switch will operate at the envelope level. In a packet-switching mode, the maximum length of a data packet including header (*i.e.*, destination and source address, type, etc.) is approximately 1000 bits.

Plans for the first phase call for some twenty Data Switching Exchanges with each serving an area of approximately fifty miles and an average line distance of fifteen miles. The line transmission rate at the primary level between Data Switching Exchanges will be the primary European CEPT standard of 2.048 Mb/s.

Status: Planning stage, first experimental model to appear in 1973/74. Experiments on packet switching at National Physical Laboratories.(38,39,40,41,42)

4. Federal Republic of Germany (48,49,50,51,52,53)

The German Post Office (Bundespost) proposed to introduce an Electronic Data Switching (EDS) system in 1973/74. EDS was conceived as a switch for low-speed data and designed to replace the obsolescent switching equipment of the German Telex network with its approximately 90,000 subscribers. The EDS system, however, is capable of handling a small amount of higher-speed data to 9.6 kb/s, and hence forms the basis of the new German Data Network, which will integrate the existing Telex, Datex, and Gentex systems. Switching systems for higher-speed data are in development.

The German Post Office planned to introduce service rates of up to 200, 2400 and 9600 b/s. The delay through an EDS centre is in the order of 100 msec and through a concentrator 200 to 300 msec. The minimum connect time is approximately 100 msec for two local subscribers directly connected to an EDS centre and can be as high as three seconds for a long distance connection of a subscriber with low-speed in-band signalling. The EDS system operates like a circuit-switched system by detecting the polarity reversals on the incoming lines and transmitting these transitions to the outgoing ones.

Because of the relatively lower speeds of the data as compared to the switching capability of the EDS the switch operates in an asynchronous mode. A store-and-forward facility for message-switching can be provided. In low-density subscriber areas, data traffic will be collected by space-division switching matrix concentrators, and connected through to the serving EDS centre. These concentrators will be fully remote-controlled by the EDS centre.

Initially transmission between EDS centres will use modems over the standardized frequency bands of existing Frequency-Division Multiplexing (FDM) carrier systems. Transmission over PCM channels is also envisioned for the future. For low-speed subscriber loops of up to 200 b/s a Standard Electric-Lorenz FSK-type modem is used which allows full-duplex operation over one pair. Higher-speed subscriber loops will probably be served by a digital baseband technique.

Facilities for multiaddressing, abbreviated dialling, speed and code conversions, etc. are planned.

Status: Trial operation in 1970/71.
Expected date of Telex service 1973/74.

5. France(55,64)

Present data traffic is over the general telephone-switched and Telex-switched networks. A new 200 b/s Telex service has been introduced.

A special telephone-type network (Caducée network) for data service using cross-bar switches and special quality transmission circuits will be introduced by the end of 1971. This supports a transmission rate of up to 2400 b/s or to 4800 b/s. Wideband circuits (capable of transmitting rates up to 50 kb/s) are for the present confined to communications within one town.

Another network for data transmission, "Hermes", is in the planning stage. This network will be closely associated to a new (still in development) time-division switched telephone network, the E1 telephone system. The service rates to be offered will be from 50 b/s to 56 kb/s on a circuit switched basis with provision for packet switching. The data network will be using part of the E1 telephone transmission and switching system. Because of this, the data structure is of two kinds:

- For a channel using the PCM voice channel each envelope byte will be eight bits ("octet") consisting of one status bit and seven data bits. Hence the data-rate will be 7/8 X 64 kb/s = 56 kb/s. However because of stuffing requirements, *i.e.*, alignment by insertion of idle envelope, the effective data-rate will be slightly less than 56 kb/s. Switching of these channels (first-level switch) will occur in equipment identical to the telephone switch E1.
- For data of lower speeds, the structure of the envelope byte is similar to the U.K. proposal, *i.e.*, (8 + 2) bits. Switching of these channels occurs at a second-level switch after passing through the first-level switch and multiplexing and demultiplexing operations.

Status: Hermes planned for 1976.

Figure 1
Digital Hierarchy

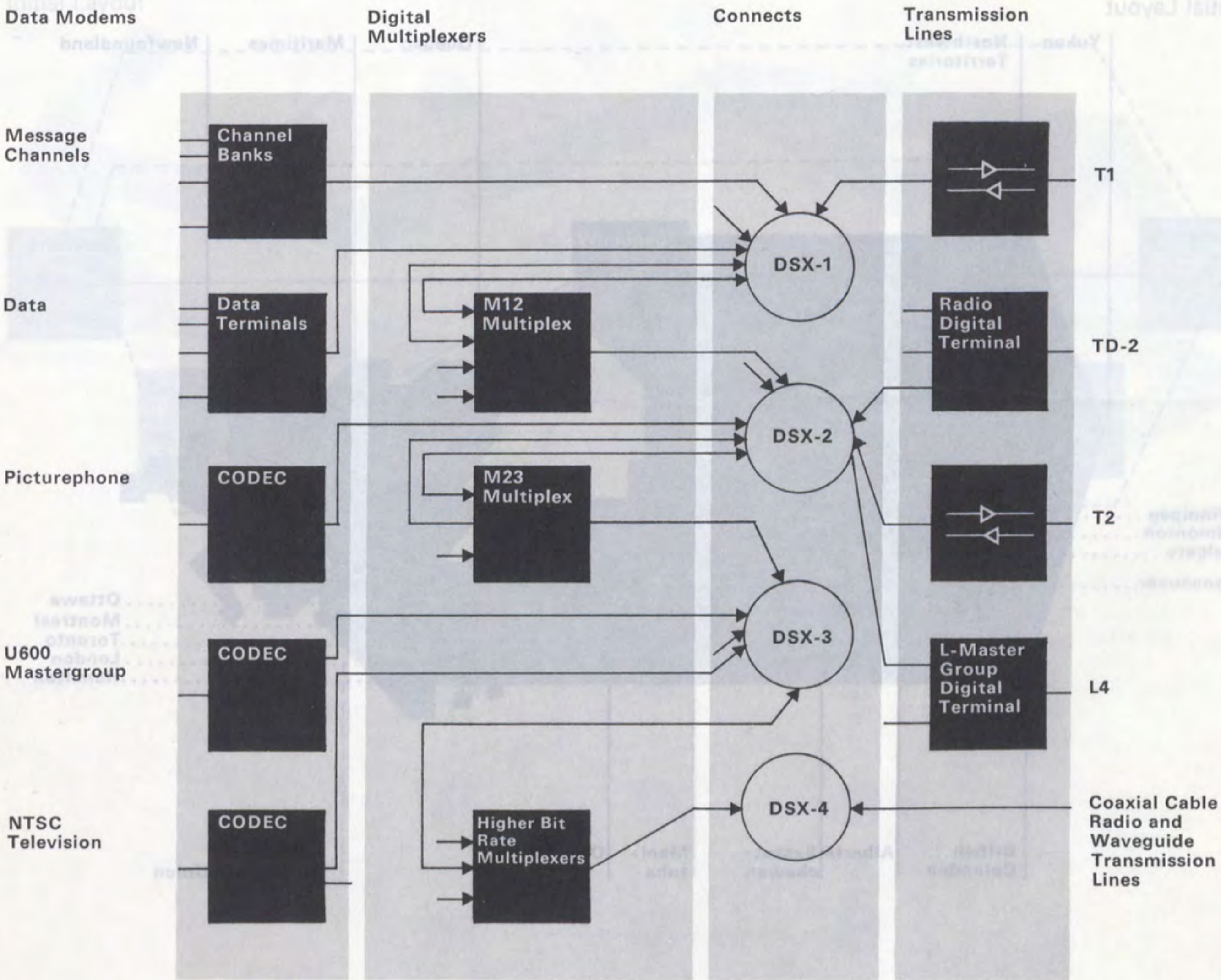


Figure 2
CN/CP Telecommunications
Broadband Exchange Service
Initial Layout

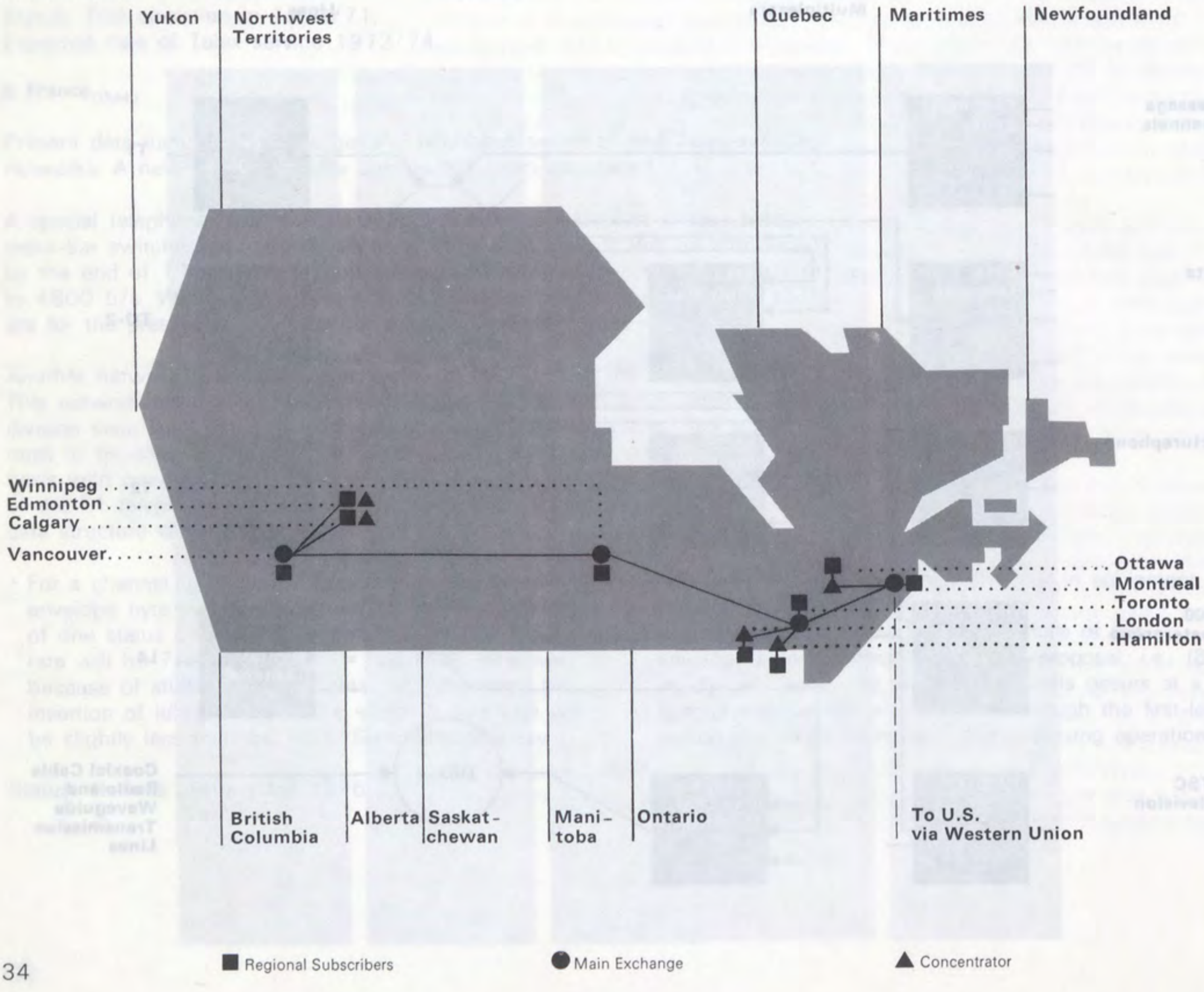


Figure 3
TCTS
Multicom Network
Initial Layout

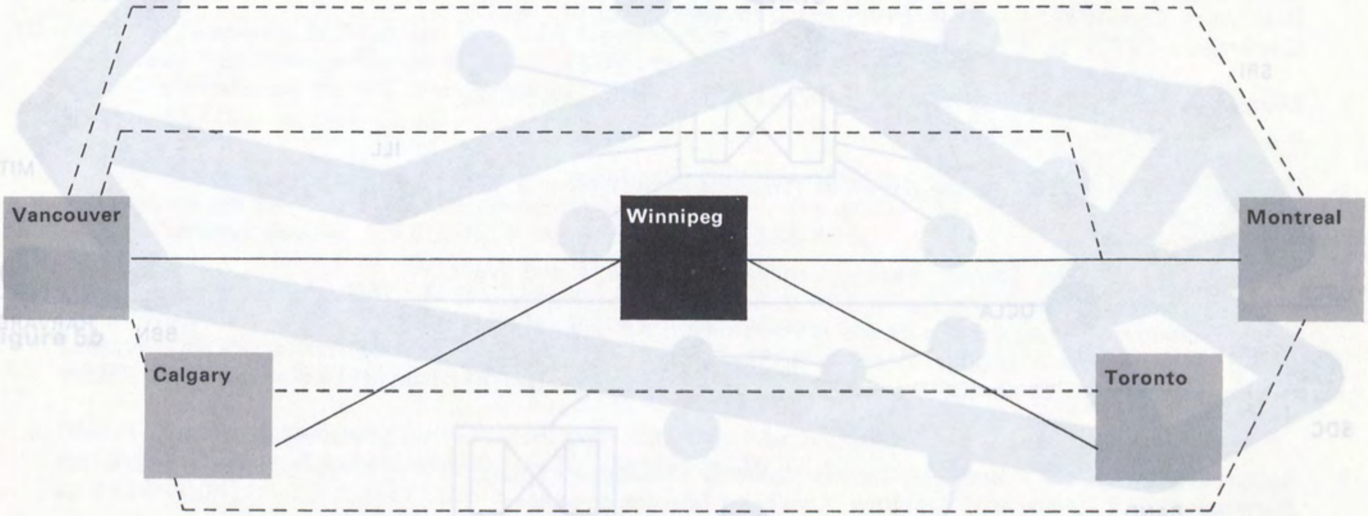


Figure 4
ARPA Network

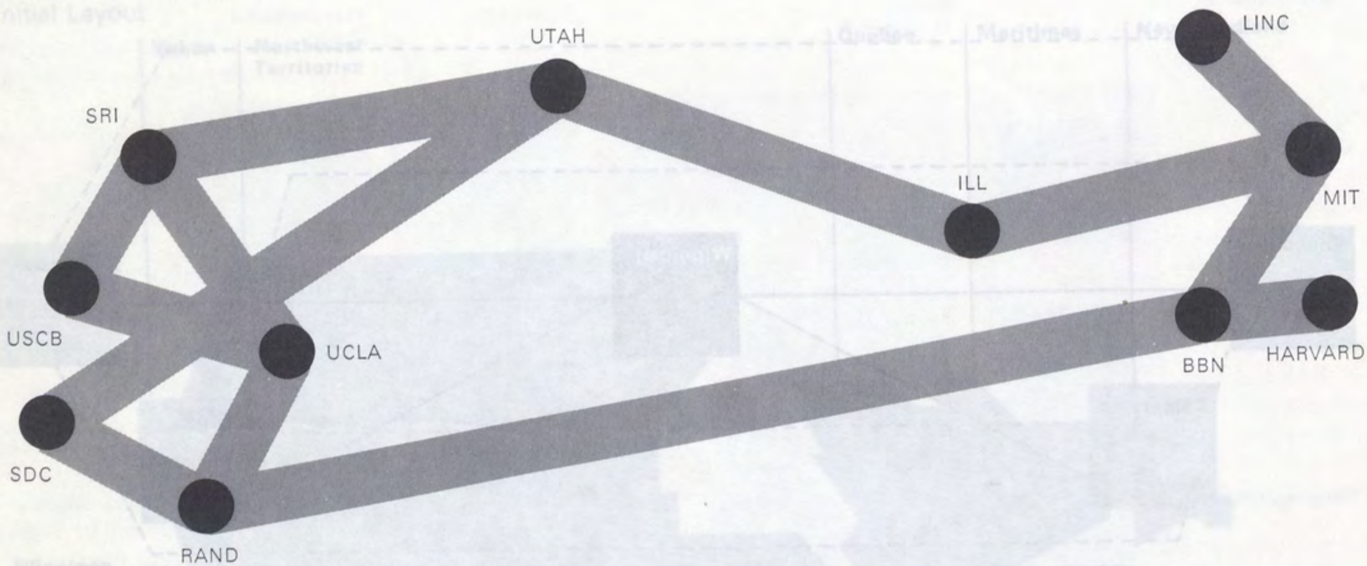


Figure 5a

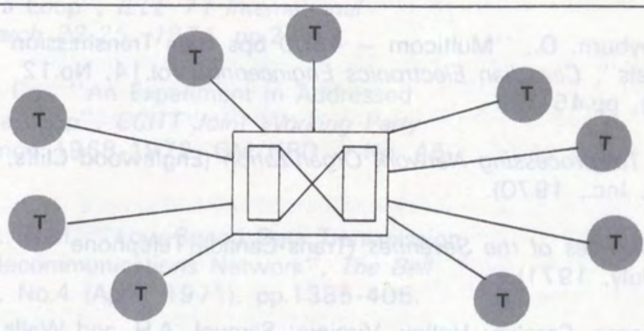


Figure 5b

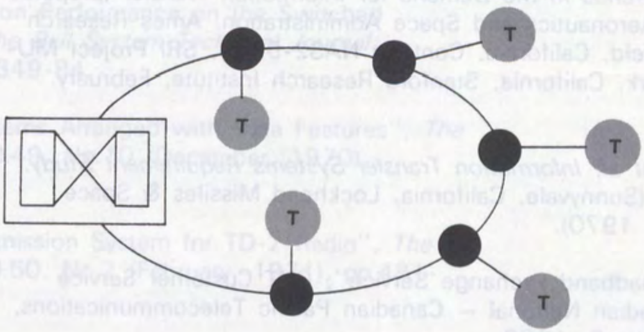
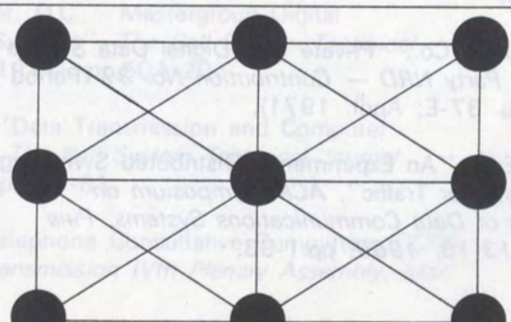


Figure 5c



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Background Papers

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The Canadian Computer/Communications Task Force

Background Papers

13 Standards

Prepared by:
CCC/TF Ottawa
August, 1972

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Introduction

Many user and supplier submissions cited the present state of standards as being inadequate for the effective development of computer/communications. A typical quotation follows:

> Data processors are generally faced with problems of standardization in the interface of computer/communications equipment.

Other comments range from those urging general standardization to warnings that across-the-board standardization would tend to inhibit new advances.

Specifically, identification and publishing of common-carrier network standards and practices were urged by data processors who also require more compatibility between hardware components of different manufacture, and more compatibility of software data management systems. It was noted also that these problems extend beyond national boundaries in many important situations, not the least of which are those where security of information is concerned.

Some of the following material on specific standardization activity can be found in *Standards in Canada*[1], which is an excellent background reference work. However, the pace of institutional activity in the standards field is high and quite a number of institutional changes which have occurred since this work was published, have been introduced here.

1. Definitions for Discussing Standards in Canada

At this point the difference should be made clear between a "standard" and a "specification" and the process of standard setting or "standardization"

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[1] Legget, Robert F., *Standards in Canada* (Catalogue No. SS31-271; Ottawa, Information Canada, 1971).

should be defined. The following are definitions which are internationally commended:[2]

(a) Standardization

"Standardization is the process of formulating and applying rules for an orderly approach to scientific activity for the benefit and with the co-operation of all concerned, and in particular for the promotion of optimum overall economy, taking due account of functional conditions and safety requirements. It is based on the results of science, techniques and experience. It determines, not only the basis for present, but also for future development, and it should keep in pace with progress. A particular application is for products and processes — the definition and selection of characteristics of products, testing and measuring methods, specification of characteristics of products for defining their quality, regulation of variety, inter-changeability, etc."

(b) Standard

"A Standard is the result of a particular standardization effort, approved by a recognized authority. It may take the form of (i) a document containing a set of conditions to be fulfilled (*'norme' en français*); (ii) a fundamental unit or physical constant, examples being —*ampère*, absolute zero (Kelvin) (*'étalon' en français*); or (iii) an object for physical comparison, an example being the standard metre (*'étalon' aussi, en français*)."[3]

(c) Specification

"A Specification is a concise statement of a set of requirements to be satisfied by a product, material or a process indicating, whenever appropriate, the procedures by means of which it may be determined whether the requirements given are satisfied. A specification may be a standard, a part of

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[2] Published in a report from STACO by the International Organization for Standardization (Geneva, 1965). Quoted in Legget, Robert F., *op. cit.*, p.23.

[3] Lagget, Robert F., *op. cit.* p.24.

a standard, or independent of a standard. As far as practicable, it is desirable that the requirements are expressed numerically in terms of appropriate units, together with their limits."[4]

2. Standards-Making Organizations

The following is a brief description of the various organizations involved in standards-making and of their levels of activity, both domestically and internationally.

(a) Computer Standards-Making in Canada

The Canadian Standards Association (CSA) has been the national standards body for Canada and, as such, CSA has had the responsibility for administering standards promulgation in the field of computers and information processing. The Standards Council of Canada, which was created by Act of Parliament in October, 1970, is to become co-ordinator for standards-making activities in Canada, but not by direct participation on standards-making committees. It is intended primarily as a general policy-making and co-ordinating body.

(b) Standards Council of Canada

The Standards Council of Canada was instituted to "foster and promote voluntary standardization in fields relating to the construction, manufacture, production, quality, performance and safety of buildings, structures, manufactured articles and products and other goods, including components thereof, not expressly provided for by law, as a means of advancing the national economy, benefiting the health, safety and welfare of the public,

[4] Legget, Robert F., *op. cit.*, p.24.

assisting and protecting consumers, facilitating domestic and international trade and furthering international co-operation in the field of standards."[5]

It is empowered to recommend procedures relating to preparation, approval, acceptance and designation of voluntary standards; to accredit organizations in Canada involved in preparing standards, testing or certification; to maintain a register of such organizations; to approve standards where appropriate, and maintain an index of approved standards; to identify areas requiring revision of existing standards or new standards; to work with accredited organizations where possible, and where necessary to establish new organizations.

It is also empowered to "unless otherwise provided for by any other Act of the Parliament of Canada or by treaty (i) represent Canada as the Canadian member of the International Organization for Standardization (ISO), the International Electro-technical Commission (IEC), and any other similar international organization engaged in the formulation of voluntary standards".[6]

The organization of the Standards Council of Canada consists essentially of the Executive Committee, office of the President and the Executive Director, other Directors and a body of Advisory Committees. Directors have been appointed for the National Standards Program, the International Standards Program and the Metric Conversion Program.

In connection with the ISO and IEC international standardization responsibilities, the Canadian National Committees on ISO (CNC/ISO) and IEC (CNC/IEC) were established to direct and guide Canada's involvement in these two international standardization organizations, with headquarters in Geneva.

While these national committees, since their establishment many years ago, reported to CSA through the CSA Board of Directors, effective April 1, 1972, and under joint agreement between CSA and the Standards Council of Canada, they were transferred to the Standards Council of Canada organization. The CNC/ISO and CNC/IEC memberships are made up of

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[5] *Standards Council of Canada Act* [1969-70, c.73]

[6] *Standards Council of Canada Act.*

individuals from industry, associations, provincial and federal governments, to fully represent the interests covered by the ISO and IEC work.

The technical work on ISO and IEC is conducted in Canada through some 104 Canadian Advisory Committees on ISO and sixty-eight Technical Sub-Committees on IEC, involving some 1,200 technical experts reporting through Chairmen to the CNC/ISO and CNC/IEC, respectively. The Secretariats for the Canadian involvement in CNC/ISO, CNC/IEC and their technical committees are administered by the International Department of the Canadian Standards Association under contract to the Standards Council of Canada. The Manager of the International Department serves as Director of the Standards Council of Canada's International Standards Program.

(c) Canadian Standards Association

The Canadian Standards Association is a non-profit, non-government association, originally incorporated by Dominion charter in 1919, under the name "Canadian Engineering Standards Association" (changed to CSA in 1944) to provide a national standardization body for Canada.

The objectives of the Association are to promote the establishment of uniform, nation-wide standards of products, processes and procedures, by providing an organization (see Figure 1, page 19); to receive requests for standardization, investigate their desirability and arrange for the formation of committees, comprising representatives of both manufacturers and users, scientific and technical societies, inspection authorities and government departments; and to prepare standards that will be acceptable to all concerned interests. CSA is also involved in certifying that products meet those standards which have already been set. The Administration of CSA is controlled through a Board of Directors elected from the Association membership.

Advice on CSA standards policy and the final authority on the approval of standards and on the creation of new committees are through the Standards Policy Board (SPB). The SPB consists of up to 100 members representing as many diverse interests as possible. Reporting to the SPB are thirty-four

Sectional Committees, representing a wide variety of engineering and commercial disciplines which have developed a need for standards. Standards committees or sub-committees, of which there are about 620, deal with specific topics and are responsible to the assigned Sectional Committee. About 3,000 volunteers participate in the work of these committees. Approval of a CSA standard is granted by the Sectional Committee if there are no negative opinions, or, in certain cases, may be granted by the SPB if there are unresolved negatives. Over 1,200 standards have been published to date by CSA.

In addition to the Sectional Committees and Standards Committees, CSA is developing advisory committees whose membership may be drawn from the leaders of particular industries and governments. One of the first of these to be established was the Advisory Committee on Systems Building, set up for the construction industry. Its objectives are of particular interest, as they can easily be rephrased to apply to computer/communications:

- To evaluate systems approaches to the needs of Canada's building industry, as these concern fields of interest to CSA;
- to establish plans and time-tables for introducing performance specifications and testing criteria;
- to evaluate the needs for dimensional co-ordination in the building industry;
- to recommend standardization projects to increase productivity;
- to consider means to rationalize the existing building industry through standardization, rather than create a new industry;
- to recommend investigations of human, labour, and personnel problems for action by other groups.

In addition to all of these committees, there are four CSA Advisory Councils on codes set up to deal with such matters as the electrical code, plumbing code, fire safety and off-site buildings. These are mostly made up of municipal and provincial officials, responsible for administering various regulations laid down by the authority having jurisdiction in the particular area in question.

CSA provides two basic and distinct services, one of standards development and the other of providing a product-testing and certification service. The former activity is supported primarily from membership fees (1,600 @ $150.00), sale of standards, and miscellaneous special projects. The latter is self-supporting, in the sense that costs are recoverable on the basis of fees established for the certification services. Total funds in 1970 were approximately $6 million. The out-of-pocket expenses of CSA committee members are underwritten by their employers.

(d) Sectional Committee on Computers, Information Processing and Office Machines (CIPOM)

The Sectional Committee on Computers and Information Processing was established in 1965. This committee acted as the senior standards body in computer sciences. On the recommendation of the committee itself, it was replaced in 1969 by the new Sectional Committee on Computers, Information Processing and Office Machines (CIPOM) with broader terms of reference.

In order to achieve a balance of interests, membership of the CIPOM Sectional Committee includes representation from users, distributors, producers and general interests. Individual members are knowledgeable in one or more of the activities involved, and are generally familiar with the overall field.

There are thirteen standards committees or sub-committees reporting to the Sectional Committee. In 1971 there were over forty-seven meetings of the committees. Six new standards were published within that year, and several are in the balloting stage.

CIPOM has an Executive Committee to organize and carry on the business of the Sectional Committee between meetings of the main committee. This committee has representatives from manufacturers, the National Research Council, Defence Research Board, universities and other interested organizations.

The Canadian Advisory Committee (CAC) for the International Organization for Standardization (ISO), through Technical Committees 95 and 97 (ISO/CAC/TC95 and TC97), composed of members of CIPOM, affords Canadian technical participation in international standardization work in related areas. Each CSA standards committee or sub-committee under CIPOM acts as an advisory group on international activity within its scope, reviewing documents from international technical committees, collecting Canadian input to these documents, and resolving difficulties that may arise due to uniquely Canadian circumstances — the French/English keyboard for example. In 1970, a total of twenty-three ISO draft recommendations were considered. Delegates also attended two ISO sub-committee meetings.

According to a CSA brief, Sectional Committee members, all of whom volunteer their time, have asked for additional support from CSA in the form of increased administrative assistance. They also require additional technical assistance in the form of analysis and comparison of standards of the ISO, the European Computer Manufacturers Association, and the American National Standards Institute, with those of CSA.

(e) Canadian Government Specifications Board

The Canadian Government Specifications Board is a government-financed and operated organization with the function of preparing standards at the request, and for the use, of government departments and agencies. The Board consists of seven deputy heads of federal government departments and agencies, with standards activities conducted by Technical Committees aided by a Secretariat located within the Department of Supply and Services (DSS). The standards are drafted by committees which are appointed for the commodity field involved, and include representation from interested government agencies and industry. Draft standards are submitted for letter-ballot approval by the Technical Committee, and to the Board for ratification and issue. Some 1,600 have been catalogued to date.

At the present time, although there is representation by the Canadian Government Specifications Board on the CSA Sectional Committee on Computers, Information Processing and Office Machines, there is no single designated federal agency for government standards-making activity in the computer/communications area. However, DSS does have a representative on the COBOL CODASYL Committee, and DSS acts as the Canadian outlet for information on the work of this committee.

(f) Department of Communications

At present, the primary responsibility of the Department of Communications for standards relating to computer/communications technology is in administration of the use of the radio frequency spectrum. Some of the responsibilities are now being delegated to other organizations, such as the Canadian Standards Association. In particular, CSA will be testing and certifying household appliances as meeting minimum radiation emission standards limits set for line-induced radio interference.

The Department maintains effective liaison with the telecommunications manufacturing industry through the Canadian Radio Technical Planning Board (CRTPB). In addition to technical specifications, other factors that the Department considers with the assistance of the manufacturers include:

"1. The relationship between cost of equipment performance standards, and the resulting effect on ability to compete in both domestic and export markets.

"2. The effect of amortization of equipment on inventories due to obsolescence because of new specification requirements."[7]

3. Standards-Making in the United States

Standards-making bodies in the United States include the American Society for Testing and Materials (ASTM), the American National Standards Institute (ANSI), the Federal Communications Commission (FCC), the National Bureau of Standards (NBS), the Electronic Industry Association (EIA), and the Conference on Data Systems Languages. The first of these, ASTM, even though it does not set standards for computer/communications technology, is of interest because it provides another example of the way voluntary standards-making can be effectively conducted.[8]

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[7] Department of Communications. *Telecommission Study 7(d): The Relationship Between the Department of Communications and the Telecommunications Manufacturing Industry* (Catalogue No. Co41-1/7D; Ottawa, Information Canada, 1971).

[8] ASTM does not have any technical committees working on communications, computers or business machine standards. ASTM "standards" are prescriptive text methods — not "standards" as defined on page 2 of this text.

Standards

(a) American Society for Testing and Materials

The American Society for Testing and Materials has, in fact, international membership and is unique because it is entirely voluntary and self-supporting. Standards are prepared through the work of 109 Main Technical Committees to which well over 10,000 individuals contribute time and talent. The sub-committees attached to the Main Technical Committees draft standards, and great care is given to attempting to resolve "negative votes".

A proposed standard which has unresolved negative votes may only be approved after full consideration at the highest authority in the Society. The Society also requires that all main committees be composed of members from three general areas: "Producer", "Consumer" and "General Interest" groups, and that the number of Consumer and General Interest members shall exceed in total the number of Producer members. Also a Producer member may not serve as Chairman of any of the main committees. This procedure for maintaining the delicate balance of membership and for resolving negative votes is known as the *Consensus Principle.*

ASTM is apparently the only major U.S. standards-writing body which conforms fully in practice to the Consensus Principle. The main reason for this is the enormous diversity of interested parties in the field of materials standards, which naturally requires a highly democratic standards-making process.

(b) American National Standards Institute

The original prime motivation for the evolution of ANSI was to provide a focal point for standards activity in the U.S., and one of its functions is to take standards prepared by other standards-making organizations and after due deliberation certify them as "American Standards". It is the official standards body for the U.S. and represents the U.S. on such international standards organizations as ISO and IEC. This representation may be achieved directly by sponsoring members of its own Technical Committees to attend international technical committee meetings, or by delegating the responsibility to some other suitable agency. Three Major Councils make up the operating arms of

ANSI: the Member Body Council, the Company Member Council and the Consumer Council. Of these, the Member Body Council is responsible for approving standards, and the other two councils for ensuring liaison and representation of their interest groups in ANSI work.

The Board of Directors, ANSI's governing body, is drawn from the three councils, with four members being nominated by the council members. Within ANSI there exist a number of Standards Boards, each responsible for standardization in a particular area, and for each Board there are a number of Technical Specifications Committees which prepare the standards.

Funds for ANSI are derived from membership fees and the sale of publications.

For the service of the Information Processing Section of industry there exists a Standards Board called the "Information Processing Systems Standards Board", and usually designated Committee X3. This Committee is sponsored by the Business Equipment Manufacturers Association (BEMA), which acts as the Secretariat providing essential administrative support.

The organization of ANSI Committee X3 differs considerably from the corresponding CSA Sectional Committee on Computers, Information Processing and Office Machines (CIPOM). The main differences are the existence in X3 of a Standards Planning and Requirement Committee (SPARC), and the greater overall level of activity within X3. SPARC is responsible for initiating standards work in new areas. Evaluation of the different areas in which standards might be prepared is complicated, and has necessitated the setting up of the SPARC committee specifically for that purpose.

In addition, CIPOM, as its title indicates, has responsibility for office machines standards, while within ANSI there is a separate standards committee, Committee X4, which is responsible for this area.

(c) Standards-Making for Communications in the U.S.

Many of the standard practices used by the common carriers in the U.S. are administered by the AT&T long lines division. This division in fact establishes technical network policy for all the interstate connections and trunk characteristics. There is close liaison with the Trans-Canada Telephone System (TCTS) in Canada, but the practices adopted by AT&T are not necessarily adopted by TCTS, and *vice-versa*.

(d) The National Bureau of Standards

Under the terms of U.S. Public Law 89-306 (the Brooks Bill), dated October 30, 1965, the Secretary of Commerce is authorized to "make appropriate recommendations to the President relating to the establishment of uniform Federal automatic data processing standards".[9] The Secretary in turn has assigned the responsibility for carrying out these functions to the Center for Computer Sciences and Technology, an organization within the Institute for Applied Technology, National Bureau of Standards.[10]

The Center for Computer Sciences and Technology of the National Bureau of Standards is much more active in the preparation of standards than any corresponding government organization in Canada. As an indication, participation of over 250 U.S. federal government employees in various ANSI X3 committee activities is co-ordinated by the Center, while in Canada participation of about twenty Canadian Government employees in the activities of CSA's Sectional Committee on Computers, Information Processing and Office Machines is not co-ordinated by any Canadian federal government agency.

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[9] United States Department of Communications, *Federal Information Processing Standards Index* (FIPS PUB 12) (SD Catalogue No. C 13.52:12; Washington, D.C. 20402, Superintendent of Documents, U.S. Government Printing Office, 1970), p.14.

[10] *Ibid.* p.15.

The National Bureau of Standards has much less responsibility for standards-making in the area of data communications than it has in the area of computing. That responsibility rests more with the Federal Communications Commission, although it is not a technically oriented body. Thus, the Federal Communications Commission may make use of the technical services available from the Bureau of Standards, although they are under no obligation to do so.

(e) Electronic Industries Association (EIA)

EIA is concerned with standards for electronic equipment. In the computer/communications field perhaps the best-known standard they have produced is RS 232, which specifies voltage levels, physical pin configurations, and pin functions for the interface between communications modems and computers.

While EIA is fairly active in standards-making relating to computers and communications, the corresponding Canadian organization, the Electronic Industries Association of Canada, is much less active in this area.

(f) Conference on Data Systems Languages (CODASYL)

CODASYL was formed in May, 1959. It consists of several inter-locking committees, of which the Programming Language Committee (PLC) has sole global responsibility for formalizing COBOL specifications. Although the CODASYL organization is principally in the U.S., the Canadian federal government has had full membership in the PLC since 1966, and DSS (through the Canadian Government Specifications Board) has printed and published the last three editions of the *Journal of Development* prepared by the PLC. The significance of CODASYL becomes apparent when it is recognized that about 50 percent of all computer programming in the U.S. and Canada is performed in COBOL.

(g) Standards-Making by Computer Manufacturers

In the United States, computer manufacturers maintain relatively large groups of people who are concerned only with setting standards for the products made by that manufacturer. Each manufacturer has a great deal of freedom to choose the standards to which the various components of his systems will adhere. Standards embedded in the specifications for a particular system are often numerous, as illustrated, for example, in the variety of standards used in the design of the hardware and software of IBM's 360. It is this freedom which makes the standardization process in data processing extremely difficult.

4. International Standards-Making

In situations where there is a great deal of international activity it would be preferable if there were no difference in a particular standard used in one country from that used in another. In practice, however, each country has its own special requirements. In addition, national or regional standards are frequently used as a means of creating economic advantage. Thus, international standards-making involves many problems in attempting to secure agreement among many different interests. In this section some very brief explanations of the activities of several international bodies concerned with standards will be given.

(a) International Electro-Technical Commission (IEC)

The IEC is made up of delegates from National Committees which exist in all forty-one participating countries. It brings together representatives of the technical and scientific groups in each country dealing with questions of electro-technical standardization. The technical work of the Commission is carried out by Technical Committees, each dealing with a major subject. The Secretariat of each Technical Committee, assigned to a National Committee by the IEC Committee of Action, plays a permanent role, working with both the Chairman and the IEC Central Office in Geneva. Standards are released in French and English simultaneously as IEC recommendations, but only when four-fifths of the member National Committees are in agreement. IEC involvement in the computer/communications field is not large.

(b) International Organization for Standardization (ISO)

This organization was established through efforts of the United Nations Standards Co-ordinating Committee (UNSCC), and became operational in February, 1947, upon ratification of a Constitution and Rules of Procedure by fifteen national standardizaton bodies. ISO is the international specialized agency for standardization, comprising in 1972 the national standards bodies of seventy countries. The work of ISO is aimed at world-wide agreement on standards, with a view to the expansion of trade, the improvement of quality, the increase of productivity and the lowering of prices.

The work is carried out through some 1,200 technical bodies. More than 50,000 experts from all parts of the world are engaged in this work, which, to date, has resulted in the publication of nearly 2,000 ISO standards, representing more than 200,000 pages of concise reference data in virtually all fields of technology.

The International Organization for Standardization has as officers a President, Vice President, Treasurer, and Secretary General. There is an elected Council, with each member holding office for three years. The work of ISO is carried out through Technical Committees, Technical Divisions, a General Assembly, and a General Secretariat.

The General Assembly is made up of delegates nominated by Member Bodies, of which there are fifty-five. It meets at least once every three years. The Council, which is composed of the President and representatives of fourteen Member Bodies, is the administrative organ of ISO. It meets at least once a year to direct the activities of the organization. The General Secretariat, headed by the Secretary General, ensures liaison between Member Bodies and the Council, receives contributions, regulates expenditures and circulates information.

It also co-ordinates the activities of the Technical Committees set up by the Member Bodies, and keeps them informed of related work being undertaken by other international organizations. The Technical Committees are composed of a delegation from each Member Body wishing to participate. There are 150 Technical Committees.

When a Technical Committee has agreed on a Draft International Standard (DIS) the General Secretariat submits the Draft to all Member Bodies and then to the Council for ballot approval. ISO TC97 on Computers and Information Processing is the Committee most involved with information processing, although the activities of CSA also relate to activities of ISO Technical Committee 95 (TC95), which is concerned with office machinery. ISO TC97 reported the release of thirty recommendations in the computer/ communications area in 1972. The Technical Committees meet annually, as do sub-committees, conducting much of their work by mail. However, working groups, established to examine a particular problem, meet two to three times between each sub-committee meeting. There are a large number of subjects as yet untouched by TC95 and TC97. These include PL-1, extensions to COBOL, data elements, and performance measurement.

(c) International Telegraph and Telephone Consultative Committee (CCITT)

CCITT is part of the International Telecommunications Union (ITU). It examines and recommends international practices for tariff and technical questions related to telegraphy, telephony and data communications. Membership in CCITT is broken into three types: government, recognized private operating agencies and related industrial concerns or scientific agencies. Full voting membership is accredited only to governments. For Canada, the Department of Communications is the government member. The Canadian Telecommunications Carriers Association (CTCA) has recently become an operating agency of ITU, replacing, among others, the Telephone Association of Canada (TAC) and the Railway Association of Canada (RAC).

CTCA will participate in the work of both the CCITT and the International Radio Consultative Committee (CCIR). The Canadian Overseas Telecommunication Corporation will maintain its individual memberships in CCIR and CCITT, and Telesat Canada in CCIR, at least for the time being.

The work of CCITT is handled by specially established study-groups. However, the subject matter for review by the study-groups is established by the Plenary Session of CCITT, held every three-to-four years. At this session the reports and recommendations of the study-groups are reviewed and voted on, and either further study authorized, or new study-groups established. The study-groups conduct much of their business by mail, particularly for submitting position papers. When sufficient material is available, a meeting is called to discuss and resolve points of contention. The work of CCITT now includes considerable effort in the data communications field. For example, "Special A" is a study-group set up to examine the problems arising from using the telecommunications networks for digital data transmission service, particularly between computers. Also, NRD is a Permanent Joint Working Party, established to study new networks for data transmission.

(d) International Federation of Information Processing

In the area of software, little standardization work is currently being performed under the auspices of official international standards-making bodies. However, there have been a number of activities in this area by special groups, and, while the main bulk of the work has been towards programming languages, other topics have received attention.

The International Federation of Information Processing (IFIP) conducts technical work in terminology and programming, and has recently established work in computer applications. The IFIP Technical Committee on Programming has been responsible for the support of ALGOL 60, and the specification of ALGOL 68. These specifications were prepared by a working group chosen for their technical competence by the Technical Committee, which is composed of one representative per country.

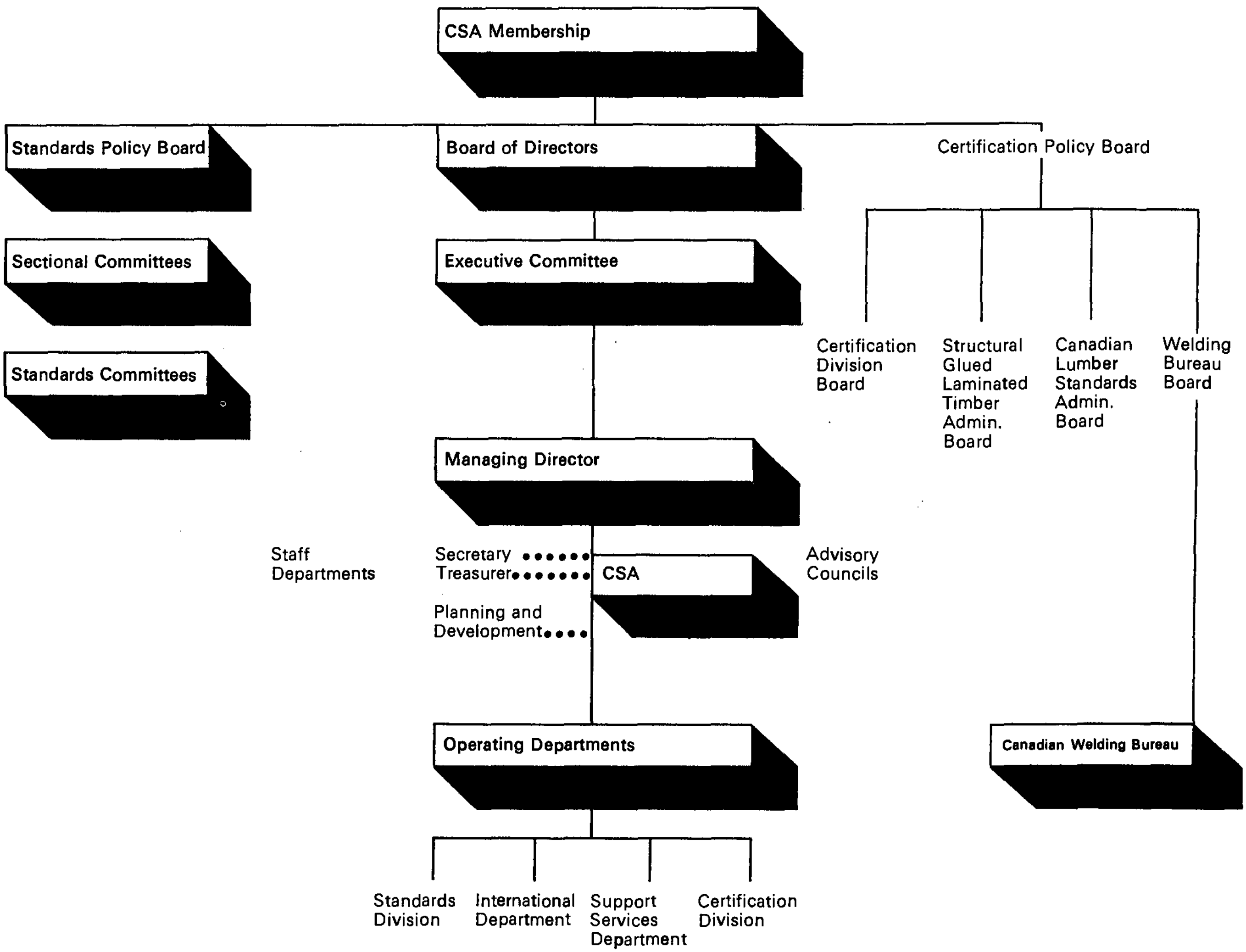
It should be pointed out that IFIP only engages in standards-making activities at the request of recognized international standards-making bodies. In response to such a request, IFIP will establish technical committees to investigate particular areas.

Standards

5. Conclusion

It is important to recognize that computer/communications technology is essentially international in character. Therefore national and international standards must be interrelated. A fully co-ordinated national standardization process is a prerequisite for participation by Canada in the international scene. In fact there are gaps between the different government organizations involved, between government and industry, and between the computer and telecommunications industries. At this early stage in the development of computer/communications, these gaps are not serious but this is nevertheless an opportune time to take note of them, and to consider ways and means for their elimination through joint government and industry planning.

Figure 1
Organization of CSA



Background
Papers

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The Canadian Computer/Communications Task Force

Background Papers

14 Technological Review of Computer/Communications

Prepared by:

CCC/TF Ottawa

August, 1972

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Introduction

In this paper an attempt is made to present an overview of the state of the art and of anticipated technological developments in the computer/communications field in the next decade. Following this introduction the paper is broken into two parts which deal with computers and communications technology, respectively. Discussions of solid-state device developments have been included under the computer section, though of course these developments also have an impact on communications technology.

The discussion of particular technological developments is intended primarily to justify cost predictions. Consequently, it is not intended to be comprehensive, though it is hoped that most major developments have been included.

The time-span covered by this paper is restricted to the period ending in 1980. This decision was based on the assumption that devices as yet undiscovered can have only a limited impact before that time.

The first successful digital computer was produced in Germany in 1941[1]. However, no further development proceeded from it, so that the first digital computer which caught world attention was the Harvard Mark I, which became operational in August, 1944[2]. One of the early industry forecasters estimated at that time that twelve computers would be adequate to satisfy total U.S. demand. This estimate was later raised to fifty[3]. Twenty-five years later there were about 50,000 computers in the U.S. alone. There were over

[1] Organization for Economic Co-operation and Development, *Gaps in Technology: Electronic Computers* (Paris, OECD Publications Office, 1969).

[2] Parkhill, Douglas F., *The Challenge of the Computer Utility* (Reading, Massachusetts, Addison-Wesley Pub. Co., 1966). For a history of early computers see pp.12-8.

[3] Diebold, John, *Man and the Computer; Technology as an Agent of Social Change* (New York, Frederick A. Praeger, 1969), p.48.

2,400 in Canada, and the estimated world-wide total was approximately 70,000[4]. A brief record of innovation in the computer industry is reproduced from an OECD report[5] in Table 1.

The Harvard Mark I computer performed logic using electromechanical relays. Multiplication of two twenty-three-digit numbers required 4.5 seconds. The first all-electronic computer, ENIAC, which became operational in 1946, was about two-thousand times faster. In contrast, the fastest computer in existence today (the Control Data Star 100) is capable (at peak efficiency) of performing 100-million multiplications of thirty-two-bit words a second.

This rate is approximately 500-million times faster than the Mark I and about 250,000 times faster than ENIAC! Since 1952 (when computers started to become more generally available on a commercial basis), the average cost for execution of a single instruction has fallen by a factor of about 10,000.

Although computer speeds and costs will continue to improve, some slackening in rate of advancement is to be expected. New technologies now in the laboratory (such as optical processing, Josephson effect devices, associative processing) show promise of yielding order-of-magnitude speed improvement over the decade, while the widespread use of integrated circuits for logic and for rapid-access memory could result in price reductions of up to two orders of magnitude in ten years. However, the existence of these capabilities does not in itself dictate the timing of their arrival in the market-place. Economic and social considerations also play a role.

As computer technology developed it began to make demands upon the communications field. The late sixties saw much pioneering telephone and telegraph carrier activity for the purpose of adapting their networks to carry data in digital form. This work is continuing amidst increasing pressure for separation of data from voice-systems. Some users want performance

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[4] AFIPS, *The State of the Information Processing Industry* (Montvale, N.J., AFIPS Press, 1966).

[5] OECD, *op. cit.*

characteristics from data communications systems which can be economically met by digital network technology. Some of this technology, *e.g.*, Pulse Code Modulation (PCM), is well advanced, and has already demonstrated economic advantage for voice transmission. Development of suitable technology and economic performance for data transmission will be needed to complement advances in computer application.

No introduction to the technology of computer/communications would be complete without reference to software. Whereas it is probable that the largest single overall possible source of cost-reduction in computers appears likely to come about as a result of savings in storage costs, these can be influenced by software. Indeed, during the next decade the increasingly high proportion of expenditures on software will bring new pressures to bear on methods of making software writing more efficient.

Greater portability of software, to permit wider usage of any given program, is one obvious goal. This trend, coupled with a tendency towards distribution of computing elements within a total hardware system, is likely to lead to increased modularity of software. Computer languages (and computer hardware instructions) will continue to become more sophisticated so that program complexity can be reduced. Auerbach[6] has discussed the likelihood of computer-assisted program design as a possible breakthrough to more efficient programming. Considerable effort will be required to reduce programming error rates, and to improve the level of understanding of the ways in which interactions between program elements can be controlled if large and complex programs are to become widespread.

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[6] Auerbach, Isaac L., "Technological Forecast, 1971", *Proceedings of the IFIP Congress, Ljubljana, August 1971* (Amsterdam, Netherlands, North-Holland Publishing Co., 1972), pp.764-75.

Table 1

The Main Inventions and Innovations in the Computer Industry
(**A** = theoretical advance, **B** = first application, **C** = first commercial application)

Description	Type, Country and Year		Responsible Firm or Individual	Remarks
1. General theory of computers	**A.** France	1936	L. Couffignal	Unknown outside France
	Germany	1936	K. Zuse	No publications. Totally unknown
	United Kingdom	1937	A. M. Turing	Relatively important influence
2. First electronic computer	**B.** Germany	1941	K. Zuse	Z3 computer. Little known outside Germany
	United States	1946	J. P. Eckert and J. W. Mauchley	ENIAC. Important work was also done by G. Stibitz at Bell Telephone (1940), H. Aiken and IBM at Harvard (1944) and V. Bush at MIT (late 1930's and early 1940's)
	C. United States	1951	Remington Rand	UNIVAC I
3. Internally stored program	**A.** United Kingdom	1937	A. M. Turing	
	United States	1946	J. von Neumann (Univ. of Pennsylvania)	
	B. United Kingdom	1948	Univ. of Manchester	MADM } Close scientific interchange between the United States and the United Kingdom
		1949	Univ. of Cambridge	EDSAC }
	C. United States	1951	Remington Rand	UNIVAC I }
4. Subroutine concept	**A.** United Kingdom	1937	A. M. Turing	
	United States	1946	J. von Neumann	
5. Read-only memory	**A.** —		—	The read-only memory has been used in automatic telephone exchanges
	B. United States	1946	J. P. Eckert and J. W. Mauchley	ENIAC computer. Limited storage
	United Kingdom	1949	University of Cambridge	EDSAC II computer. Storage of the entire control information
	C. Several countries		Most manufacturers	
6. Associative memory concept	**A.** } United States	1946	V. Bush	
	B. } United Kingdom	1952	Ferranti	ATLAS } The full possibilities of associative memories have not yet been exploited
	C. } United States	1965	IBM	360-67 }
7. Microprogramming	**A.** } United Kingdom	1948	University of Manchester University of Cambridge	} Close interchange
	B. } United States	1948	IBM (J. Backus), U.S. Navy (G. Hopper)	}

Table 1

The Main Inventions and Innovations in the Computer Industry
(**A** = theoretical advance, **B** = first application, **C** = first commercial application)

Description	Type, Country and Year		Responsible Firm or Individual	Remarks
8. First compiler (A2)	**B.** United States	1951	U.S. Navy (G. Hopper)	In the late 40's, Grace Hopper worked in the U.K.
	C. United States	1951	Remington Rand	UNIVAC I: first computer to have a compiler
9. FORTRAN language	**B.** United States	1953-1954	IBM Users Association (SHARE) and IBM	First FORTRAN compiler written by J. Backus of IBM
	C. United States	1954	IBM	
10. High-speed drum printer	**C.** France	1954	Bull	First application of the "on the fly" principle for printing
11. Ferrite core memory	**A.** } United States	1955	MIT (Lincoln Laboratory)	Important work was also done at Harvard
	B. }			
	C. } United States	1956	Remington Rand, then IBM	UNIVAC 1103A, IBM 704 and 705
12. Transistorized computers	**A.** United States	1947	Bell Telephone	Discovery of the transistor effect in 1947
	B. United States	1956	Bell Telephone	Leprechaun computer
	C. United States	1958	Philco, IBM, GE	Philco 2000, IBM 7090, ERMR system
	United Kingdom	1959	Elliott	Elliott 803
	Germany	1959	S.E.L.	ER56 computer (S.E.L. is a subsidiary of the American ITT)
13. ALGOL language	**B.** Several countries	1958	ACM (USA) and GAMM (Germany)	ALGOL was jointly developed by American and European specialists convened in Zurich, Switzerland. The first ALGOL compiler was written by Dijkstra of the Netherlands. ALGOL was subsequently adopted by most manufacturers, and is presently more widely used in Europe than in the U.S.
	C. All countries after	1958	Several manufacturers	

Table 1

The Main Inventions and Innovations in the Computer Industry
(**A** = theoretical advance, **B** = first application, **C** = first commercial application)

Description	Type, Country and Year		Responsible Firm or Individual	Remarks
14. Multiprogramming	**C.** United States United Kingdom	1960 1962	Honeywell Ferranti	H800 computer Orion I computer } No interchange independent developments
15. COBOL language	**B.** United States **C.** Several countries after	1960 1960	U.S. Department of Defence Most manufacturers	
16. Family of compatible computers	**B.** United States **C.** United States	1955 1963-1964	U.S. Army IBM, Honeywell, RCA, GE, CDC	FIELDATA plan.* IBM 360 series, CDC 3000 and 6000 series, Honeywell H 200 series, RCA Spectra 70 series
17. Time-sharing	**B.** United States **C.** United States	1964 1966	MIT, Dartmough College, GE GE, then several large U.S. manufacturers (IBM, CDC, etc.)	Civilian application (Project MAC)

Sources: U.S. reply to check-list, Appendix 3.1. Chronology of computing in Africa, Asia, Europe and Latin America by J. Connolly, New York, 1968. Discussions and correspondence with experts O.E.C.D. Visits to companies.

Finally, it is to be noted that new software concepts are already firmly re-established in the design and operation of the new electronic switching systems, where stored software programs for switching control are now being introduced into the voice telecommunications systems of the carriers. Thus the marriage of computer and communications technologies is already evident.

Part A

Computer Technology

A new form of computer hardware which has an assured future is the mini-computer. As the price of the basic mini-computer comes down, the number of applications where its use is economic multiplies. Applications vary from industrial control, typesetting, patient monitoring and traffic control through conventional small business data processing to their use as communications controllers, "intelligent" remote computer terminals and peripheral controllers on large computer-systems. Mini-computers of considerable versatility are now available for under $3,000 (without peripherals), and it is clear that their price will continue to decline.

Manufacturers of super-computers will be increasingly involved in fighting for a share of medium- to large-computer business. It seems unlikely that super-computers will ever supplant the latter – there will always be a requirement for both, but, on balance, a faster growth-rate for super-computers than for medium- to large-computers seems probable. The arguments and counter-arguments which led to this conclusion are listed below[7].

Some of the arguments which have been advanced in favour of growth of medium- to large-computers are as follows:

- Grosch's Law does not hold, *i.e.*, computing capacity does not quadruple for every doubling of expenditure on computing equipment, largely because monitor software overheads dilute (and, some argue, completely compensate for) speed gains in the computing hardware.
- Computing costs will decrease very much faster than communications costs; thus the cost of communications will become an ever-increasing fraction of total costs for remote computing operations, which, in turn, will severely limit the radius of operation of remote-access computing facilities.

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7 Smith, William D., "Future of the Computer Is Assessed", *New York Times* (August 5, 1971), pp.45&50 (in which a similar conclusion was reported and attributed to F. G. Withington of Arthur D. Little, Inc.); and *Computer Based Services of the Seventies* (Trans-Canada Telephone System, Ottawa, July, 1971).

- Adequate security of files cannot be provided for users of computer-service bureaux, so that most of them will want an in-house computer-system which can give them that protection. Few users are large enough to justify use of a private super-computer.
- Unless he has his own computer, the user cannot ensure that rush jobs receive the appropriate treatment, and, more generally, he is, in a sense, at the mercy of the computer-service vendor with regard to what is usually a vital segment of his operations.

These problems make it evident that users will want their own computing systems.

- There is a prestige associated with the possession of a computer, and individual businesses and departments will fight for in-house computers for this reason, though the decision will be rationalized on other grounds.
- Because of the vital importance of good communications between computer programmers and those initiating the job, it is essential to have the computer located on the business premises.

Some of the arguments and counter-arguments which have been advanced by the proponents of the super-computers are:

- Grosch's Law does hold, at least for another generation of computers. While acknowledging that experience has been bad with third-generation computer monitors, which commonly require from 25-to-50 percent of Central Processing Unit (CPU) time, proponents of the super-computer argue that this lesson has been learned, and that the new super-computers will allocate the bulk of monitor overhead operations, either to much smaller peripheral computers, or to specialized hardware. Furthermore, hardware economies of scale will continue to hold.
- Although communications costs are likely to decrease much more slowly than computer costs, it can be argued that if communications facilities were better adapted to data transmission, communications costs could be considerably reduced. Further, many urban centres have enough computing requirements to easily satisfy the appetite of the next generation of super-computers, so that only low-cost local transmission need be involved for the majority of users.
- Most computer-service bureau operators will hotly defend the sanctity, or potential sanctity, of data manipulated on and stored by these organizations. They claim that the data security problem is more mental than actual, and that, where necessary, a few loose ends can be tied up at only slight additional cost (which they claim a customer is seldom willing to pay). In fact, most service bureaux have much better data security procedures than their customers.
- It is clear that the computer owner has ultimate control over the use of his computer at any given time. Super-computer advocates acknowledge this fact, but claim that it is a luxury that few will be able to afford. They also argue that by implementing a system of job priorities (with differential charges and runtime limitations when appropriate) and, if necessary, by assuming contractual obligations, the vendor can supply the user with the service he requires.
- The "prestige-of-computer-ownership" argument is countered on the grounds that obsolete practices soon lose prestige value in a business environment.

- Super-computer proponents maintain that the requisite system reliability (through duplication of hardware and careful maintenance) can more easily be obtained in large centralized facilities. Protection of files and of the computer facilities themselves from riot or revolution can likewise be more economically ensured. (On the other hand, the mere concentration of so much information and processing power in one central place makes super-computers a much more desirable target for revolutionary activity.)
- Although it may well be important to keep system programmers physically close to those whose job requirements they are fulfilling, this no longer means that the computer itself must be located on the same premises. A wide range of versatile remote-access computer terminals is available to system programmers. An even wider range of terminals is anticipated.

In balance, it would appear that demand for super-computers will increase faster than demand for the "middle-of-the-line" computers.

Concurrent with super-computer growth, and probably more startling, will be the growth of intelligent remote terminals controlled by mini-computers of varying sizes. Indeed, intelligent terminals will probably increasingly release the central processing unit from mundane tasks, which may well include the execution of the less demanding jobs submitted through it, as well as the communications control function.

Relative growth-rates (projected and actual) for different computer sizes are shown in Figure 8, *Branching Out*, Volume 1.[8]

The best-known empirical work on the relationship between computer cost and size was performed by Knight[9]. His original work was done in the middle 1960's, at a time when Grosch's law was under heavy attack. He was able to show not only that Grosch's law was quite accurate for any given year, but also that the number of operations executed per dollar had also increased at a phenomenal rate.

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[8] Report of the Canadian Computer/Communications Task Force, *Branching Out* (Department of Communications, Ottawa, Information Canada, 2 Vols., May, 1972).

[9] Knight, K.E., "Changes in Computer Performance", *Datamation*, Vol.12, No.9 (September, 1966), pp.40-54; and Knight, K.E., "Evolving Computer Performance 1963-1967", *Datamation*, Vol.14, No.1 (January, 1968), pp.31-5.

Economies of scale within the IBM 360 series of computers were investigated by Solomon[10]. He found that, except for programs which are heavily input/output oriented, Grosch's law is surprisingly accurate. Solomon went on to report that a survey had demonstrated additional personnel salary savings at large installations.

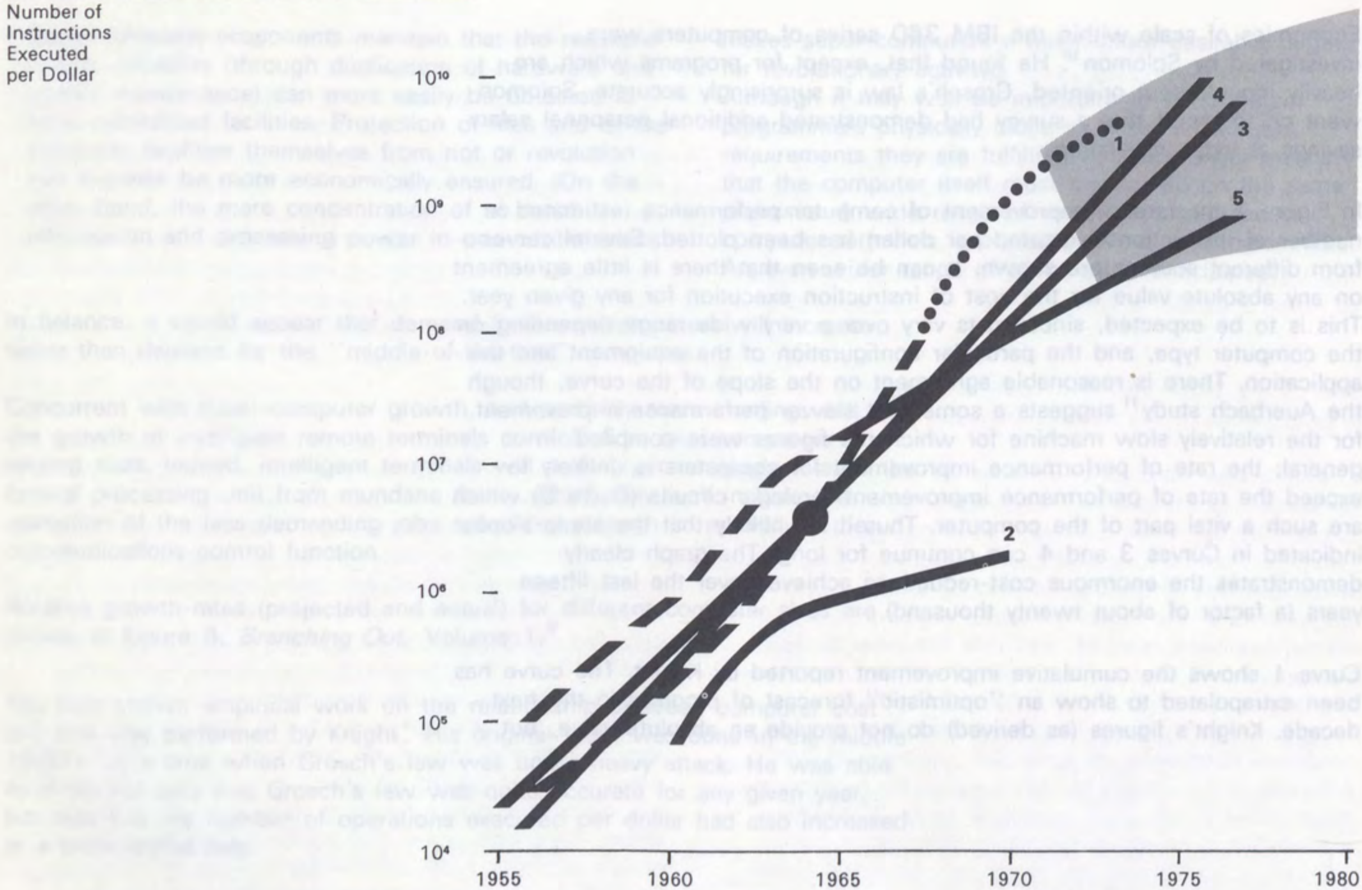
In Figure 1 the rate of improvement of computer performance (estimated in number of instructions executed per dollar) has been plotted. Several curves from different sources are shown. It can be seen that there is little agreement on any absolute value for the cost of instruction execution for any given year. This is to be expected, since costs vary over a very wide range depending on the computer type, and the particular configuration of the equipment and the application. There is reasonable agreement on the slope of the curve, though the Auerbach study[11] suggests a somewhat slower performance improvement for the relatively slow machine for which the figures were compiled. In general, the rate of performance improvement for computers is unlikely to exceed the rate of performance improvement for logic circuits (Curve 5) which are such a vital part of the computer. Thus it is unlikely that the steep slopes indicated in Curves 3 and 4 can continue for long. The graph clearly demonstrates the enormous cost-reductions achieved over the last fifteen years (a factor of about twenty thousand).

Curve 1 shows the cumulative improvement reported by Knight. The curve has been extrapolated to show an "optimistic" forecast of progress in the next decade. Knight's figures (as derived) do not provide an absolute value, but

[10] Solomon, Martin B., "Some Computer Economics: Economies of Scale", *Proceedings of the 1971 Data Processing Institute Conference* (Ottawa, 1971), pp.223-9.

[11] Auerbach Technology Evaluation Service, *Computer Software* (EDP Series No. 7; Philadelphia, Pennsylvania, Auerbach Information Inc., 1971).

Figure 1
Number of Instructions
per Dollar *versus* Year



Various estimates and projections as described in the text

1 Knight
2 Auerbach
3 Armer
4 Ware
5 Notz, *et al*

they have been "normalized" to a value of 5 X 10^6 instructions per dollar in 1964 (as estimated from data provided elsewhere in his paper)[12]. The relative values themselves were derived from an evaluation of over three hundred computers. Curve 2 shows figures given by the Auerbach Corporation[13] for a computer capable of 10,000 operations per second (*i.e.*, a slow machine). Curve 3 depicts a prediction by Armer quoted in Kimbel[14] that the cost of raw computing power has declined and will continue to decline by an order of magnitude every four years. Armer's prediction has been normalized to 5 X 10^6 instructions per dollar in 1964 as well. His rough estimate agrees well with that of Willis Ware of the Rand Corporation (Curve 4)[15] that by 1975 there will have been a 200,000-fold reduction in the unit cost of calculation over a time-span of two decades. (Ware also predicted a 160,000-fold increase in installed capacity over the same period, concurrent with a 10,000-fold decrease in size and a 40,000-fold speed increase.)

Finally, Curve 5 shows the actual and predicted decreases in the cost of electronic components of the computer, as converted into instructions per dollar by Notz, *et al*[16].

Because of the enormous variety of computer-systems (tailored to perform a variety of different tasks) which are now on the market, it has become very difficult to conceive of an adequate measure of computing power which is at the same time practical to use. Measurements of the type undertaken by Knight are no longer practical, except within specified ranges of computer

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12 Knight, K.E., "Evolving Computer Performance 1963-1967", *Datamation*.

13 Auerbach Technology Evaluation Service, *op. cit.*

14 Kimbel, Dieter, *Computers and Telecommunications — economic, technical and organizational issues* (OECD Publication No. DAS/SPR/71.63; Paris, November 24, 1971, CONFIDENTIAL), pp.51-2.

15 Ware, Willis H., *On Limits in Computing Power* (Document No. P4208; California, The Rand Corporation, October, 1969).

16 Notz, William A.; Schischa, E.; Smith, J.L. and Smith, M.G., "Large Scale Integration — Benefitting the System Designer", *Electronics*, Vol.40, No.4 (February 20, 1967), pp.130-3.

types. Knight himself has refused to update his work for computers introduced subsequent to 1967 on these grounds. Nonetheless, the curves in Figure 1 probably give a fair indication of the startling price reductions in computer processing over the last fifteen years, even if the absolute values are themselves open to some question and difficulty of interpretation.

1. How Big Will Super-Computers Become?

The next decade will see a continuing increase in the operating speed of super-computers (the speed increase in terms of instructions per second was by a factor of about twenty during the last decade)[17]. The technology to support a further speed increase of similar magnitude is already in the laboratories.

Figure 2[18] depicts the growth-rate of large computers.

The measure of computing power used in this case is the product of computing speed and memory capacity for the largest computers existing in each time-period. Three points have been added to the original plot in an attempt to update it (the CDC 7600, the IBM 360/195 and Star 100). It would appear that, by this measure, there has been some recent slackening in the growth-rate.

In Figure 3, a plot of computing power using number of instructions per second only as the measure[19] is shown.

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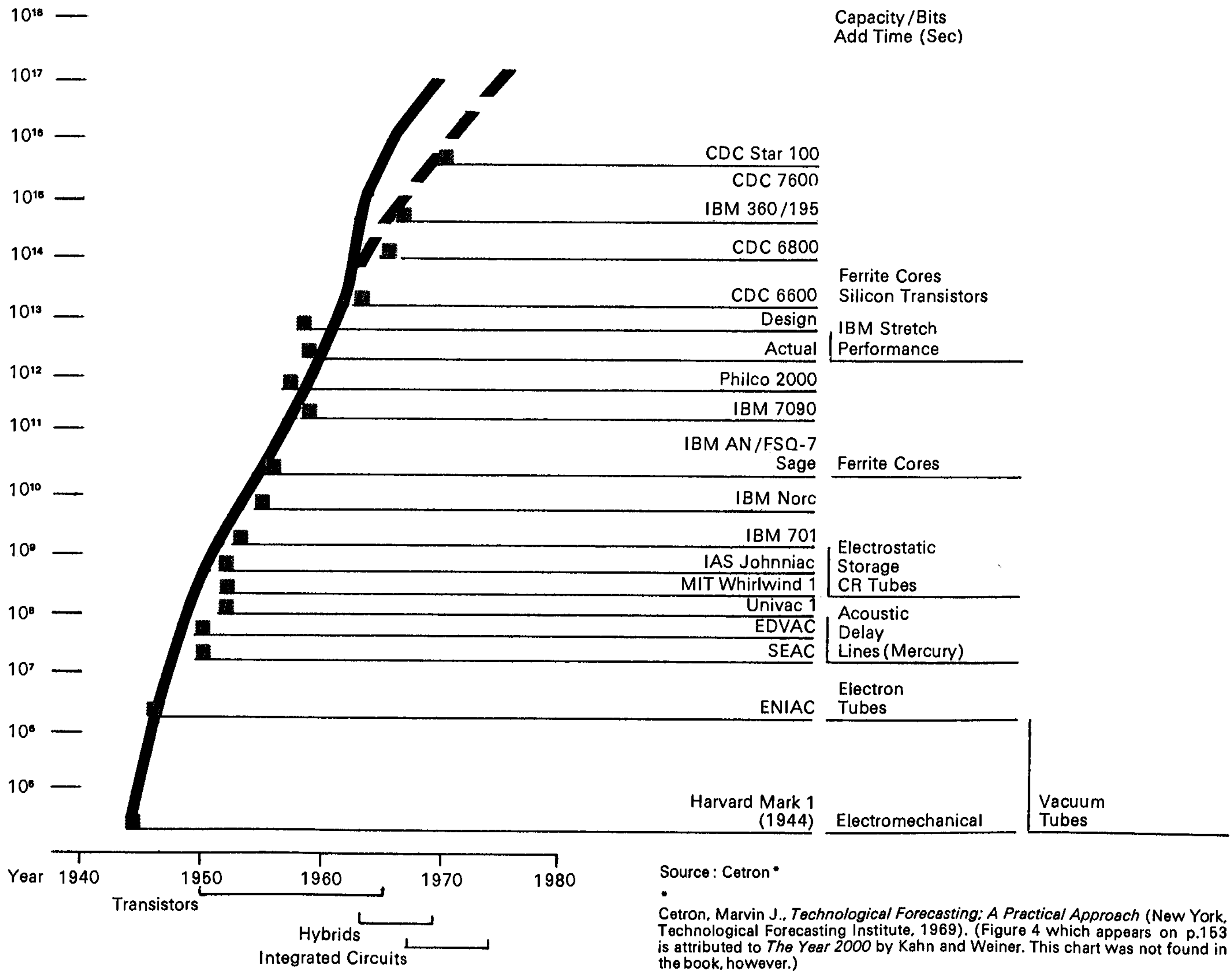
17 Martin, James and Norman, Adrian, *The Computerized Society; an Appraisal of the Impact of Computers on Society Over the Next Fifteen Years* (Englewood Cliffs, N.J., Prentice-Hall, Inc., 1970).

18 Knight, K.E., "Changes in Computer Performance", *Datamation*.

19 Martin, James and Norman, Adrian, *op. cit.*

Figure 2
Computer Trends



Source: Cetron*

* Cetron, Marvin J., *Technological Forecasting; A Practical Approach* (New York, Technological Forecasting Institute, 1969). (Figure 4 which appears on p.153 is attributed to *The Year 2000* by Kahn and Weiner. This chart was not found in the book, however.)

Straight-line extrapolation from this plot appears to be pessimistic, since the Star and ILLIAC IV computers both fall well above this line. However, it is possible that the observed rate of progress will continue.

The Star computer employs a type of organization known as pipeline processing, which is somewhat analogous to a car assembly line. Each individual instruction takes 1.28 microseconds to execute; however, execution requires a number of steps. A new operation can enter the assembly line or pipeline as soon as the previous instruction has completed the first step. Thus, as long as the operations are all of the same type, the work throughput is very high (up to one hundred million multiplications a second). If, however, the instruction type is changed, then the pipeline must be cleared out before the new instruction starts.

The ILLIAC IV employs a number of separate processors which operate in parallel in order to achieve its high speeds (sixteen parallel processors in the first machine). It has a similar limitation to the Star, in that in order to achieve the benefit of the parallel processing, all instructions must be of the same type (for example, all must be floating point additions). It should perhaps be mentioned that Star too has up to four parallel processing streams, although it is normally thought of as the archetype of a pipeline machine.

While there is no question that repetitive processing of the type required to take advantage of pipeline or parallel processors is encountered in many classes of problems, there are many others in which it is not. Furthermore, in order to boost the efficiency of these processors, software specially tailored to their architecture will be required. It remains to be seen to what extent this will be possible.

In summary, then, it appears that some slowdown in the rate of increase of speed of computers is to be expected. However this is unlikely to seriously affect the tendency towards very large computing installations (perhaps containing several computers), since there are economies to be derived from

Figure 3
Increase of Speed for High-Speed Computers

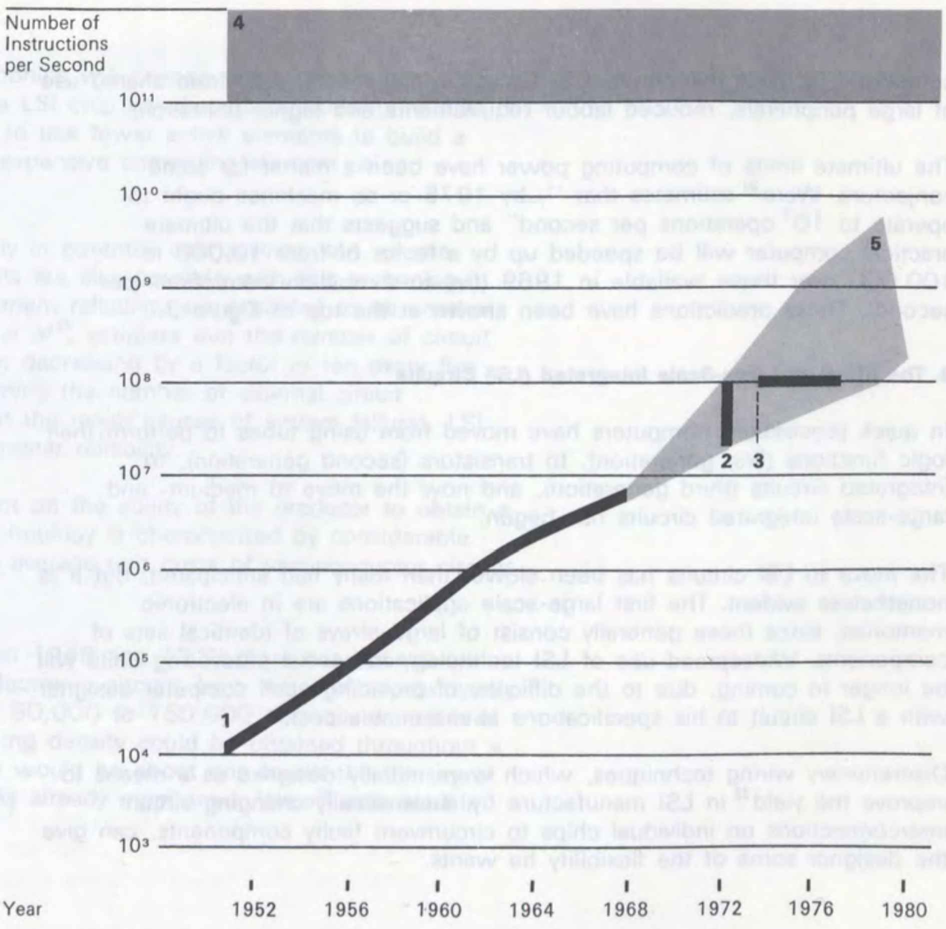
1
Prediction by Martin and Norman*

2
Estimated computation speed of the CDC Star 100

3
Prediction by Ware**

4
Approximate practical computation speed limit as predicted by Ware**

5
Predicted range of future development



*
Martin, James and Norman, Adrian, *The Computerized Society; an Appraisal of the Impact of Computers on Society Over the Next Fifteen Years* (Englewood Cliffs, N.J., Prentice-Hall, Inc., 1970).

**
Ware, Willis H., *On Limits in Computing Power* (Document No. P4208; California, The Rand Corporation, October, 1969).

centralized facilities independent of Grosch's law effects, *e.g.,* from shared use of large peripherals, reduced labour requirements and higher utilization.

The ultimate limits of computing power have been a matter for some conjecture. Ware[20] estimates that "...by 1975 or so machines ought to operate to 10^9 operations per second" and suggests that the ultimate practical computer will be speeded up by a factor of from 10,000 to 100,000 over those available in 1969 (five-to-six million instructions per second). These predictions have been shown at the top of Figure 3.

2. The Effect of Large-Scale Integrated (LSI) Circuits[21]

In quick procession, computers have moved from using tubes to perform their logic functions (first generation), to transistors (second generation), to integrated circuits (third generation), and now the move to medium- and large-scale integrated circuits has begun.

The move to LSI circuits has been slower than many had anticipated, but it is nonetheless evident. The first large-scale applications are in electronic memories, since these generally consist of large arrays of identical sets of components. Widespread use of LSI technology in central processing units will be longer in coming, due to the difficulty of providing each computer designer with a LSI circuit to his specifications at reasonable cost.

Discretionary wiring techniques, which were initially designed as a means to improve the yield[22] in LSI manufacture by automatically changing circuit interconnections on individual chips to circumvent faulty components, can give the designer some of the flexibility he wants.

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20 Ware, Willis H., *On Limits in Computing Power.*

21 Integrated circuits are electronic devices wherein an entire circuit — *viz.,* several transistors, resistors, capacitors, and interconnections — is fabricated on an extremely small "chip" of silicon. LSI is the simultaneous fabrication of 100 or more of such integrated circuits into one chip.

22 The term "yield" refers to the percentage of good devices manufactured. Successful manufacture requires closely controlled environmental conditions in order to achieve acceptable yields.

It is also likely that design philosophies will change when it becomes substantially cheaper to adapt to a LSI chip which perhaps does more than is desired a little more slowly, than to use fewer active elements to build a "more efficient" but much more expensive computing element using integrated circuits.

The advantages of LSI are primarily in potential cost-savings, but volume reductions and speed improvements are also possible with this technology. Substantial improvements in equipment reliability are expected to be another important benefit from LSI. Notz, *et al*[23], estimate that the number of circuit failures per 1,000 hours has been decreasing by a factor of ten every five years since 1950. By greatly reducing the number of external circuit interconnections (which are one of the major causes of system failure), LSI can continue this trend towards greater reliability.

Cost-savings are strongly dependent on the ability of the producer to obtain a large production run, since the technology is characterized by considerable development costs. The decline in average unit costs of semiconductor circuits is shown in Figure 4.

It has been estimated that between 1948 and 1970 there has been a reduction in the physical size of electronic circuits by a factor of approximately 100,000. Component densities of 50,000 to 150,000 per square inch are obtainable today. If the same packing density could be obtained throughout a cubic inch, the component density would be about one-fourth the density of nerve cells in the human brain[24]. As already mentioned, Ware[25] estimated in

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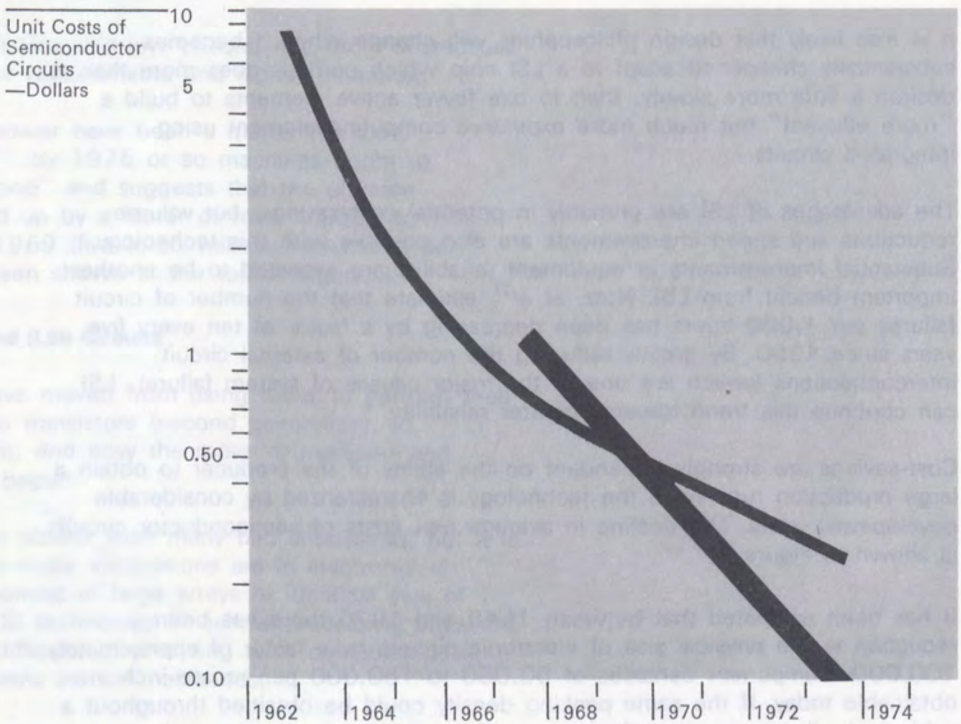
[23] Notz, William A., *et al*, "Large Scale Integration – Benefitting the System Designer", *Electronics*.

[24] Heath, F.G., "Large-Scale Integration in Electronics", *Scientific American*, Vol.222, No.2 (February, 1970), pp.22- 31.

[25] Ware, Willis H., *On Limits in Computing Power*.

Figure 4
Unit Costs of Semiconductor Circuits



Integrated Circuits

Integrated Electronic Components*

Source: Stanford Reasearch Institute**

* Equivalent to Medium-Scale Integration (MSI)

** Zeidler, H. M.; Lipinski, A. J.; Moll, L. J.; Shapiro, E.B.; Kent, W. A. and Wensley, J. H., *Patterns of Technology in Data Communications* (Stanford Research Institute Report No. 7379B-4) (Prepared for the Federal Communications Commission, Washington, D.C.) (Menlo Park, California, Stanford Research Institute, February, 1969).

1969 that there would be a 10,000-fold decrease in the size of electronic circuits in the two decades between 1955 and 1975. Ultimate ''conceptual limits'' for circuit densities of 16,000 gates per square inch have been quoted[26].

Speed improvements do not necessarily follow from greater component density. The ultra-fast computers were still being built with discrete components long after the introduction of integrated circuits (*e.g.*, the CDC 7600 announced in 1969). The reasons were that better component matching and increased design discretion were possible with discrete components. As circuit-switching speeds increase, the importance of the length of interconnecting leads increases correspondingly. It takes approximately 10^{-9} seconds for an electrical signal to travel one foot. Ultimately, ultra-fast computers will have to use LSI technology. In the mean time, manufacturers of ultra-high-speed equipment may well refrain from using LSI in critical circuits. This situation could well continue over the decade.

3. The Possible Impact of Associative Processing

Associative memories have been under investigation and development since 1957. The basic concept involves access of storage by specification of the contents of storage locations, rather than by specification of addresses of locations. Such memory systems usually contain additional control facilities to speed up accessing where not all of the storage is involved.

All words requiring a search are interrogated at the same time and all words which match the search criteria set a switch in a response register. Thus, assuming three machine cycles to set the selection criteria, only one more cycle is needed to interrogate all (or a selected portion) of the storage.

Because the logical tests are essentially performed at each memory location,

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26 Zeidler, H.M.; Lipinski, A.J.; Moll, L.J.; Shapiro, E.B.; Kent, W.A. and Wensley, J.H., *Patterns of Technology in Data Processing and Data Communications (Stanford Research Institute Report No. 7379B-4)* (Prepared for the Federal Communications Commission, Washington, D.C.) (Menlo Park, California, Stanford Research Institute, February, 1969).

instead of the more usual process of reading each word out of the memory in serial fashion and performing the tests in the central processing unit, each word of an associative memory contains some logic circuitry of its own. For this reason, associative storage is more expensive than conventional memory, but it can carry out complex search operations much more quickly than conventional memories. The cost trade-off is involved with the time of parallel operation *versus* conventional serial operation.

The major areas of use of associative memories are:

- buffer memories
- peripheral memories
- primary memories

Buffer-memory use is in current practice. The IBM 360, Model 85 uses a large (up to 32,768 16-bit words) associative memory to improve the performance of a machine whose primary memory is quite slow.

Similar use of associative memories is made in modern, very high-speed computers for special internal registers, and in various advanced peripheral devices, such as modern disc units with special search capabilities. This type of application will be relatively standard in many computer-systems within the next four-to-five years.

During 1972, Rome Air Development Centre is expected to go out for bids on a system which has 4,096 words of 288-bit primary associative memory with a fast 10^8-bit backup memory. The primary memory can be loaded in 100 microseconds. This system is expected to be capable of a search through all 4,096 words (or some field within the words) in 100 nano-seconds. It is expected that the system will take four-to-five years to complete.

The concepts which were being explored in 1957 are beginning to come to fruition. However, before associative memory hardware can realize its full potential, new programming techniques and methods will have to be developed, along with new methods of solving problems. In addition, these methods and techniques will have to be embodied in compilers handling existing languages, so that the broad majority of computer users will not be required to undertake extensive retraining. The time-scale for such developments is long, even if some of the best developmental talent available today is applied to the task. For these reasons, it is not felt that systems using associative memory for primary storage will have a significant impact in the next ten years. At the end of the decade the situation may change due to pressure from users of large data bases.

4. The Optical Computer

The Laser Computer Corporation (formerly Computer General Inc.) claims to have developed an optical computer with performance specifications which can only be labelled fantastic. The computer, called the CG-100, was originally scheduled for delivery to the first customer in May, 1971. What the final delivery date will be is uncertain.

Details of the machine are a closely-guarded secret, but the computer is said to have a main storage of 10^{13} bits with a read/write cycle time of twenty nano-seconds. Storage costs are supposed to be of the order of 10^{-7} cents per bit, and the purchase price for the computer is said to be $1.6 million, or about 10 percent of the cost of an IBM 360/195 which has a memory one-three-hundred-thousandth the size of the CG-100 memory (*i.e.*, 32.5 million bits)[27].

There is some skepticism about the ability of the company to produce the computer. Nonetheless, most experts agree that the computer is theoretically possible as a laboratory model. The skepticism originates from doubts about the ability of anyone to produce such machines commercially at this time.

At the time of going to press, it would appear that this venture has not been able to fulfill its promises. However, such concepts as these do indicate the extraordinary potential of computer technology.

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[27] Weber, Samuel and Parkinson, Gerald, "Optical Computer Reads Like a Dream....", *Electronics*, Vol.44, No.7 (March 29, 1971), pp.81-2; and, Myers, Edith, "He Dreams the Impossible Dream...or Does He?", *Datamation*, Vol.17, No.13 (July 1, 1971), pp.52-3.

5. Intelligent Machines

Although they are most unlikely to be in general use during the next decade, work on so-called "intelligent processors", or processors with a learning capability, is proceeding on both sides of the Atlantic. Simulation work for such processors has continued for some time, and adaptive microcircuits are now being produced in reasonable quantities. It is claimed[28] that, by combining these adaptive elements into large arrays with electrical feedback, learning processes analogous to human learning can be achieved. At the University of Kent in England, a rudimentary array of these adaptive devices has been "trained" to recognize some distorted consonant sounds and to produce the perfect sounds at the output, all for a small fraction of the cost incurred using a conventional computer to perform the pattern recognition and clean-up process.

6. Software

Although concrete figures are difficult to uncover, there is no doubt that software costs comprise a very large fraction of total computer-system costs. An often quoted rule-of-thumb is that a computer manufacturer can expect to spend approximately equivalent amounts in software and hardware development of new computers. Once the new computer is in the hands of the individual user, he is likely to expend a further 50 percent to 100 percent of his computer hardware costs in application programming effort.

Frost and Sullivan[29] estimated that the cost per instruction for an average program has dropped 25 percent in the past ten years, and may drop a further 25 percent in the next ten years. Although this is not a very large drop in programming costs, there have in fact been enormous improvements in programming technology, and further substantial developments are expected to occur in the future. The reasons why these have not been reflected in lower costs will be discussed below, after first describing some of the factors which lead to advances in programming technology.

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[28] Aleksander, Igor, "Electronics for Intelligent Machines", *New Scientist and Science Journal*, Vol.49, No.742 (March 11, 1971), pp.554-5.

[29] In a recent study quoted in *Computerworld* (December 22, 1971).

(a) Improvements in Programming Technology

One of the most important factors is the use of more powerful and concise programming languages. In this respect, one of the best languages is A Programming Language (APL), which shortens the length of the programs that the user must write by between one and two orders of magnitude in general, and by as much as three orders of magnitude in special cases. By way of comparison, Fortran programs are typically four times shorter than the corresponding machine language programs. Specialized programming languages and packages of sub-routines can offer even greater brevity of expression to the user in particular cases. For example, there have been dozens of languages developed for various kinds of simulation which relieve the user of the details of scheduling events in the simulation, allowing him to concentrate on the logical relationships between events. As another example, large integrated packages of sub-routines for civil engineering calculations are finding wide application in the design of buildings and highways.

Another of the factors leading to some reduction in programming costs has been the development of a number of systems or languages for use by systems analysts in formulating descriptions of programs or systems at a suitable level of detail. The amount of detailed work required of a systems analyst (whose job it is to prescribe the method of solution of a problem, leaving to the programmer the job of implementing his solution) should be just enough so that the programmer can proceed without additional information. Many companies have attempted to create a formal system of communication between the systems analyst and the programmer, primarily to regularize the systems-analysis function and make it more amenable to management. In Canada, a successful example of such a system is the SCOT program developed by Great West Life in Winnipeg. It has been successfully marketed to over forty companies. It seems likely that, in the next few years, standards-making bodies will work toward a standard system specification language, making use of many of the commom elements of languages now in existence.

A third important factor in improving programming technology is the easy availability, through modern operating systems, of an ever-increasing library of commonly used sub-routines, utilities and programming aids, often provided at little or no charge by the originator. These range from massive packages for statistical analysis and mathematical programming, to complex file updating and sort/merge routines. Although thousands of programs have been written in these categories, most of them are not widely used, even though they perform very nearly the same function as many others. The greatest difficulty in this area is to find efficient means for the co-ordination and dissemination of knowledge regarding what is already available for any given task. As the computer industry matures, it is to be expected that this situation will gradually improve, with more directories of tested programs being established and used.

One of the difficulties that must be overcome is the problem of transferring a program from one environment to another. Even with widely-used languages, such as Cobol or Fortran, there are difficulties in transferring a source-program from one machine to another, and the problem is more severe when programs are written in other languages. Considerable research effort is being expended to improve this situation, particularly with regard to the complications created by differing environments. The General Services Administration of the U.S. Federal Government is attempting to encourage programming language stabilization. It has introduced a requirement that all the software purchased through it be written in one of the common languages for which there are agreed standards.

Time-sharing is another important factor in improving programming technology. From the programmer's point of view, time-sharing is a way of obtaining, on demand, a sufficient share in the use of a computer (including CPU time slots, memory resources, and programming aids) to permit progress at a rate which is constrained only by the programmer's ability, and not by any difficulties in gaining access to the computer. Attempts to measure the resulting improvements in programmer productivity have so far failed, primarily because of large variations in the natural abilities of programmers. The sharing of computer-system resources in such a way that several people have apparent use of the computer on demand naturally results in computer usage overheads that would not otherwise be present. The resultant loss of efficiency in computer utilization is judged by the proponents of time-sharing to be more than offset by improvements in programming efficiency. Time-sharing is, of course, a commonly-used technique in many applications other than program development. It is generally indispensable in any type of application (such as airline reservations) where a variety of users need access to random segments of data and programs.

Another factor which has had a favourable effect on programming costs, and is likely to have an increasing impact in the future, is the continuing development of standard compilers in order to make them more powerful and more adaptable, and to provide the programmer with diagnostics to permit him to detect and locate programming errors with much less loss of time.

(b) Reductions in the Cost of Programming

As mentioned above, programming costs have not come down as rapidly as expected. While this is due, in part, to increased salaries and a high management and documentation overhead in programming projects, these do not, of themselves, suffice to explain the continuing high costs.

Part of the reason for the apparent slow rate of decrease in programming costs is the difficulty of finding programs with an equal level of complexity to use as a basis for comparison. There can be no doubt that average program complexity has greatly increased over the last decade. J.D. Aron[30] has compiled a figure (Figure 5) which summarizes historical data on programming costs from a number of large IBM projects. He has also verified the figure against some non-IBM projects. The projects include both system and application programs. Mr. Aron noted that the figure was as valid in 1969 as it was in 1960, which suggests that programming costs for large programs

[30] Aron, J.D., "Estimating Resources for Large Programming Systems", *Software Engineering Techniques (Report on the Conference Sponsored by the NATO Science Committee, Rome, Italy, 27-31 October, 1969)* (April, 1970), pp.68-79 (available from the Scientific Affairs Division, NATO, Brussels 39, Belgium).

have not decreased over the period. There are several reasons why this should be so:

- Improvements in diagnostic capability have not materially influenced the major portion of debugging costs for large programs, which arise from the interactions amongst program elements which are brought together from different sources.
- Untrained programmers enter the field at such a rate that the average ability to use programming know-how does not improve.
- Programmers fail to learn better methods.
- Programs are getting more difficult at the same rate that programmer skills improve. This implies that as computers become more powerful we use them to tackle harder problems.

Mr. Aron believes that the last reason is the most important factor.

Examination of Figure 5 yields some interesting results. For example, short-duration easy projects appear to have about half of the productivity of long-duration easy projects. This can probably be accounted for by the higher overhead associated with the larger staff required to accomplish tasks in a shorter time-period. On the other hand, short- and long-duration difficult projects have about the same productivity, indicating that project complexity is much more significant than overhead costs. The degree of difficulty of the projects has been measured by the extent of interaction of the program with other elements of the complete system, as indicated on the right-hand side of the figure. Mr. Aron assumes that if the duration and degree of difficulty of a project are fixed, programming costs are a strictly linear function of the number of instructions in the program, whereas the longer a project can be permitted to take, the more nearly it approaches the minimum cost per instruction realized for projects of duration greater than twenty-four months.

There is thus a basic dilemma facing any one who attempts to measure improvements in programming efficiency, for it would appear that the rate at which new and more difficult programming systems are tackled either exceeds, or is about equal to, the rate of improvement in our understanding of programming systems.

Figure 5
Software Productivity Table

Row	Difficulty	Duration: 6 Months	12 Months	More than 24 Months	
Row 1	Easy	20	500	10,000	Very Few Interactions
Row 2	Medium	10	250	5,000	Some Interactions
Row 3	Difficult	5	125	1,500	Many Interactions
	Units	Instructions per Man-Day	Instructions per Man-Month	Instructions per Man-Year	

Source: J. D. Aron

(c) Improvements in the Technology of Compilers

There have been very few studies done that attempt quantitative measures of the relative performance of different compilers.

Two principal reasons exist for the relative lack of more detailed studies:

- Research has concentrated on making improvements to compilers and not on measuring the end result.
- The different factors that must be considered in any proper comparison of compilers are complex. A partial list would include:
  (i) Do the machine language versions of programs translated by the compiler make the maximum efficient use of the computing resources? Amongst the resources which need to be conserved are: length of compiler time on the computer, amount of memory required for program storage (*i.e.*, efficiency of memory utilization in performing the job), and amount of computer time required to execute the program (*i.e.*, the efficiency of the code in performing the job)?
  (ii) Does the compiler translate directly into machine language, or is there some post-processing required on the output from the compiler before it can run on the computer?
  (iii) Are all the features of the source language translated by the compiler?
  (iv) How much overhead required during translation is charged to the compiler, and how much is absorbed by the operating system, particularly input/output overhead?
  (v) Does the computer which is doing the translations have any special characteristics which make it particularly well- or ill-suited for doing translation?
  (vi) Is extensive error-checking and correcting done during translation?

A few figures can be given to roughly indicate improvements in the technology of compiling over the past decade. These figures are measurements of compiler speed, expressed in "instructions executed (during translation) per source card compiled" (i.e./s.c.c.). This is a very interesting measure of compiling speed, as it is relatively independent of computer speed, allowing compilers on different computers to be easily compared. The figures are taken from a report by C. E. Earnest[31] of New York University. About ten years ago, an IBM 7094 Algol compiler ran at about 137,000

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[31] Earnest, C.E., "Appendix II: Comments on Industrial Compiler Practice", in *Programming Languages and Their Compilers* (Preliminary Notes, Second Revised Version) by John Cocke and J.T. Schwartz (New York, New York University, Courant Institute of Mathematical Sciences, April, 1970).

i.e./s.c.c. About five years ago, Fortran H on the IBM 360/65 ran at about 37,000 i.e./s.c.c. The UNIVAC 1108 Fortran compiler runs at about 14,000 i.e./s.c.c., and it is an optimizing compiler (*i.e.,* it contains many extra instructions designed to produce highly efficient translated versions of the source programs it receives). These figures are sufficiently imprecise that to plot them and draw a trend line to forecast future compiler speeds is pointless. The best one can say, and it is undoubtedly true, is that there will be further substantial improvements in the future. Techniques for measurement of compiler performance should also improve in coming years.

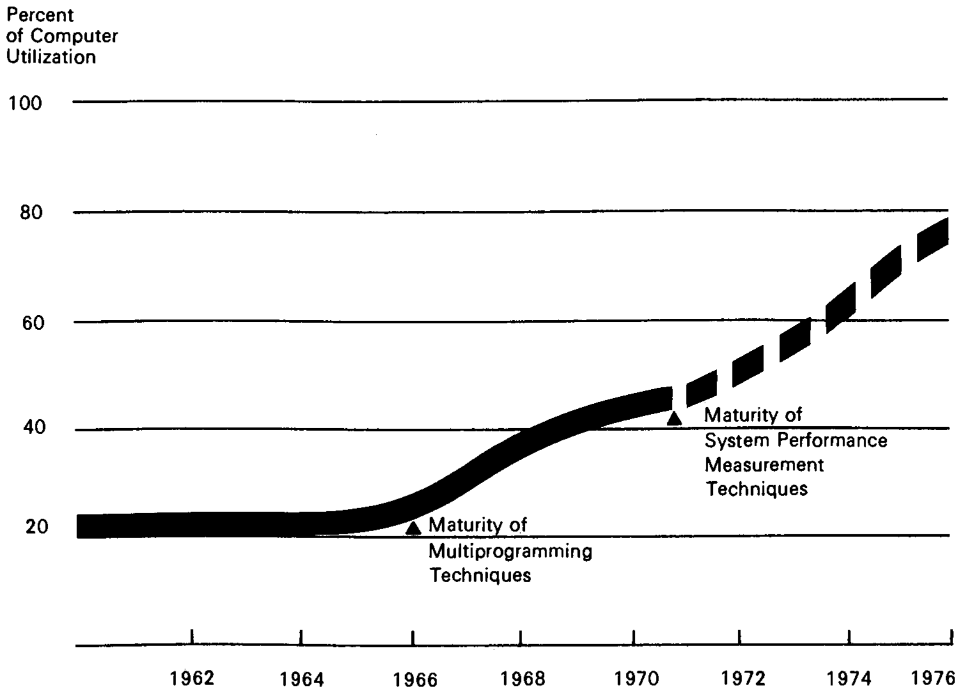
(d) Improvements in Operating System Performance

Recently, there has been considerable interest in computer-system performance, by which is meant essentially operating system performance. Many computer installations are beginning to measure how successful their operating systems are in allocating resources to the different activities in the system. It is anticipated that as these measurement techniques are refined, and as they become more widely used, substantial improvements in efficiency of computer utilization will result. (See Figure 6.) The result of the improvements will not, of course, be to reduce programming costs, but rather it should lead to reduced costs for program execution in the computer.

7. The Effect of Microprogramming Development

Recently, there has been a resurgence in the use of microprogrammed instructions. This facility essentially allows the machine user to devise his own instruction set out of a much smaller subset of micro-instructions. In the earlier microprogrammed machines, microprograms were usually stored in Read-Only-Memory (ROM), so that changes in the instruction set required a physical change in the ROM. In the newer machines, however, microprograms are more easily altered, though frequent alteration is still not easy in most cases. The efficacy of microprogramming is strongly dependent on the existence of small, but very fast, memories which can cycle at least several times during a main memory cycle period.

Figure 6
The Projected Effect of Multiprogramming and System Performance Measurement Techniques on Computer Efficiency



Source: Auerbach*

* Auerbach Technology Evaluation Service, *Computer Software* (E.D.P. Series No. 7; Philadelphia, Pennsylvania, Auerbach Information Inc., 1971).

The applications of microprogramming are generally as follows[32]:

- As a simplified method of providing a complex and varied instruction set for the computer.
- To make emulation of earlier computers and sometimes earlier operating systems easier.
- To provide unique instructions for special devices; for example, to provide special instructions for data communications systems or graphics processors.
- To provide support for user-oriented systems (for example, a special microprogram set for Fortran has been suggested).
- To provide special instructions for system maintenance, and to enhance system reliability by providing an emergency microprogrammed "back-up" instruction for complex hardware instruction implementations.

It would appear that the primary impact of microprogramming will be on the small computers. Here it will help stem tendencies towards numerous, highly-specialized mini-computers by allowing one microprogrammed machine to adapt to several purposes, though probably at the expense of some loss in processing speed. For example, special microprograms could adapt the same mini-computer for such diverse tasks as typesetting, oil refinery control and patient-monitoring in a hospital.

It is likely that the larger computers will also continue the trend towards microprogramming, though not at the expense of elaborate hardware instructions. It seems more likely that their principal application will be for the more efficient implementation of special-purpose instructions in language processors and in control software, and for the emulation of other computers.

8. Memories

Along with the logic elements discussed under the heading of large-scale integrated circuits, memory elements are basic to digital computer operation. They also are a major element of the computer system cost. Fast-access memory accounted for 20-to-25 percent of the $7,500,000,000 expenditure

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32 Flynn, M.J. and Rosin, R.F., "Microprogramming: An Introduction and a Viewpoint", *IEEE Transactions on Computers*, Vol.C-20, No.7 (July, 1971), pp.727-31.

on computer systems in the U.S. in 1970[33]. Slower-access memory (drums, discs and tape units) probably accounted for another 15-to-25 percent of expenditures.

(a) Memories and Data Banks

Apart from their key role in the basic operation of computers, memories are, of course, essential to the operation of computerized data banks. In particular, the availability of large memories of low cost and easy access, coupled with a growing demand for large data bases, is likely to lead to the establishment of very large computerized data banks during the decade.

These data banks will not arrive overnight, even though the basic memory elements are now available. We have yet to learn how to sort and search through large data bases efficiently. Nor do we have any established data-base manipulation languages or formats. But these will surely evolve quickly. The cheap mini-computer and expensive associative memories will both play a role in reducing data search costs. Proposed standard data-base languages have already been published by the American National Standards Institute. Whether or not these achieve widespread usage, the pressures are surely there for the evolution of some standards in this area.

Thus, it would appear that the required concurrence of societal need and technological competence exists for the substantial growth of large-scale data banks over the decade.

(b) Memory Cost

Cost data for memories of various types are plotted in Figures 7 and 8.

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33 "Why Cores Could Become Just a Memory". *Business Week*, No.2156 (December 26, 1970), pp.60-1.

Figure 7
High-Speed Memory Costs

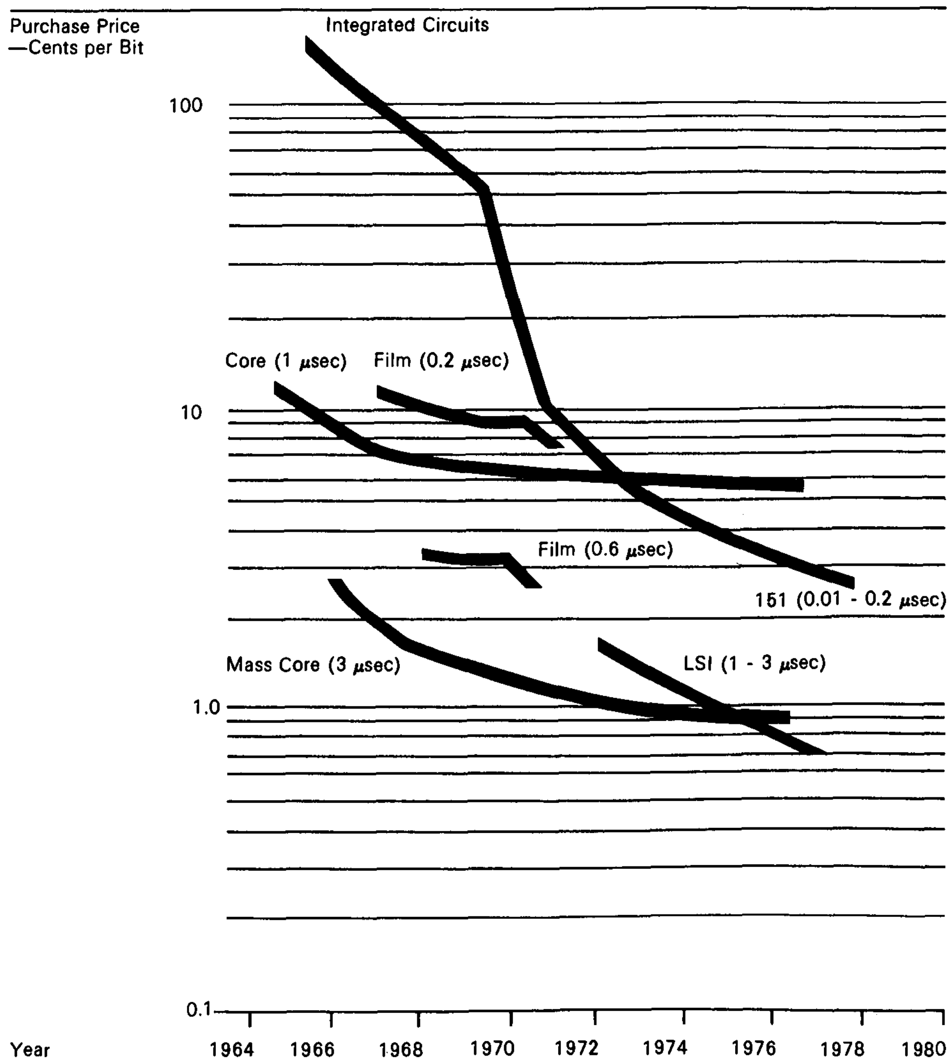
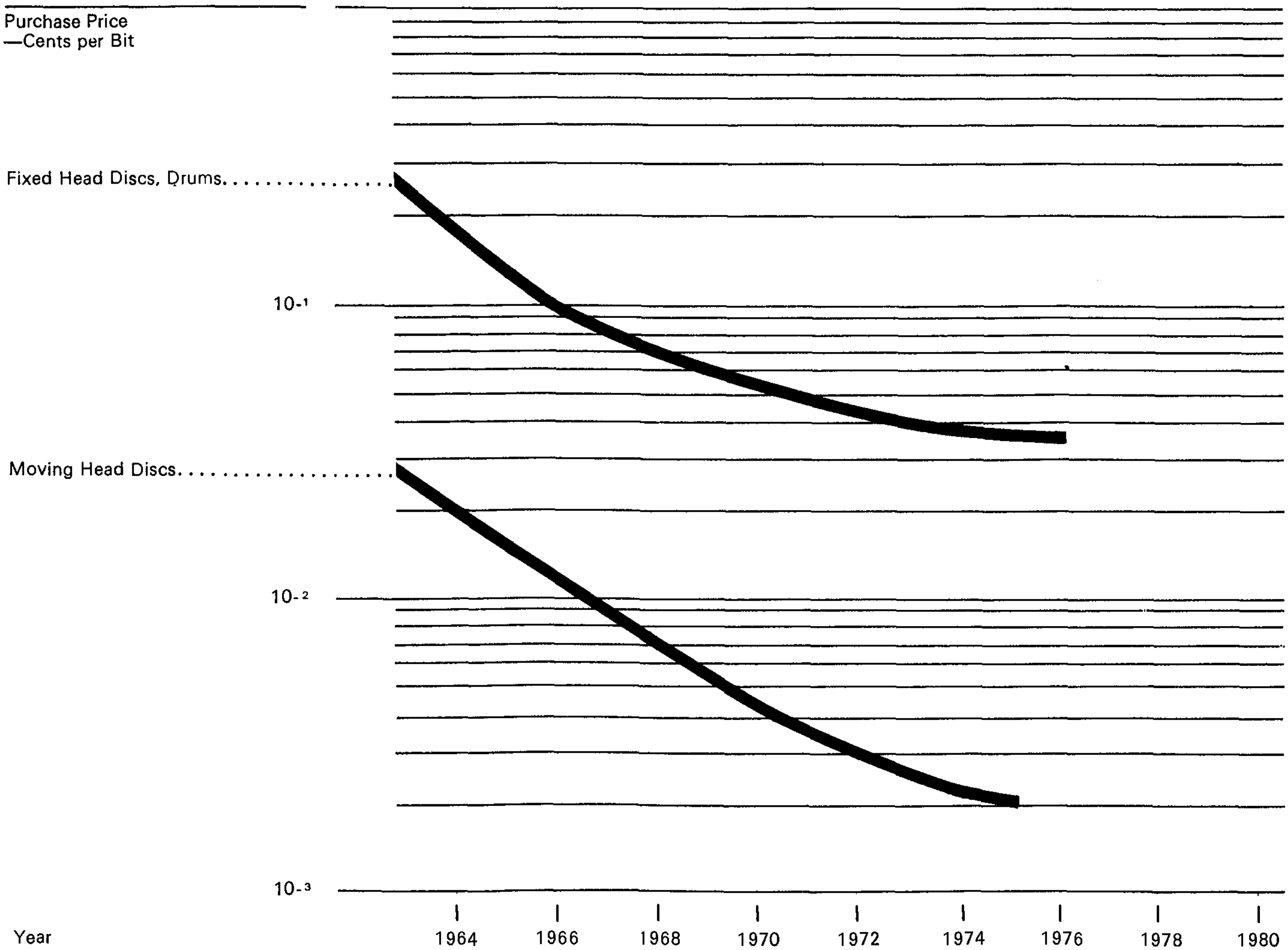
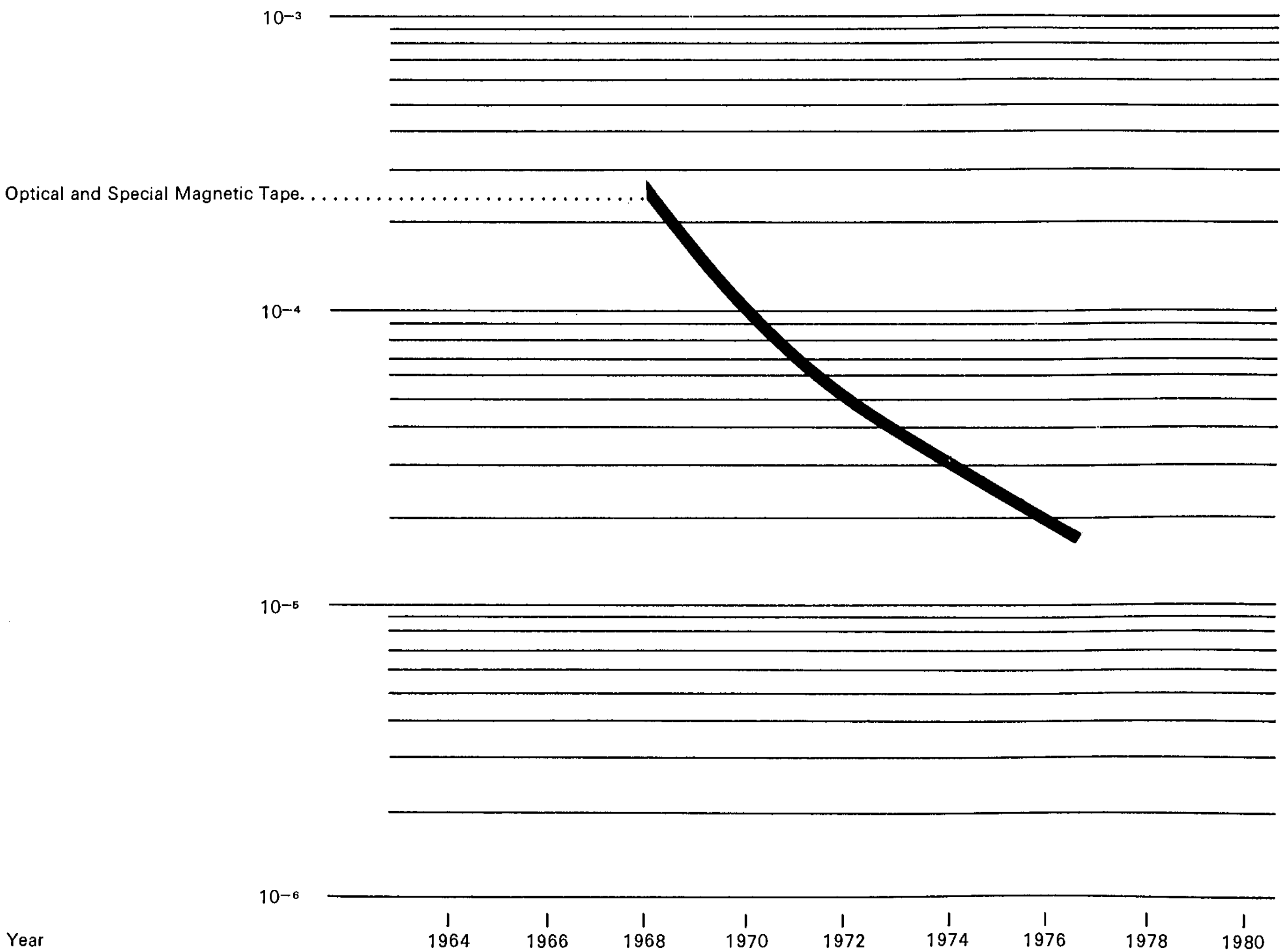


Figure 8
Low-Speed Memory Costs





10−3
Optical and Special Magnetic Tape
10−4
10−5
10−6
Year
1964
1966
1968
1970
1972
1974
1976
1978
1980

The primary source of information for these plots was the Stanford Research Institute forecast[34], but it has been updated by information obtained from various sources. As can be seen from the figures, there is a wide variation in both costs, and performance amongst the various types of memory available. For the sake of discussion, memories will be divided into the following categories:

- Rapid-access memory (<10 microsecond access)
- Slower-access on-line memory
- Off-line memory
- Micrographic memory

Because of the much greater cost of high-performance memory, there is an increasing trend towards a complex hierarchical memory structure which is organized in such a way that CPU data requirements are anticipated far enough ahead of time for peripheral processors to access the data from slow memory and move it up through the hierarchy into fast memory. The larger memory systems require a small computer to manage data accesses and transfers on a full-time basis, thus helping to reduce software overhead in the main computer.

After spending some years in the technological wilderness (having been available on some computer-systems as long ago as 1964) virtual memory is at last coming into its own. Systems with this feature permit the programmer to ignore the size of core and other memories on the computer, and leave it up to the computer monitor to ensure that the correct program and data elements are in executable memory when required. The virtual memory feature requires little modification to the memory itself. The major difficulty in virtual memory implementation lies in the writing of suitable control software, and in the provision of special-purpose hardware in the CPU to fetch the "pages" of data from slow memory as required. However, one effect of the feature is likely to be that the demand for executable memory is slowed down, due to the more efficient use of memory that a virtual memory system provides in most cases. Two other important effects are the reduced burden on the programmer, who no longer has to be as concerned with the transfers of data through the memory hierarchy, and the greatly reduced dependence of

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[34] Zeidler, H.M., *et al, op. cit.*

programs on particular computer memory configurations, which allows greatly increased program portability between differing computer-systems.

9. Rapid-Access Memories

(a) Core Memories

Since the 1950's, magnetic-core memories have been traditionally used for rapid-access memories. Core memory has undergone intensive development, and it seems unlikely that significant performance or cost improvements are on the horizon. The fastest core memories now available have a cycle time of the order of 200 nano-seconds, and cycle times in the range of 750-to-1,500 nano-seconds are common. In 1970, it was estimated that sales of core memories amounted to approximately 100 percent of the market for rapid-access memories, a market of one-and-a-half to two billion dollars in the U.S. alone. It has been predicted by one core memory manufacturer that, although core sales will continue to increase until 1975, the share of the market will, by that time, be only 50 percent, the remainder having been taken over by large-scale integrated circuit semiconductor memories[35].

A major disadvantage of core memory is that it cannot be fabricated in large batches, but rather each must be threaded separately, though there are machines capable of threading the cores automatically. In order to reduce power consumption and increase speed it is desirable to use the smallest cores possible. Cores with a twelve-to-thirteen-mil outer diameter and a seven-mil inner diameter are being successfully wired, and eight-to-ten-mil cores can be wired. The limiting constraints appear to be the increasing electrical resistance of the finer wires used to thread the cores, and the decreasing fracture strength of the smaller cores (the fracture strength of thirteen-mil cores is less than fifty grams)[36]. Power consumption in small-core

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35 "Why Cores Could Become Just a Memory". *Business Week*.

36 Koehler, Frederick H., "An Impartial Look at Semiconductors". *Datamation*, Vol.17, No.14 (July 15, 1971), pp.42-6.

memories is strictly comparable to, and, in high performance memories, somewhat lower than, power consumption in today's electronic memories. Power consumption for core memories as low as 0.25 milliwatts per bit is quoted by Koehler[37].

(b) Semiconductor Memories

A major advantage of semiconductor memory is that costs are relatively independent of size of organization, and it is thus particularly competitive with core when relatively small memories are required. Furthermore, unlike core, it is amenable to batch production. Indeed it shares the characteristic common to all LSI circuitry of high development costs and relatively low production costs. There is still widely-ranging experimentation on circuit types and materials. The competing technologies of bipolar and Metal Oxide Semiconductors (MOS) are becoming blurred as work proceeds on hydrid designs. Circuit types are also in a fluid state, as variations on the basic flip-flop circuit are developed. In particular, charge storage memory elements, which make use of capacitive effects for memory storage, show promise of significantly improved packing densities with reduced power dissipation (one-tenth of a milliwatt per bit has been reported)[38]. It seems likely that over the next five years the circuit types and technology will stabilize into a few specific approaches, each optimum for particular memory requirements. Koehler[39] has identified the current lack of standardized LSI memory circuits (with a corresponding lack of second-source memory suppliers) as the major problem to be faced by suppliers of electronic memories. Until this problem is solved, he maintains that sales will be drastically curtailed.

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37 *Ibid.*

38 Vadasz, L.L.; Chua, H.T. and Grove, A.S., "Semiconductor Random-Access Memories", *IEEE Spectrum*, Vol.8, No.5 (May, 1971), pp.40-8.

39 Koehler, Frederick H., *op. cit.*

The principal advantages of semiconductor memories are their speed (cycle times as short as ten nano-seconds or less) and their compatibility with logic elements in the central processing units. The principal disadvantages have been their volatility (unlike core memory, if power is lost the contents of the memory are erased) and, until the advent of LSI, their expense. As can be seen from Figure 7, projected costs are now very near the cross-over point with high-speed core memory. They should be less than half the cost of core memories of equivalent performance (for most applications) by the mid-1970's.

(c) Thin Film and Plated Wire Memories

Thin film and plated wire memories, once thought to be the successors to core memories, have not materialized as expected. Plated wire memories are still in use in limited applications, particularly in military systems. The major cause for lack of development has been the difficulty in obtaining sufficiently high yields, and the related problem of achieving process repeatability.

(d) Ovonic Devices

Considerable mystery and drama has surrounded the development of these amorphous (glass) switches and memory. Development of these devices continued for several years without a clear understanding of their theory of operation. Many attractive claims have been made concerning their potential for extremely high switching speed, non-volatility of the memory, and their potential cheap manufacture. The first Ovonic device is now being marketed. It is a 256-bit "Read Mostly Memory", which has a non-destructive read-time of 100 nano-seconds and a write-time of two-to-ten milliseconds. It sells for $60.00 in quantities of 100[40].

Recently a theory of operation for Ovonic devices has been confirmed[41], based on providing enough heat to crystallize the glass in a small "filament". Under

[40] "L'Effet Ovshinsky est au salon". *Inter electronique* (April 2, 1971), pp.56-7.

[41] "Ovshinsky Hot and Cold". *Nature*, Vol.231, No.5301 (June 4, 1971), pp.284-5.

such circumstances, it seems unlikely that the glowing promise of these devices as memory elements will be fulfilled, though they may well find application elsewhere.

(e) Josephson Effect Memories

The Josephson effect was first predicted by Brian Josephson at Cambridge University in 1962, and was observed in several U.S. laboratories within a year. The now well-confirmed prediction was that "...if two super conductors were weakly coupled, a d.c. current would flow or tunnel between them without any potential being applied". It was further predicted that "...a bias applied across the super conductors would generate an a.c. current with frequency proportional to the bias level".[42]

Some interesting work is proceeding on fabrication of high-speed cryogenic memories making use of the combined effects of normal tunnelling, and Josephson tunnelling through thin insulators separating two super conductors[43]. The potential advantages of this technology are:

- Memory cycle times in the range of fifteen-to-forty nano-seconds appear reasonable. Even faster cycle times may be possible.
- Power consumption is extremely low and is required only when reading from, or writing in, memory. (It has been estimated that power consumed in the memory is about one ten-thousandth of that consumed by an equivalent semiconductor memory.)
- High packing densities are predicted (about 10^8 bits per cubic foot).
- Address decoding can be carried out in the memory, so that very few lead-outs are needed to connect the memory to external circuitry.

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[42] Doyle, Owen, "Josephson Junctions Leave the Lab...but Only a Few at a Time", *Electronics*, Vol.44, No.5 (March 1, 1971), pp.38-42.

[43] Anacker, Wilhelm, "Potential of Superconductive Josephson Tunneling Technology for Ultrahigh Performance Memories and Processors", *IEEE Transactions on Magnetics*, Vol.MAG-5, No.4 (December, 1969), pp.968-75.

Unfortunately, considerable development is yet required on this memory, and it is anticipated that it will be about ten years before memories based on this technology are marketable. One interesting problem which is anticipated is the difficulty of servicing a memory which is operational only at temperatures near 3.6° Kelvin (-447°F). It is not possible at this early stage of development to make any sensible cost predictions.

It is interesting to note that high-speed memories are only one potential area of exploitation of the Josephson effect. Josephson junctions are already in use by the National Bureau of Standards in Washington as a primary voltage standard, with an accuracy of several parts in 10^8. Applications (in various stages of development) include their use as supersensitive magnetometers (sensitivities down to 10^{-11} gauss have been achieved) and high-sensitivity voltage (10^{-11} volts) and current (10^{-11} amperes) meters[44].

Of particular interest in the communications field is the potential use of the Josephson junction as a highly sensitive frequency convertor at frequencies "ranging from radio to far infrared"[45].

10. Slower-Access On-Line Memories

This class of memory comprises all those memory elements which cannot easily be located remotely from the computer-system but which do not fall into the category of rapid-access memories. The following are included under this heading:

- Magnetic drums and fixed-head discs
- Some optical memory systems
- Magnetic-bubble memories
- Charge-coupled devices

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44 Doyle, Owen, *op. cit.*

45 Longacre, Andrew, "A Josephson Frequency Converter", *Electronics*, Vol.44, No.5 (March 1, 1971), pp.44-6.

(a) Magnetic Drums and Fixed-Head Discs

These devices have been available in various forms for many years, in a wide range of speeds and capacities. Capacities normally vary between 10^5 and 10^9 bits, and average access-times are normally in the range of 5-to-100 milliseconds. Transfer rates, once the first data word has been accessed, are also highly variable in the general range, which is 10^5-to-10^7 b/s. This speed of read-out is normally accomplished by parallel reads from several tracks simultaneously.

There has been a steady trend towards larger, faster and more economic disc and drum units. As with core memories, disc and drum development is at a fairly mature stage, and it would appear that order-of-magnitude improvements are unlikely to be seen over the next ten years, though recent improvements in magnetic coating materials will undoubtedly lead to performance gains.

As the price of integrated circuit memory declines, the smaller units will become uneconomic. It is likely that development will be concentrated on large units with very high transfer rates and latencies of the order of ten msec. They will be used to provide fast core swapping in large computer installations. Prices of about 0.05 cents per bit for 500-megabit units appear to be reasonable within the next few years. This is a factor of about ten less than the likely price of slow electronic memory.

(b) Optical Memory Systems

Several ultra-large optical memory systems are either completed or are under development. The IBM Model 1360 "Photo-Digital Storage System" was one of the first available (in late 1967). It had a capacity of one trillion (10^{12}) bits. Data was stored on small film chips by an electron beam. This system was built to satisfy a special requirement and is not in the regular IBM product line.

A more recent development is the Precision Instrument "Unicon" memory, containing 10^{12} bits of storage. This memory system employs a laser beam to record on a special film, which once written on cannot be erased. (Since the film itself is very cheap, and the bit packing density is high, this may not be a significant disadvantage.) Each "strip pack" of film will store approximately two billion bits, which are accessible in approximately 100 milliseconds. Provision is made for the automatic selection of any one of 450 strips with an access-time in the order of twenty-to-thirty seconds. Since a complete system sells for about $1.6 million[46], the cost per bit is about 1.6×10^{-4} cents.

Holographic memory devices of similar size are also under development. The storage densities obtainable are comparable to those obtained by the "point-by-point" Unicon method (10^8 bits per square inch); however, holographic methods have the significant advantage that they have a low sensitivity to dust or other defects on the recording medium, since information on any one single bit is dispersed over a much wider area (and intermingled with information from other bits). A 10^{12}-bit holographic memory is reported to be under development at Radiation Incorporated in the U.S. and should be available in 1973. Work is also in progress in Russia[47].

RCA are working on a holographic memory of smaller size and faster access, using an erasable memory. The holograms are recorded by heating a manganese bismuth film to the Curie point at regions of high light intensity which results in its magnetization being reversed when it cools down. Write-time is only twenty nano-seconds, but read-time is approximately twenty microseconds. Average access-time is in the hundreds of microseconds. The memory is designed to contain 10^8 bits, and to cost less than one cent a bit[48]. Further development is still required on this system. In particular, the device requires a very high-powered laser, a fast beam deflector, and fast,

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46 "Arpa Net to Have Trillion-Bit IR System", *Datamation*, Vol.17, No.10 (May 15, 1971), pp.86-7.

47 Mikaeliane, A.L. and Bobrinev, V.I., "Holographic Memory Devices", *Opto-Electronics*, Vol.2 (1970), pp.193-9.

48 Lohman, R.D.; Mezrich, R.S. and Stewart, W.C., "Holographic Mass Memory's Promise: Megabits Accessible in Microseconds", *Electronics*, Vol.44, No.2 (January 18, 1971), pp.61-6.

durable light modulators. In a more recent announcement RCA claim to have developed a "sugar-cube"-sized crystal, made of lithium niobate and barium sodium nitrate doped with metallic impurities, which is capable of storing 10^{12} bits of information[49].

(c) Magnetic-Bubble Memories

The idea of storing information in magnetic domains, or "bubbles", moving in thin films of magnetic material, was first reported by A.H. Bobeck of Bell Laboratories in October, 1967[50]. The subsequent discovery that garnet was a suitable magnetic material substantially increased the potential of the technology, not only because garnet is much cheaper to produce than the orthoferrite material previously used, but also because greater bubble mobility and greater packing densities can be obtained.

The technology for producing magnetic-bubble memories is very similar to that for producing semiconductor memories, except that fewer stages are involved, and tolerances are not as critical. This is expected to lead to higher yields which, in turn, will probably result in greater storage capacity per chip than will be practical for semiconductor memories. It is anticipated that magnetic-bubble memories will be "a few times" cheaper than semiconductor memories and "substantially cheaper"[51] than core memories. Magnetic-bubble memories can be cycled at between one and ten megahertz, and packing densities of 10^5-to-10^7 bits per square inch and 10^8 bits per cubic inch[52] are

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[49] *EDP Weekly*, Vol.12, No.11 (July 5, 1971), p.15.

[50] Bobeck, A.H., "Properties and Device Applications of Magnetic Domains in Orthoferrites", *The Bell System Technical Journal*, Vol.46 (October, 1967), pp.1901-25.

[51] Bobeck, A.H. and Scovil, H.E.D., "Magnetic Bubbles", *Scientific American*, Vol.224, No.6 (June, 1971), pp.78-90.

[52] "100 Million Bits Per Cubic Inch in New Devices", *Bell Laboratories Record*, Vol.49, No.1 (January, 1971), p.33.

predicted. It is likely that magnetic-bubble memories will be commercially available in the 1973-74 time-frame.

It is important to note that magnetic-bubble memory is unlikely to be available in a random-access configuration, being much better suited to cyclic access. It is thus often considered to have its greatest potential as a replacement for the high performance fixed-head disc and/or bulk memory. The technology has the interesting property that logic elements can easily be combined within the normal storage structure. It has been suggested that this might contribute to new forms of distributed computing architecture. In the nearer term, this facility is more likely to be useful as a device to permit the addressing of one of several cyclical registers on a single magnetic-bubble chip.

As a general rule-of-thumb, the diameter of the magnetic bubbles is also constrained, in the order of one-to-two times the thickness of the magnetic material, and bubble spacing should not be closer than two or three bubble diameters (due to repulsive forces between bubbles); thus the thickness of the magnetic material is an important design factor. Current design limitations appear to be the difficulty of detecting the presence of small bubbles reliably, and the limits on the minimum line thickness available, when using photolithographic techniques. This latter constraint may be overcome by moving to electron beam lithography.

(d) Charge-Coupled Devices

It is perhaps an indication of the danger of predicting the dominance of any one device or technique over another in the whole area of memory development, that charge-coupled devices were only announced by the Bell Telephone Laboratories in the spring of 1971, and yet they have already caused a considerable stir in the industry, and several companies are now building advanced models.

The charge-coupled device is similar to magnetic-bubble memories in that buckets of charge are shifted down a chain of electrodes much the same way that magnetic bubbles are shifted along chains of magnetic receptors. As with magnetic-bubble memories, the technology for producing charge-coupled devices is very similar to that for producing semiconductor memories, except that fewer stages are involved. The technology is as yet far too new to make reliable cost predictions, but at this stage a reasonable guess would be that a charge-coupled shift register memory will have a comparable cost to a magnetic-bubble shift register of similar performance. The latter have been estimated as likely to be a few times cheaper than semiconductor memories.

It has been pointed out[53] that charge-coupled memory devices will operate at ten megahertz data-rates and will consume only five microwatts per bit, using today's technology. It is expected that, with development, permissible data-rates will increase to 100 megahertz, and bit packing densities of one million bits per square inch will be achieved.

Perhaps even more exciting is the potential these devices have as image sensors. Indeed Bell have already produced a charge-coupled imaging device containing ninety-six light sensing elements[54]. These devices are particularly attractive for image sensing because (a) they are easily fabricated in silicon which has a good response over the visible spectrum, (b) due to the simplicity of the sensors it is expected that adequate yields will be obtainable even with large sensor arrays, and (c) the sensor is self-scanning, and works with a low operating voltage.

11. Off-Line Memory

(a) Disc Packs

As with fixed-head discs, the development of disc packs is in a relatively advanced state, so that order-of-magnitude advances in price performance

53 Altman, Laurence, "The New Concept for Memory and Imaging: Charge-Coupling", *Electronics*, Vol.44, No.13 (June 21, 1971), pp.50-9.

54 "Memorizing More on Tape", *Business Week*, No.2172 (April 17, 1971), p.65.

with this technology are not expected. Some improvements in magnetic coatings which could significantly increase bit packing density are foreseeable, but the extent of improvement obtainable over the next decade is difficult to predict.

Disc packs vary in size from about 1-to-200 megabits, and are often ganged together in multiple drives to produce several times the above-mentioned capacity. Average access-times are typically in the range of 100-to-200 milliseconds, though disc pack units (with a read/write head per track) are available with average access-times in the ten-millisecond range. Prices vary considerably with capacity and speed, but, most typically, they fall into the range of 0.005-to-0.2 cents per bit, including the cost of the disc drive. Since the disc packs are removable, this cost is not perhaps a completely fair representation. Additional data can be stored on spare disc packs for as little as 10^{-5} cents per bit.

(b) Magnetic Tapes

As with disc technology, magnetic tapes have, until recently, appeared to be in a relatively mature state of development. Bit packing densities have been constantly increasing as magnetic coatings have been improved. Recent developments[55] suggest at least a three-fold improvement in the maximum bit packing density will soon be available. Tape quality is not the only limitation to bit packing density, however. Variations in read-head alignment effectively limit packing densities to about 20,000 bits per square inch using conventional read-head geometry[56]. It is obvious also that increased bit packing densities invite increased errors caused by dust particles.

55 "Memorizing More on Tape", *Business Week*.

56 "A Particle that Jams More Data on Tape", *Business Week*, No.2171 (April 10, 1971), pp.42-4.

Magnetic tapes currently serve two functions. First, they are used as a data interchange mechanism between computers. When used in this way standards are all-important, and improvements are likely to come slowly. Second, tapes are often used as a memory extension in much the same way that disc packs and drums are used. Most users employ their tape units for both functions.

There are some applications where tape units are employed as memory extensions to the limits of their capability. For example, in the U.S. the Social Security Administration is currently using six IBM 360/65 computers to search 1,400 reels of tape each night. About 99 percent of the time is spent in searching for the data required, and only 1 percent in actually processing it. In such circumstances there is a strong incentive to depart from industry standards if significantly better performance can be obtained.

Ampex have announced a new tape system called the Terabit Memory which appears to have done much to put tape systems back in direct contention with laser memory systems for massive memory stores. The Ampex system achieves bit packing densities of 1,500,000 bits per square inch, by recording and reading across the tape instead of along it, thus reducing head alignment problems. In its largest configuration the system can store 3×10^{12} bits on sixty-four tape drives. An end-to-end tape search takes approximately forty-five seconds. The average access-time should be substantially less than half the end-to-end search time in most situations, since on such a large system it is likely that the required data could be grouped better than would happen if recorded randomly.

The price of the largest Terabit system is expected to be three million dollars, which works out to 10^{-4} cents per bit. This is somewhat cheaper than the optical "Unicon" system. First deliveries of Terabit are scheduled for the fall of 1972. Competitive systems employing the same technology have been announced since the Ampex achievement.

(c) Computer Output Microfilm (COM)

In many applications, records must be maintained for possible future reference, but there is no significant need to ever alter the records or to further manipulate the data contained in the records. If large quantities of data are involved, the most economical way to retain the data may well be on microfilm.

Microfilm cameras attached to computers are a relatively new phenomenon. It has been estimated[57] that there were approximately fifty COM units installed in the world at the end of 1968. By the end of 1970 this figure had risen to somewhere between 700 and 800.

The major disadvantages of COM are that, unlike magnetic tape, the film cannot be erased for alterations or corrections, nor can the data be as easily read back into the computer if further processing should be required, as it could be if it had been stored in digital form. Conversely, it is possible to obtain legible copies of records without recourse to the computer to decode records stored digitally. Further, a COM record is much more permanent than magnetic tape which must currently be rewritten every three-to-six months.

For many applications comparison with a line printer is appropriate. The major advantages of COM are its price (the film costs about one-sixth the price of the equivalent line-printer paper), its speed (speeds of 40,000 lines per minute are available *versus* 2,000 lines per minute for a fast-line printer), its compactness (space requirements are about 2 percent of that required for equivalent line-printer output) and the ease of making multiple high-quality copies.

While most professional clairvoyants are predicting high growth-rates (25 percent to 40 percent) for COM equipment beyond 1975, it is interesting to note that Quantum Sciences have been reported[58] to predict that, by 1975, market saturation will be approaching, "...since more than 50 percent of the

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[57] Askanas, Charles, "Commentary", *Datamation*, Vol.17, No.14 (July 15, 1971), p.72.

[58] "Was COM a Victim of Overreaction?", *Datamation*, Vol.17, No.15 (August 1, 1971), p.49.

major EDP users — those with over $50,000 monthly EDP rental bills — will have COM systems installed, and few users require more than one machine". It is also predicted that, by that time, the purchase prices of COM units will start at about $25,000, and average $35,000. The corresponding figures for 1971 are $30,000 and $60,000.

12. Terminals

It is difficult to say much that is not overwhelmingly general on a subject as broad as terminals, for it is possible to find a terminal at almost any price, from a touch-tone pad at $15.00 to a high-speed intelligent terminal at $100,000. Special-purpose terminals, such as big board plotting displays, can cost even more.

In this discussion, four categories of terminals will be arbitrarily selected for brief examination. These are:

- keyboard/printers
- keyboard/CRT type displays
- touch-tone/voice answer-back terminals
- point-of-sale terminals

The most promising technological advances appear to be:

- increasing incorporation of large-scale integrated circuit components and electronic memory buffers;
- the continued introduction of electrostatic printing devices.

While the introduction of LSI chips should help to reduce the cost of terminal logic elements, these typically constitute a relatively small percentage of manufacturing costs. Cyclic buffer memories (magnetic-bubble or charge-coupled) may also result in some cost-reductions, but they will face tough competition from displays containing their own storage elements, such as storage CRT tubes, photochromic glass and plasma displays.

(a) Keyboard/Printers

The keyboard/printer is, to date, the most widely used terminal device. Since keyboard/printers were already in quantity production for use in Telex and TWX systems before the requirement for computer terminals arose, their adaptation to use as computer terminals was natural.

Purchase prices for keyboard/printers normally fall into the range of $600 to $7,000. Much of the price differential is due to variations in sturdiness of construction, but speed and size of character set are also considerations.

Most of the impact printers operate at, or below, 120 b/s. Devices using ink-spraying or electrostatic techniques operate somewhat faster. It seems likely that electrostatic printers, which are inherently quieter, faster, more reliable, and capable of graphic output, will gradually supplant the slower impact printers. However, in their cheapest models, the impact printers are hard to beat in a straight price competition, so that their demise is likely to be slow.

(b) Keyboard/CRT Type Displays

This type of display is becoming increasingly popular, particularly when hard-copy records are never or only occasionally required. The high speed of data display is their main feature, but they also have greater flexibility in data formats, and, if equipped with a cursor or pointer, permit greater freedom of interaction with the computer than is available with a printer.

Terminals using a normal cathode ray tube require constant refreshing of the display, so that buffer memories are required, which adds substantially to the terminal cost. Prices start at about $1,500. Such features as graphics capability, editing facilities, enlarged character sets, and large screen size, add extra cost. In particular, a high-precision vector capability adds greatly to expense. Several such terminals cost over $100,000.

One interesting development is the manufacture of portable terminals, consisting of a telephone acoustic coupler, a keyboard and a character generator and buffer memory. The user employs the nearest television set as his video screen by attaching a cable to the aerial input on the TV. The result is a light and easily portable terminal which currently sells in Canada for about $1,200. Devices such as this show promise of becoming the prototype model for a home computer terminal. Since a relatively large percentage of its cost is in electronics, and since such devices have not yet experienced the economies of large production runs, it is probably reasonable to anticipate that the price of these or similar devices will halve over the next five years.

(c) Touch-Tone/Voice Answer-Back

For some years to come, the only practical way to make computer access from the home available on a widespread basis is via a touch-tone telephone input and voice answer-back system. Such a system is fairly restrictive in its capabilities, but it has the virtue that the user need make no extra investment in terminal equipment if he already has a touch-tone telephone. (Some systems have even been devised which use an ordinary dial telephone.)

Computer-operated voice answer-back machines have been available for some time. Typical machines cost from about $30,000 for a machine with a vocabulary of thirty-two words, one access line and a mini-computer to control it, to about $140,000 for a machine with sixty access lines and a vocabulary of 2,000 words. Most devices currently use human speech for playback which has been recorded either on celluloid film or on a magnetic disc or drum. At least one device generates words from the basic phonemes of human speech, giving it, in essence, an unlimited vocabulary.

Voice answer-back systems are likely to be most useful for answering simple enquiries, but more sophisticated uses are also possible. Typical applications include credit authorization, inventory control, price checks, order entry and factory data collection.

General Motors in Canada have been effectively using a voice answer-back system since 1969 to handle dealer enquiries as to the whereabouts of cars placed on order. They describe the touch-tone/voice answer-back method as "highly underutilized", since, in their experience it is both inexpensive and effective. Only fourteen man-weeks of programmer effort were required to set up the system, which they claim gives satisfactory responses to 70 percent of enquiries, and gives the remaining 30 percent of enquirers the data they need to follow up with a request for human intervention. The system has recently been adopted by a GM division in the U.S.

Voice recognition equipment, which could eliminate the need for a touch-tone pad to input data by correctly recognizing words of human speech, is still in a very early state of development, and is unlikely to be in widespread use during this decade. IBM does have an experimental system in operation which is capable of recognizing thirteen words from IBM customer engineers[59]. Information on its performance for a variety of accents was not disclosed.

(d) Point-of-Sale Terminals (POS)

POS computer terminals have, to date, been used primarily to check consumer credit. Hence, the terminals are usually the epitomy of simplicity, the more common ones consisting of a touch-tone pad and indicator lights. The potential for POS terminals to perform other useful functions, such as on-line accounting and inventory control, has not been lost on the industry, nor has the potential size of the market (it is estimated that there are over six million cash registers in the U.S. alone). The principal problem has been to produce an economic terminal.

The industry has just now begun to blossom, and there is a fairly wide selection of POS terminals on the market, ranging from the aforementioned touch-tone pads to multikeyed units, and even to units (primarily designed for supermarkets) which have a "magic wand" which the checkout girl passes over the price tag on each item to read out the price and (if desired) the stock number.

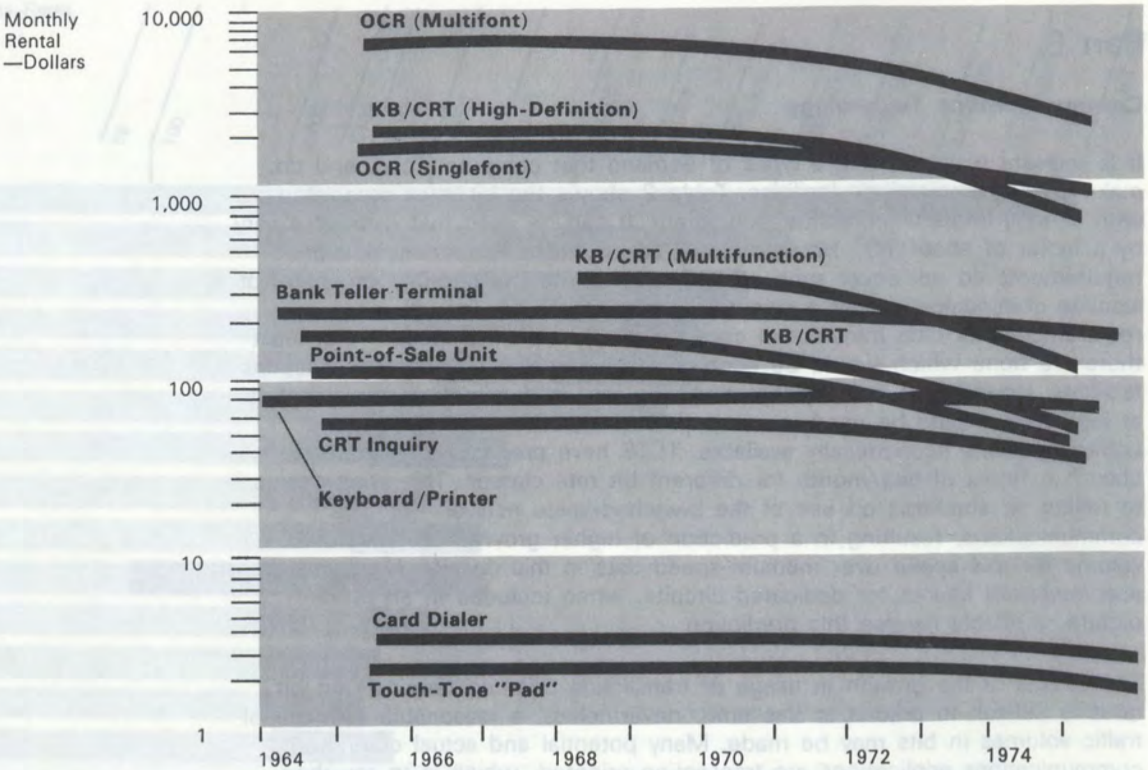
In order to improve the utilization of POS terminals, and hence their economic viability, some effort has been expended to provide facilities which would

59 "IBM Voice Recognition Only 'Experimental'", *Datamation*, Vol.17, No.18, (September 15, 1971), p.48.

increase the number of clerks who can use the same equipment. One interesting approach is a terminal, developed by Lyman Richardson of T-Scan Ltd., which uses a marked card that is dropped into a slot from which it is ejected seconds later with an appropriate response message printed on the back of the card. The terminal is fast enough that many users can easily have access to the same terminal, either by walking over and dropping the card in for "real-time" processing, or, by saving the cards for "batch" insertion at the user's convenience. This terminal, of course, has wider application than POS. (The experiment in which it was first tested is described in the CCC/TF Background Paper 2, *Peel County Pilot Education System* by Lyman Richardson.)

Except that very rough cost projections appear in Figure 9, this overview has not treated a host of other terminals, most of which employ similar technologies to those discussed. Bank-teller, ticket-dispensing, stock-quotation, and remote-batch terminals are four which are seen to have wide application.

Figure 9
Monthly Rental of Data Terminal Units



Source:
Stanford Research Institute

Part B

Communications Technology

It is relevant to consider the types of demand that computers can, and do, make on communications facilities. Table 2 shows the bit rates associated with various items of computer equipment. It can be seen that data-rates vary by a factor of about 10^8. However, in practical terms telecommunications requirements do not cover such a large range. With the possible exception of satellite communications of a scientific nature, there are, as yet, no requirements for data transfers at core memory cycle time-speeds — at least there are none which would be economic using available telecommunications facilities. However, it is likely that magnetic tape and microfilm data transfers at high rates would be used in many circumstances, were higher-speed communications economically available. TCTS have prepared a traffic load chart[60] in terms of bits/month for different bit rate classes. This chart seems to reflect an emphasis on use of the switched-voice network for data communications, resulting in a prediction of higher growth-rate and total volume for low-speed over medium-speed data in this decade. However, the accompanying figures for dedicated circuits, when included in an overall picture, probably reverse this prediction.

The effects of the growth in usage of transaction-oriented terminals on bit rates is difficult to predict at this time; nevertheless, a reasonable estimate of traffic volumes in bits may be made. Many potential and actual computer/communications applications are transaction-oriented, which is to say they involve very limited flows of information. Airline-reservation systems are, perhaps, the classic transaction-oriented example but there are many others. Hough, *et al*[61] have predicted transaction volumes in the U.S. for 1990 — by which time most applications of the type they considered are likely to have

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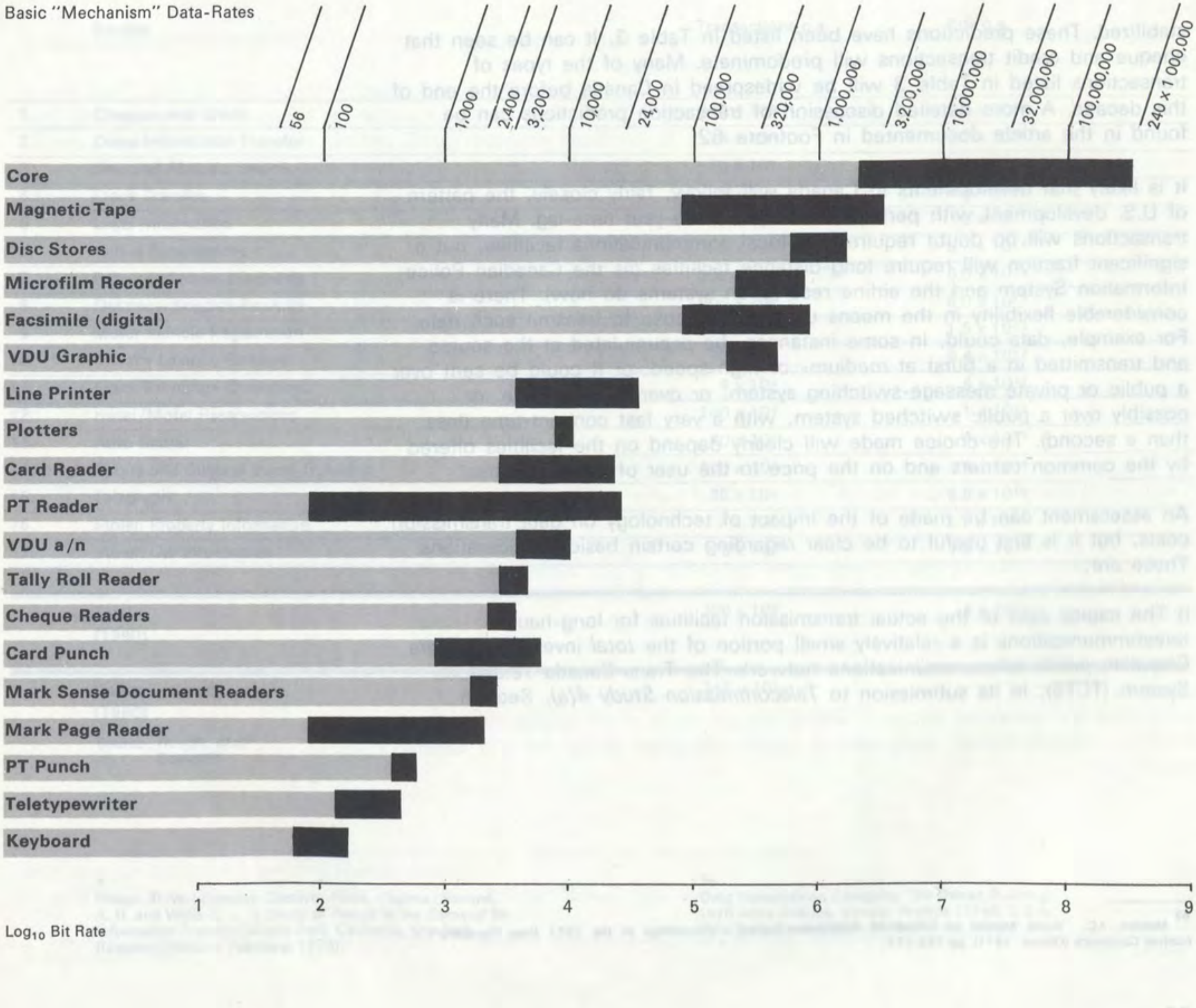
[60] Zeidler, H.M., *et al, op. cit.*

[61] Hough, R.W.; Fratessa, Carolyn; Holly, Virginia; Samuel, A.H. and Wells, L.J., *A Study of Trends in the Demand for Information Transfer* (Prepared for the National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California, Contract NAS2-5369, SRI Project MU-7866) (Menlo Park, California, Stanford Research Institute, February, 1970).

Table 2
Data-Rates in a Computer System



stabilized. These predictions have been listed in Table 3. It can be seen that cheque and credit transactions will predominate. Many of the types of transactions listed in Table 3 will be widespread in Canada before the end of this decade. A more detailed discussion of transaction predictions can be found in the article documented in Footnote 62.

It is likely that developments in Canada will follow, fairly closely, the pattern of U.S. development with perhaps a two- or three-year time-lag. Many transactions will no doubt require only local communications facilities, but a significant fraction will require long-distance facilities (as the Canadian Police Information System and the airline reservation systems do now). There is considerable flexibility in the means users can choose to transmit such data. For example, data could, in some instances, be accumulated at the source and transmitted in a burst at medium- or high-speed, or it could be sent over a public or private message-switching system, or over a private line, or possibly over a public switched system, with a very fast connect-time (less than a second). The choice made will clearly depend on the facilities offered by the common carriers and on the price to the user of those facilities.

An assessment can be made of the impact of technology on data transmission costs, but it is first useful to be clear regarding certain basic considerations. These are:

i) The capital cost of the actual transmission facilities for long-haul telecommunications is a relatively small portion of the *total* investment in the Canadian public telecommunications network. The Trans-Canada Telephone System (TCTS), in its submission to *Telecommission Study 4(a)*, Section

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[62] Madden, J.C., "Some Aspects of Transaction Telecommunications", *Proceedings of the 1971 Data Processing Institute Conference* (Ottawa, 1971), pp.193-216.

Table 3
Transaction Predictions for the U.S. for the Year 1990

	Service	Transactions p.a.	Bits p.a.
1.	Cheques and Credit	340×10^9	1.4×10^{14}
2.	Crime Information Transfer	70×10^6	2.1×10^{13}
3.	Title and Abstract Search	20×10^6	1.8×10^{13}
4.	Stock Transfer	5×10^9	1.5×10^{13}
5.	Legal Information	30×10^6	9×10^{12}
6.	Airline Reservations	4.2×10^9	6.7×10^{12}
7.	Remote Medical Diagnosis	200×10^6	6.0×10^{12}
8.	Electrocardiogram Analysis	200×10^6	6.0×10^{12}
9.	Motor Vehicle Registration	245×10^6	1.5×10^{12}
10.	Driver's Licence Renewal	90×10^6	5.4×10^{11}
11.	Stock Exchange Quotations	4×10^9	4×10^{11}
12.	Hotel/Motel Reservations	100×10^6	1×10^{11}
13.	Auto Rental	40×10^6	4×10^{10}
14.	Sports and Cultural Event Ticketing	200×10^6	4×10^{10}
15.	Telegraph	35×10^6	3.5×10^{10}
16.	Stolen Property Information	7×10^6	2.1×10^{10}
17.	Stolen Car Information	5×10^6	1.5×10^{10}
	Total (1990)	360×10^9	4×10^{14}
	Datran Estimate (1980)	248×10^9	

Source: Hough, *et al**
Datran**

*
Hough, R. W.; Fratessa, Carolyn; Holly, Virginia; Samuel, A. H. and Wells, L. J., *A Study of Trends in the Demand for Information Transfer* (Menlo Park, California, Stanford Research Institute, February, 1970).

**
Data Transmission Company, The Datran Building, 1920 Aline Avenue, Vienna, Virginia 22180, U.S.A., "The Data Transmission Market of the 1970's".

5.1(b), discussed the distribution of the investment in network facilities. The capital cost distribution given for an individual subscriber was:

• Station and its associated connection	7.5 percent
• Distribution facilities	37 percent
• Local switching equipment	35 percent
• Tandem switching facilities	5.5 percent
• Long- and short-haul transmission facilities	15 percent

The above figures apply for a residence telephone, but are not greatly different for business users.

Thus, local plant accounts for approximately 80 percent of the total capital investment, and almost half of that cost is to be found in the local loop, *i.e.*, the twisted wire pair which runs between the local switching office and the subscriber.

ii) Data traffic currently accounts for a small fraction of total telecommunications revenue (about 6 percent). If voice traffic is assumed to be equivalent to 2,400 b/s, then TCTS estimate that data traffic accounts for only 0.08 percent of combined voice and data traffic for all Canadian carriers[63]. These two figures provide some indication of the inefficiency of the voice communications system for data transmission, though there are other factors, such as the rental income from terminal equipment (which accounts for approximately 30 percent of Bell Canada data services revenue), which inflate data transmission revenues relative to those from telephone usage.

iii) Unlike the computer industry, where equipment is often written off in forty months, common-carrier equipment is usually designed to last for over twenty years.

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[63] *Communications, Computers and Canada* (Trans-Canada Telephone System, Ottawa, November, 1971, revised December, 1971).

1. Long-Distance Transmission

In the next decade, the major impact of new technology is likely to be in long-distance transmission. In an appendix to the President's Task Force on Communications Policy in the United States (Rostow Report)[64], it has been estimated that the investment cost of adding a voice circuit mile of long-distance transmission facilities to the Bell (U.S.) system, which averaged $11.50 in 1969, will be about $1.50 by 1979.

The dominant characteristic of long-distance transmission is the economy of scale which is possible. The Rostow report gives, as a rule-of-thumb, that a doubling of the number of circuits on a terrestrial route involves an increase in total investment of about 60 percent. This effect of large trunk groups on costs was also apparent in a more recent Canadian study on digital communications[65]. The effect is well illustrated in Figure 10.

The principal technologies employed or projected for long-distance transmission are summarized in Table 4.

A brief discussion of the various technologies follows. Much of this information was obtained from *Telecommission Study 4(a).*[66] In some cases, entire paragraphs have been incorporated, and have remained essentially unaltered.

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64 Rostow, Eugene V., *A Survey of Telecommunications Technology, Part I* (President's Task Force on Communications Policy) (Washington, D.C., U.S. Superintendent of Documents, June, 1969).

65 Worrall, John, *Branching Out, Background Paper 11 — Local Facility Study* (Ottawa, Information Canada, August, 1972).

66 Department of Communications, *Telecommission Study 4(a): The Future of Communications Technology* (Ottawa, Information Canada, 1971).

Figure 10
Cost Trends in Terrestrial Transmission

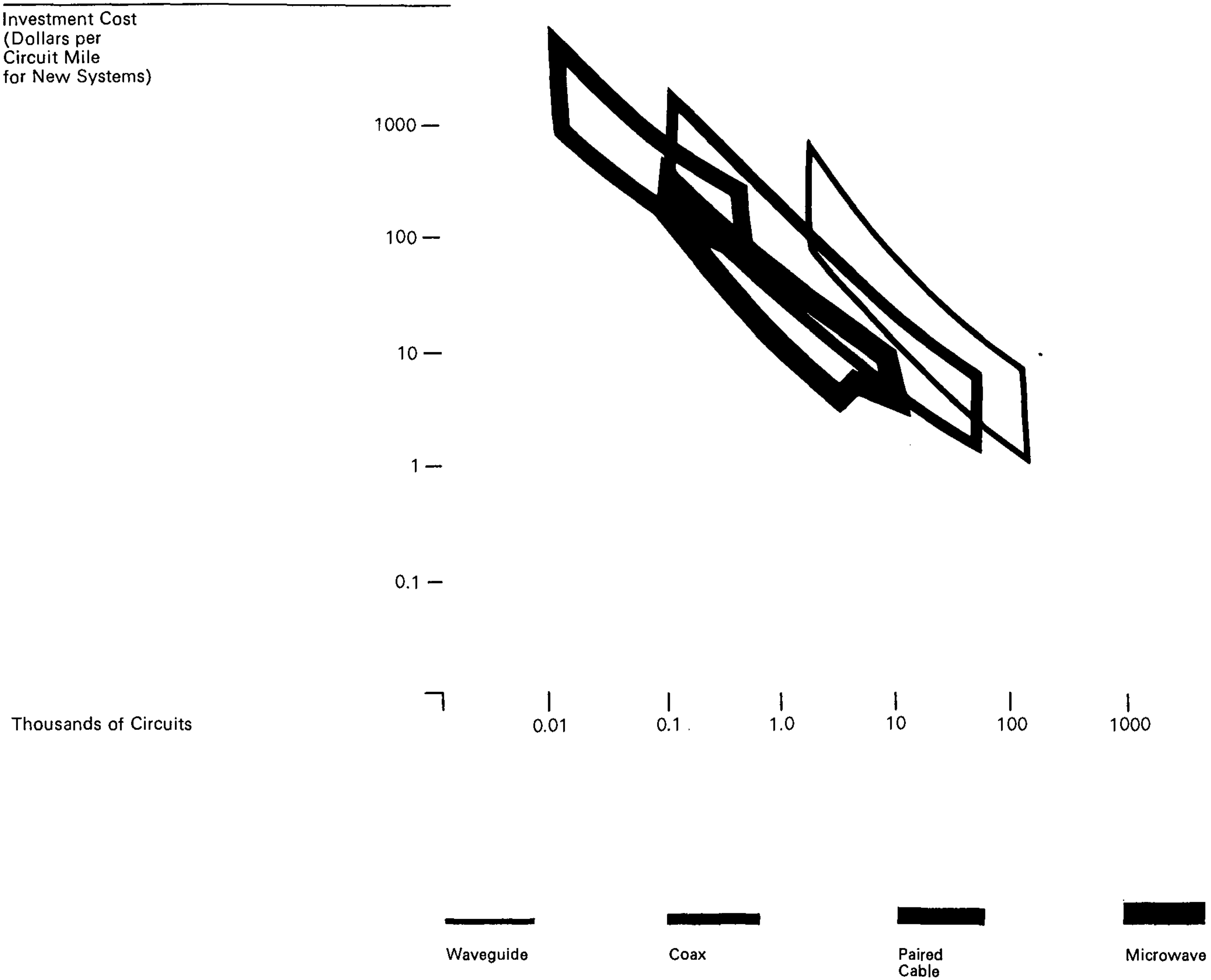

Table 4
Transmission Technology Summary

Technique	Bandwidth	Estimated Cost/Voice Channel/Mile	Availability	Comments
Cable pair	several MHz	see Figure 12	Now	Attenuation 26 db per mile at 1 MHz (22 gauge wire). T-1 carrier used at 1.5 MHz.
Coaxial cable	several hundred MHz	see Figures 12 & 13	Now	Used for CATV systems. First long-haul cable to be operational in Canada in 1975.
Microwave	currently restricted to 30 MHz	see Figures 12 & 13	Now	Backbone of present long-haul in Canada at 4-6 GHz frequency range. Probable extension to 10-30 GHz frequency range as required.
Satellite	several GHz	see Figure 15	Now	Canadian Telesat operational in 1973.
Waveguide	about 65 GHz	see Figures 12 & 13	1973-1980	Laboratory systems operational.
Light fibre	about 50 GHz	unknown	1980's?	Technology developing rapidly.
Light pipe	about 1,000 GHz	unknown	1980's?	

(a) Twisted Pairs

Twisted wire pairs are used for low-capacity transmission (less than twenty-four voice channels). Existing digital transmission systems in Canada transfer information at 1.5 Mb/s. Such high transfer rates are not available on local loops, however, principally because the switching gear is not designed to cope with the associated high frequencies. The principal problem in transmitting high data-rates is that signal attenuation increases relatively rapidly at high frequencies, so that the spacing of amplifiers or repeaters along the line has to be reduced accordingly.

(b) Coaxial Cables

Coaxial cables are used in Canada for cable TV distribution systems. High-capacity long-haul transmission on coaxial cable is common in many countries. Bell Telephone Laboratories have recently developed a cable (L5) capable of carrying approximately 90,000 voice channels.

In Canada, Bell.Northern Research has undertaken a major development program for a long-haul digital coaxial cable system[67]. This cable, designed for first service in 1975, operates at 283 Mb/s, sufficient for 4,032 voice channels per coaxial cable tube. Each full cable will contain twelve tubes, giving a total capacity of some 20,000 two-way voice channels when allowance has been made for spare capacity in case of breakdown. The cable has been designed for trunks up to 4,000 miles in length, but will be used first in the region between Quebec City and Windsor, Ontario. In this area, traffic densities of up to 12,000 voice circuits are already being encountered. Requirements for cross-sections of over 100,000 voice circuits are predicted for the mid-1980's in this region. The principal advantages of cables over microwave are, first, that for high-capacity digital transmission, they are in a more advanced state of development; and second, the transmission itself is

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[67] Doyle, Frank J. and Goodwill, Daniel Z., *An Exploration of the Future in Medical Technology* (Montreal, Bell Canada, March, 1971); and *Communications, Computers and Canada* (TCTS).

narrowly channelled (*i.e.*, within the cable), rather than being broadcast over a relatively wide area. In densely populated regions, where available microwave bandwidths are near capacity, the latter advantage can be significant. Thus, although digital microwave is likely to be cheaper when fully developed (as indicated in Figure 11), there is also likely to be a place for coaxial cables in the hierarchy of long-distance transmission facilities.

(c) Microwave

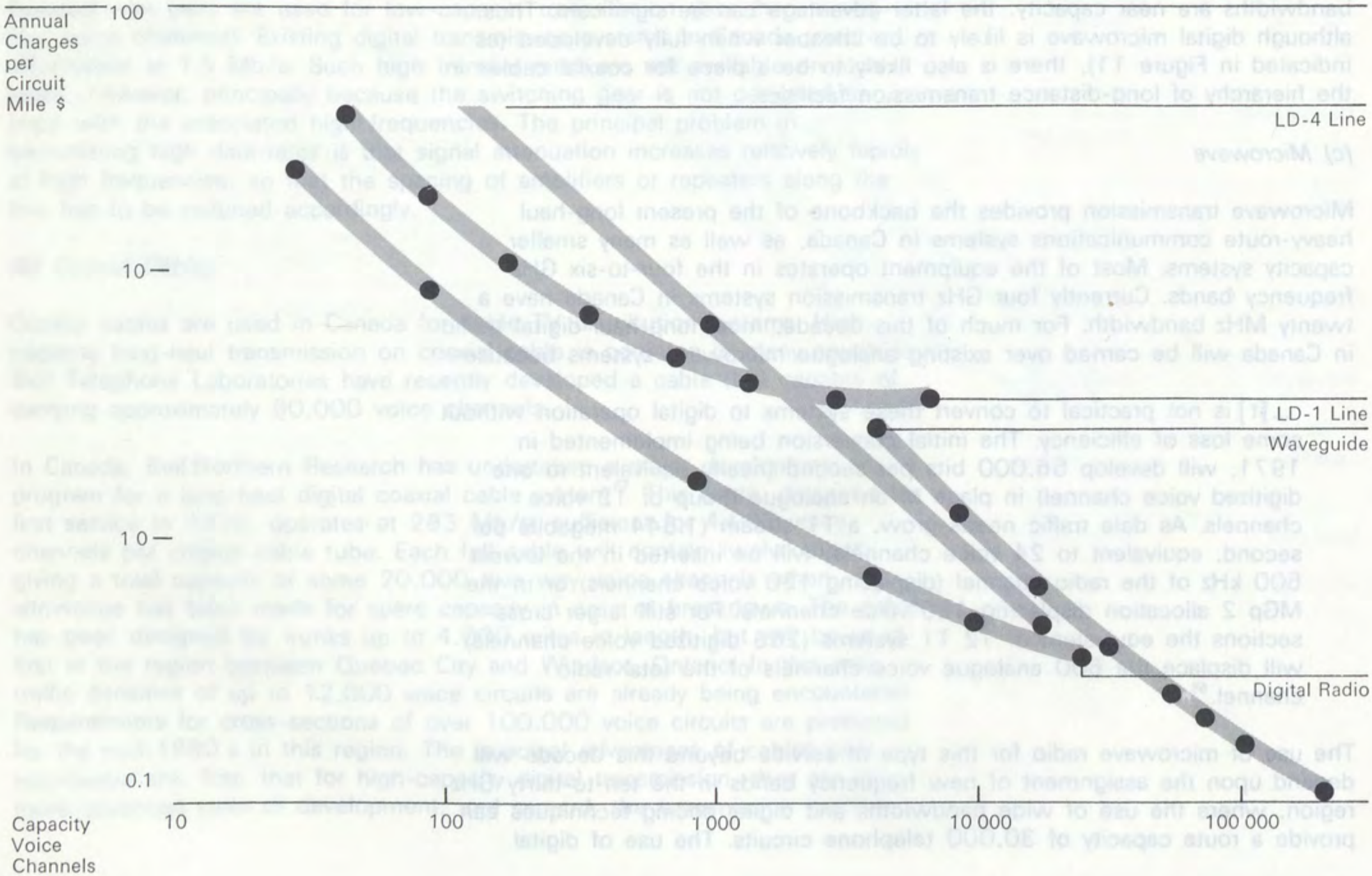
Microwave transmission provides the backbone of the present long-haul heavy-route communications systems in Canada, as well as many smaller capacity systems. Most of the equipment operates in the four-to-six GHz frequency bands. Currently four GHz transmission systems in Canada have a twenty MHz bandwidth. For much of this deçade, most long-haul digital traffic in Canada will be carried over existing analogue microwave systems because

> ...[it] is not practical to convert these systems to digital operation without some loss of efficiency. The initial conversion being implemented in 1971, will develop 56,000 bits per second (nearly equivalent to one digitized voice channel) in place of an analogue group of 12 voice channels. As data traffic needs grow, a T1 stream (1.544 megabits per second, equivalent to 24 voice channels) will be inserted in the lowest 500 kHz of the radio channel (displacing 120 voice channels) or in the MGp 2 allocation displacing 180 voice channels. For still larger cross-sections the equivalent of 12 T1 systems (288 digitized voice channels) will displace the 600 analogue voice channels of the total radio channel.[68]

The use of microwave radio for this type of service beyond this decade will depend upon the assignment of new frequency bands in the ten-to-thirty GHz region, where the use of wide bandwidths and digital coding techniques can provide a route capacity of 30,000 telephone circuits. The use of digital

[68] *Communications, Computers and Canada*, p.28.

Figure 11
Annual Charges / Circuit Mile *versus* Circuit Capacities for LD-1, LD-4, Digital Radio and Waveguide



Source: TCTS*

* *Communications, Computers and Canada* (Trans-Canada Telephone System, Ottawa, November, 1971, revised December, 1971).

signalling techniques will also permit greater route densities and hence increased capacity. The feasibility of this type of service and its capability to overcome rain attenuation problems has been demonstrated, and it will probably prove attractive economically in comparison with cable, waveguide and satellite systems within the next five-to-fifteen years.

Digital microwave links are operational in several countries. A complete digital microwave transmission system is planned for the U.S. by the Data Transmission Company. It will serve thirty-five major metropolitan areas and employ 259 microwave repeaters. Initial capacity will be 4,000 full duplex, 4,800 b/s circuits. Proposed charges appear to be approximately one-third of the current charges using the telephone system, though direct comparisons are hard to make[69]. The system is expected to have 48,000 subscribers by 1975[70].

(d) Satellite Relay

Present communications satellites are located in geostationary orbits and have earth-illuminating antennas. A continuing advance in the capability to place and maintain powerful satellites with narrow beam, fixed or steerable antennas in accurately specified positions, can be predicted.

Communications satellites are currently used to carry telephone and television signals between continents, and are also planned to provide communications within Canada. Within the time-period 1971/89, satellite relays have the potential to provide unique services in addition to the trunk facilities and TV distribution facilities that can be foreseen as becoming operative in the immediate future. These are:

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69 Fisher, C.R., "Introduction to the Datran Switched Digital Data Network", *IEEE International Conference on Communications, Montreal, June 14, 15, 16, 1971, Conference Record* (IEEE Cat. No. 71C28-COM), pp.23-1 to 23-3.

70 Hersch, Paul, "Data Communications", *IEEE Spectrum*, Vol.8, No.2 (February, 1971), pp.47-60.

- Direct communication between points, eliminating the need to detour communications through terrestrial nodal points.
- Assignment of circuits between earth terminals on demand, to provide for changes in channel requirements and traffic destination.
- Relay of data from a wide variety of sensors, located over a large area for geological, meteorological, and other purposes.

The Canadian Telecommunications Satellite, scheduled for orbit in 1973, will provide twelve RF channels each with a useful bandwidth of thirty-six MHz. Annual rental for a single RF channel is to be three million dollars plus.

There are now four Intelsat IV satellites in orbit, each with a capacity for 6,000 two-way voice circuits.

One technical problem with geostationary earth satellites is the time delay of about 290 msec per hop introduced due to the long transmission path from the earth to the satellite and back[71]. Maximum overall delays for telephone conversations of 400 msec have been recommended, thus limiting voice transmission to a single hop unless direct communications between satellites are used. Data transmission will not, in most cases, be inhibited by such delays, although some design changes on methods of error-checking may be required. If a copy of the original is retained at the transmitting station until confirmation of correct transmission is received, somewhat larger buffers will be needed to retain transmitted data because of the longer delay.

The cost of earth-stations is directly related to the power of the satellite transmitter. In the Rostow report[72] it is estimated that the cost of two-way Intelsat earth-stations will drop by a factor of ten to less than $500,000

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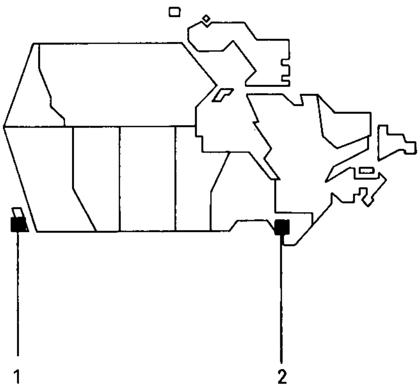
71 Wirz, Member of the Editorial Group of GAS/3, "Revision of COM GAS/3 – No.4: Chapter B.VI; Communications-Satellite Systems", *CCITT Special Autonomous Working Party No. 3 – Contribution No. 16* (Period 1968-1972, GAS/3 – No. 16-E; November, 1970).

72 Rostow, Eugene V., *A Survey of Telecommunications Technology, Part I.*

Figure 12
Location of Earth Station Sites
for Initial Canadian Domestic System

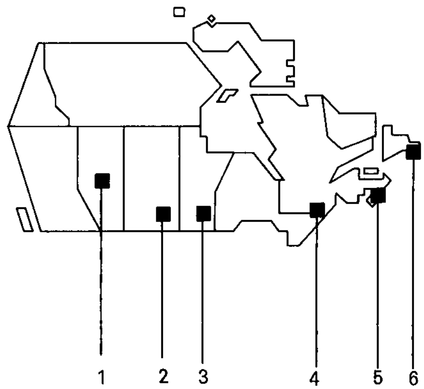
Heavy Route



1
Lake Cowichan

2
Allan Park

Network Quality TV



1
Edmonton

2
Regina

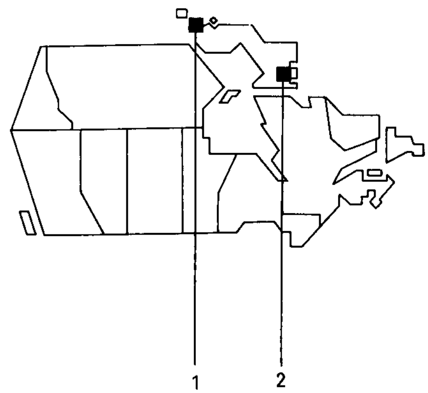
3
Winnipeg

4
Montreal

5
Halifax

6
St. John's

Northern Telecommunications

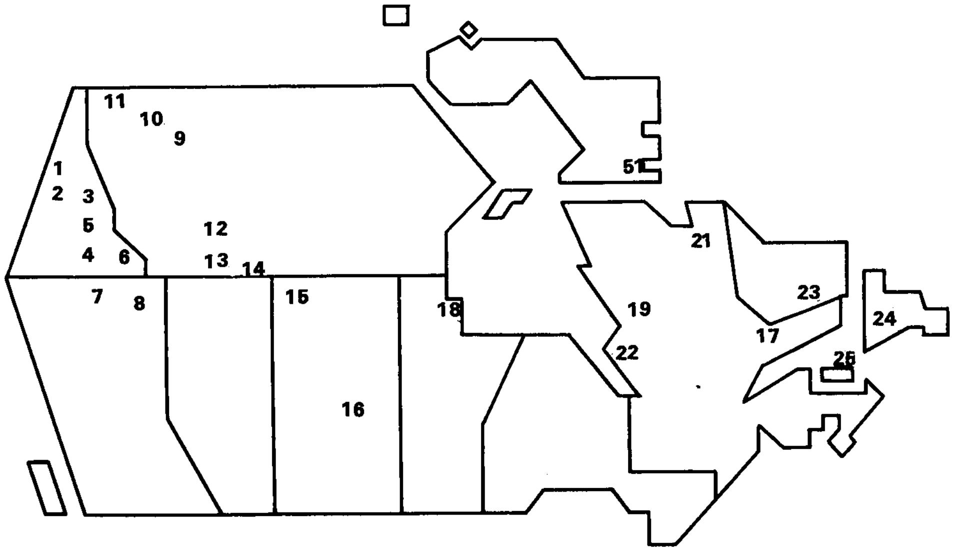


1
Resolute Bay

2
Frobisher Bay

Figure 12 (cont.)

Remote Television



1
Clinton Creek

2
Dawson

3
Elsa

4
Whitehorse

5
Faro

6
Watson Lake

7
Cassiar

8
Fort Nelson

9
Norman Wells

10
Fort Good Hope

11
Inuvik

12
Yellowknife

13
Pine Point

14
Fort Smith

15
Uranium City

16
La Ronge

17
Sept Iles

18
Churchill

19
Great Whale

21
Fort Chimo

22
Fort George

23
Goose Bay

24
Port au Port

25
Magdalen Island

51
Frobisher Bay

during the 1970's, primarily due to the provision of increased power in the satellite. The two major ground stations for Telesat Canada are costing in the order of six million dollars each, inclusive of electronics and buildings.

A major feature of satellite communications is that transmission costs are distance independent over the area covered by the satellite (approximately one-third of the earth's surface area), though costs are of course dependent on there being a ground station within easy reach by terrestrial transmission methods. A cost model for Intelsat IV (1973 time-period) was described in Footnote 72. The results are depicted in Figure 13.

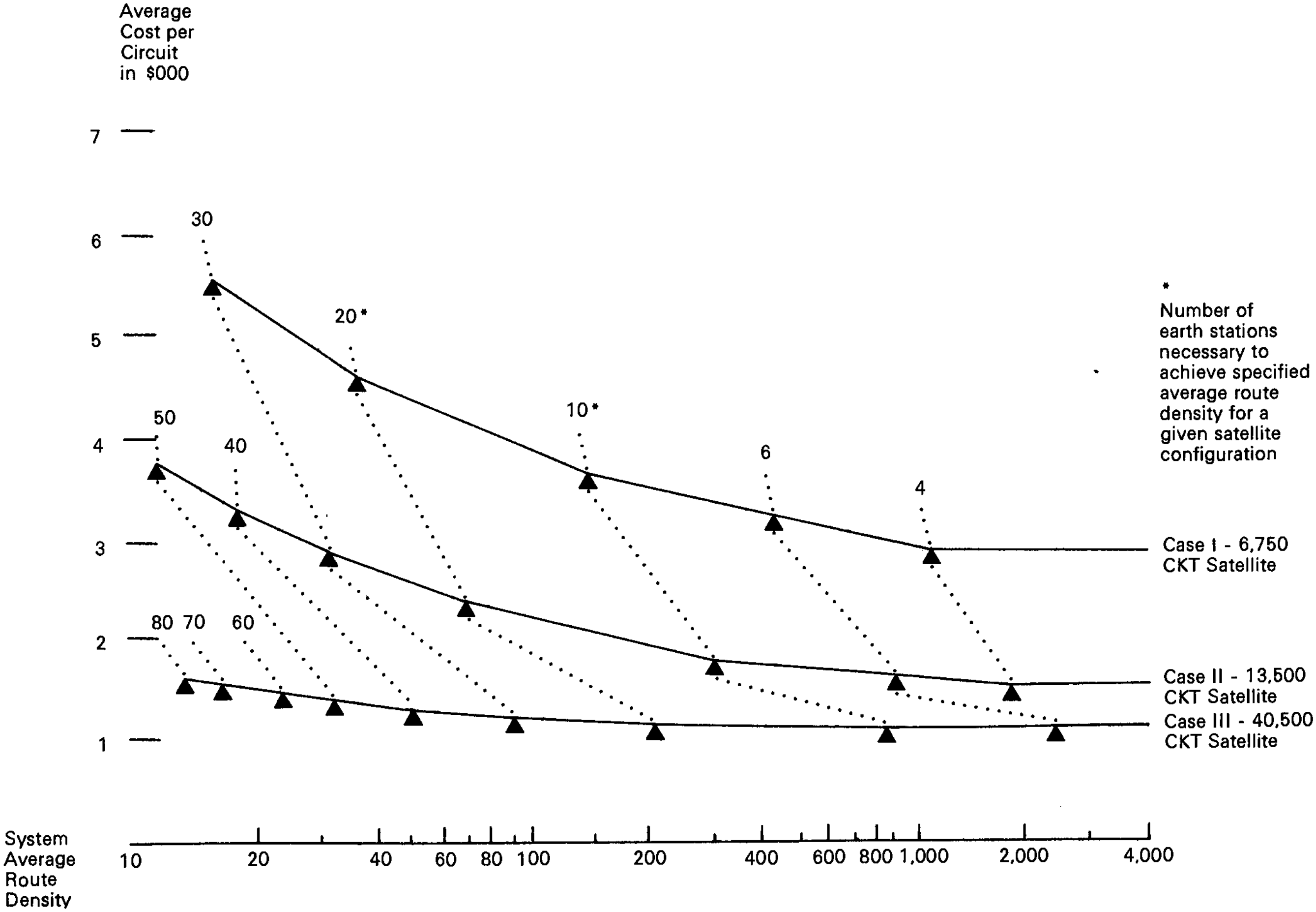
It can be seen that costs are strongly dependent on the average route densities, since proportionately more earth-stations are required for low-density routes.

Once cheaper ground stations are available (with more powerful satellites), this form of long-distance transmission could do much to improve communications in remote areas. Facilities of this type are unlikely to be available much before the end of the decade.

(e) Waveguides

Millimeter waveguide systems are now technically feasible, and installations in the U.S., the U.K., and Japan appear certain in the second half of the seventies. A typical system uses digital phase modulation at a 300-Mb/s rate, an one-GHz channel separation, and repeater spacings of fifteen to twenty-five miles. The guide itself, a two-inch round copper tube, has either a dielectric coating and/or a helical winding in it; improvements in knowledge of dielectric coatings may allow significant loss reduction. Capacities of 250,000 voice channels are planned, and increases are possible with improved modulation techniques, closer channel spacings, and reduced losses. The guide itself must be manufactured and installed carefully, to minimize reflections and mode conversion.

Figure 13
Satellite Systems Cost Trends



(f) Light Fibre

Recent advances in fibre optic technology have made long-haul data transmission down light fibres feasible. Fibres with a total loss of about eighteen db/km have recently been manufactured by Corning Glass Works in the U.S. It is estimated that losses as low as ten db/km will be achieved before the end of the decade. Although there are still many practical problems to be solved, there seems little reason to doubt that intercity trunks carrying time-multiplexed digital signals of a few hundred megabits per second per fibre, with a repeater spacing of one-to-two miles, could be built. A bundle of a few hundred fibres could therefore carry several tens of gigabits per second[73]. Such systems could be in prototype operation by the early 1980's.

Li and Marcatili[74] list the following attractive features of optical fibre transmission:

- Small size — important for inter-office trunk applications in metropolitan areas where duct space is expensive and congested.
- High capacity — a fibre can carry a single voice channel or a highly multiplexed channel, depending on the terminal electronics.
- Growth capacity — cables of fibre bundles afford an economic way of spatial multiplexing; an optical fibre system can therefore grow naturally and gracefully as demand increases.
- Economy — glass is plentiful and cheap; however, inexpensive fibres of adequate optical quality are yet to be manufactured in large quantities.
- Small bending radius — especially important in on-premises "wiring" applications.
- Equalization of the medium is often not necessary — frequency dispersion by the material over a few hundred megahertz is negligible.
- Fibre is noninductive — there is no stray field pick-up; with proper design, cross-talk should be minimal; also, protection against lightning is unnecessary.
- No need for cable pressurization — moisture and temperature problems should not be critical.

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73 Li, Tingye and Marcatili, Enrique A.J., "Research on Optical-Fiber Transmission", *Bell Laboratories Record*, Vol.49, No.11 (December, 1971), pp.330-7.

74 *Ibid.*

There are also some problems, associated with optical transmission:

- Electrical power cannot be sent along the fibre.
- Installation, handling and repair of fibres will require imaginative new approaches.

Such is the versatility of this new material that suggestions have also been made that glass fibres be used for inter-office single-channel voice or videophone communications (using ordinary incoherent light and analogue intensity modulation).

(g) Light Pipe

The light pipe allows communications engineers a great deal of flexibility. It permits spatial, frequency, and time multiplexing. This flexibility is provided by laser sources of short (picosecond) pulses, with small beamwidth allowing many beams (600) in one pipe with adequate resolution, and various colour possibilities. Capacities of greater than 2,000,000 channels with fifty-mile repeater spacings are contemplated. The pipe itself must not move in such a way as to interrupt a beam; either it must be kept invariant under ground movements, or the beam must be bent. However, despite their glowing promise, uncertainties about feasibility, reliability, cost and size make these systems impractical in the seventies. Inexpensive systems appear attractive in the eighties, if a need for very high capacity is encountered.

In summary, it can be seen that sizable cost-reductions for long-distance digital transmission are dependent on a greatly increased demand for transmission. In Figure 14[75] the expected growth for long-distance calls (voice only) is shown (on the lower line). As stated in *Telecommission Study 4(a)*[76]:

"Costs per channel mile have been steadily decreasing in Canada for long-haul facilities as shown in the upper curve of Figure [15] The lower curve is

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[75] Department of Communications. *Telecommission Study 4(a)*, pp.33-4.

[76] *Ibid.*

the theoretical limit based on utilizing full system capacities as soon as they are introduced.

"The decrease in costs of these systems has been brought about by the continual advances in technology in increasing the system cross-section capacities. The real economy is in the economy of scale of a route, and the upper curve indicates a trend to approach the lower limit, as the cross-section capacities increase in Canada. The curves shown are only approximate averages as actual figures vary significantly year by year, especially when new routes must be introduced."

It is notable that most of the new developments in long-distance transmission employ pulse-coded modulation to transmit voice data. This technique is well suited for data transmission and should permit much more efficient utilization of long-haul facilities, thus leading to lower data transmission according costs. Cost-reductions (by a factor of nine for long-distance data transmission) to U.S. data on the subject are possible by the end of the decade.

2. Switching

The most promising developments in the area of switching equipment for data transmission are: first, the development of high-speed line-switching equipment, and second, the further development of message-switching capability. To some extent, these two developments are competitive, since the provision of one is likely to reduce the demand for the other, but the overlap is by no means complete. It is significant that the General Post Office (GPO) in the United Kingdom is planning to provide both services on a restricted experimental basis in the 1975-76 time-frame[77].

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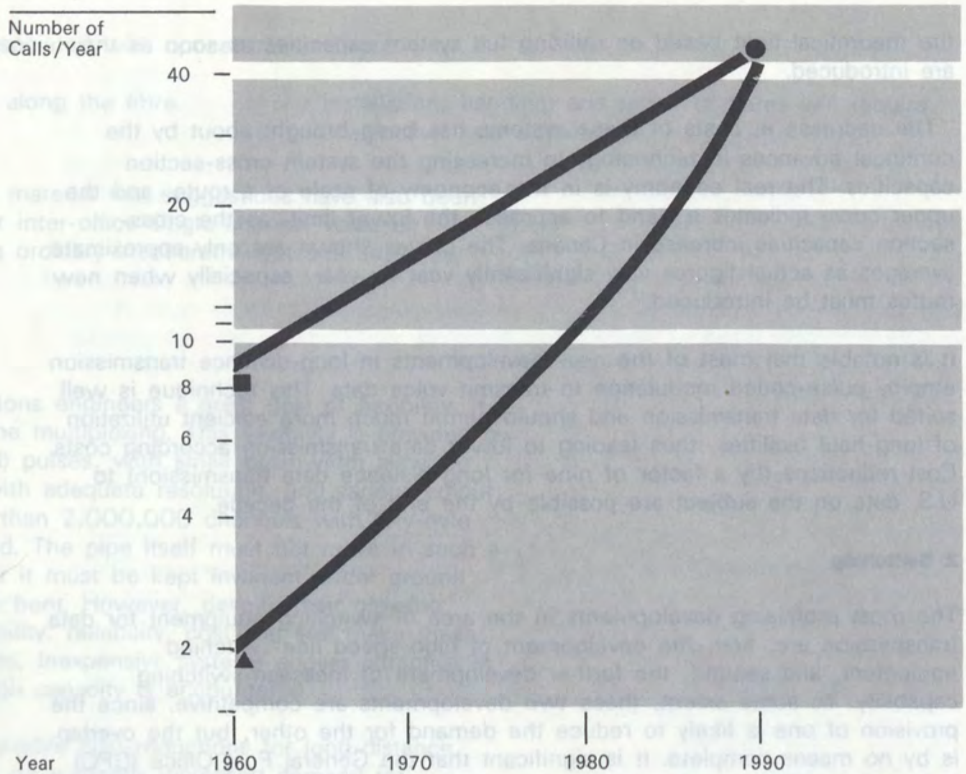
77 Allery, G.D. and Chapman, K.J., "Features of a Synchronous Data Network for the United Kingdom", *IEEE International Conference on Communications, Montreal, 1971*, pp.31-10 to 31-13. (Some information was also derived via private conversation.)

Figure 14
Expected Growth of Existing Common Carrier Switched-Networks for All Services for Both Local and Toll Calling



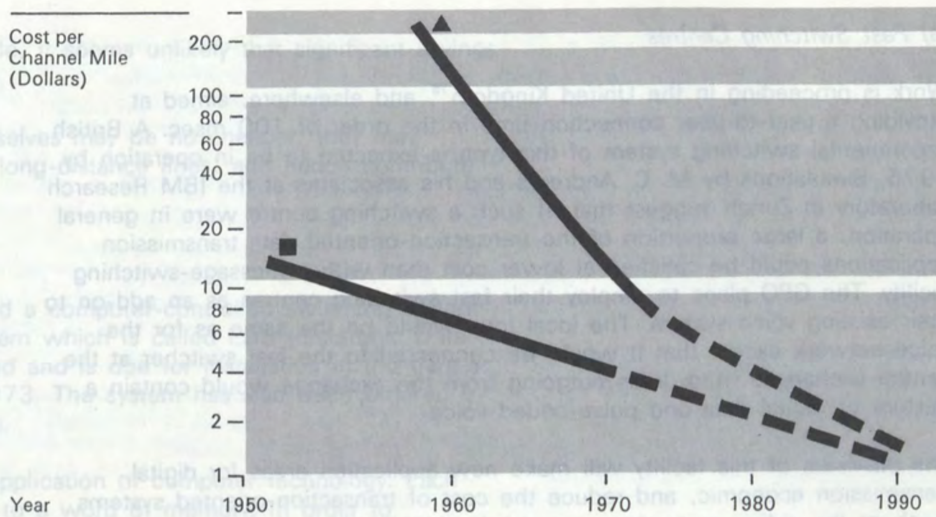
▲ Switched Voice Band Services Toll Calls Scale X 10^8

■ Switched Voice Band Services Local Call Scale X 10^9

Source: *Telecommission Study 4(a)* *

* Department of Communications, *Telecommission Study 4(a): The Future of Communications Technology*, p.83.

Figure 15
Long-Haul Facilities Less Terminal Equipment



▲ Average Due to Route Size in Canada

■ Theoretical Lower Limit

Source: *Telecommission Study 4(a)* *

* Department of Communications, *Telecommission, Study 4(a): The Future of Communications Technology*, p.83.

(a) Fast Switching Centres

Work is proceeding in the United Kingdom[78], and elsewhere, aimed at providing a user-to-user connection time in the order of 100 msec. A British experimental switching system of this type is expected to be in operation by 1976. Simulations by M. C. Andrews and his associates at the IBM Research Laboratory in Zurich suggest that, if such a switching centre were in general operation, a large proportion of the transaction-oriented data transmission applications could be satisfied at lower cost than with a message-switching facility. The GPO plans to employ their fast switching centres as an add-on to their existing voice system. The local loop would be the same as for the voice-network except that it would be connected to the fast switcher at the central exchange. Trunk lines outgoing from the exchange would contain a mixture of digital data and pulse-coded voice.

The provision of this facility will make new application areas for digital transmission economic, and reduce the cost of transaction-oriented systems (such as the airline reservation networks) which will be able, once again, to make economic use of the switched-network. Furthermore, since the fast switch can reasonably be treated as an add-on to the present switched-network, installation can proceed without revolutionizing the existing system.

The impact of new technology on switching costs is very hard to assess. It is significant, however, that Bell Telephone Laboratories in the U.S. and Bell.Northern Research in Canada have undertaken sizable research efforts in solid-state devices applicable to electronic switching. The Data Transmission Company (Datran) in the U.S. has recently announced that it will use electronic switches capable of realizing a 100-microsecond connect-time on their projected U.S. data transmission network. On balance, though, because of the slow rate of conversion to electronic switching equipment on the voice-network, and because any high-speed data switch which may be developed as an add-on to the current system is unlikely to be produced in

[78] Allery, G.D., *et al, op. cit.*

large quantities over the next decade, it seems unlikely that significant savings in switching costs can be expected.

However, while the switches themselves may be no cheaper, they may significantly affect the utilization of long-distance lines, and hence contribute indirectly to cost-savings.

(b) Electronic Data Switching

Siemens in Germany have developed a computer-controlled switching system exclusively for digital data. The system which is called EDS (Electronic Data Switching) has been built and tested and is due for installation in the (large) German Telex system starting in 1973. The system has also been ordered by Western Union in the United States.

The switch itself is an interesting application of computer technology. Each incoming line is directly connected to a word of memory. In order to "establish a connection" it is necessary only to write the memory address, associated with the "destination" line in the "origination" line memory-word, and set a "use" flag bit. The reciprocal address is written in the destination memory-word also, to allow two-way data traffic. Whenever there is a polarity change on the incoming data line, an interrupt flag is set, commanding the computer to transfer the polarity change to the outgoing line. Unless a polarity change occurs, no action by the computer is required. The computer services sequentially interrupts (*i.e.*, not on a first-come, first-served basis) at a maximum rate of one interrupt per computer cycle time (currently one microsecond). Thus, an absolute maximum throughput of data through the switch would be two Mb/s. In practice, the rate is somewhat lower in order to keep data transfer delay times to a reasonable level, and to permit the computer to attend to various overhead operations. A rate of 800,000 b/s is thought to be a reasonable upper limit. The switch can have up to 16,384 lines connected to it.

There are some interesting features of this unique switch design.

First, relays have been virtually eliminated from the switch itself (though they are used in remote data concentrators), which reduces the maintenance required. High reliability has been designed into the system through provision of redundant elements and error checks.

Second, "connections" are made virtually instantaneously (*i.e.*, within microseconds) and, up to a maximum data-rate of 9,600 b/s (and a minimum of about two b/s), any data-rate can be accommodated, whether synchronous or asynchronous. Furthermore, the fraction of the switch's capability engaged is directly proportional to the data-rate through the switch.

Third, the fact that the switch is computer-controlled makes a number of special features relatively easy to provide. For example, hot-line service can be provided between two sites simply by leaving the "use" flag bit continuously set. Private networks can also be provided by programming allowed interconnections into the computer.

There are, however, some important disadvantages. These are:

- The type of switching used can introduce considerable jitter at high data-rates. In this regard, it should be pointed out that the switch was designed to process data 93 percent of which was 200 b/s or less. The manufacturers have provided a facility to off-load high data-rate connections using conventional switching.
- Although the system appears well suited to the German environment, with its relatively compact geography and high population density, in Canada, it seems important, at least in the long-term, to provide a switching system which is adaptable to many telecommunications requirements, so that all services can benefit from the economies of scale to be derived from heavy utilization of facilities. EDS is not designed for, nor is it practically adaptable to, voice or video communications switching. Of course the economies-of-scale argument can be overemphasized. It is quite possible that, in the shorter term, the EDS switch will fill a gaping hole in existing data communications services.

(c) Message-Switching

Message-switching store-and-forward systems are not new. They have been used by the military and by the telegraph companies for many years. The introduction of computers to store-and-forward systems greatly increased the potential speed and flexibility of such systems.

The principal advantage of the store-and-forward technique is that messages can be transmitted essentially instantaneously, without any concern by the sender as to the availability of all the line segments over which the message will travel to the receiver. Furthermore, by queueing the messages at each node, it is possible to achieve high line utilization, although, depending on traffic characteristics and queueing length, at the cost of some delay. Additional advantages of store-and-forward systems are:

- It is relatively easy to transmit the same message to more than one receiver with such a system.
- It is possible to introduce the concept of priorities, where those who are prepared to wait to have their data transmitted will pay less.
- A message-switching computer can be used as a means of centralizing several functions which might otherwise have to be performed at each individual terminal. These functions include:

  (i) Assembly of locally received information into packets for efficient transmission;
  (ii) code conversion or encryption of incoming or outgoing data (if desired);
  (iii) attachment of routing and error-checking information to the packet, and
  (iv) performance of transmission error checks on receipt.
- The switching computer can be instructed to provide deliberately delayed message delivery.

A number of private computerized message-switching networks are now in use (in Canada and elsewhere), some of which use privately-operated node computers, and some of which rent a portion of message-switching facilities from the common carriers.

Recent work sponsored by the Advanced Research Project Agency (ARPA) in the U.S.[79] and by D.W. Davies at the National Physical Laboratories in the U.K.[80], has greatly advanced the state of the art in this field. The store-and-forward sub-system of the data transmission network planned for the U.K. is based on Davies' investigations.

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[79] Frank, H.; Frisch, I.T. and Chou, W., "Topological Considerations in the Design of the ARPA Computer Network", *AFIPS Conference Proceedings, Volume 36: 1970 Spring Joint Computer Conference, May 5-7, 1970, Atlantic City, New Jersey* (Montvale, N.J., AFIPS Press, 1970), pp.581-7.

[80] Davies, D.W., "The Principles of a Data Communication Network for Computers and Remote Peripherals", *Proceedings of the IFIP Congress 68, Volume 2 — Hardware Applications, Edinburgh, August 5-10, 1968* (Amsterdam, Netherlands, North-Holland Publishing Company, 1969), pp.709-15.

It seems unlikely that a message-switching system will be able to operate as economically as a fast line-switching system. However, because of its additional capabilities, it may well be a useful adjunct, even if the fast switcher does become available. In the shorter term, it will provide an otherwise unobtainable service. Research into the feasibility of providing a public computer message-switching system in Canada is being undertaken by TCTS. Telephone and telegraph companies in Canada currently provide this service for private use only.

3. Local Loops

As mentioned at the start of the section on communications, the carrier investment in local loops represents approximately 37 percent of total investment. There is little prospect for substantial cost-savings in this area over the next decade, but there is likely to be more pressure to increase the information-carrying capacity of local loops. Some preliminary work in switched broadband systems has been carried out in Canada but the general availability of a broadband switched-network of the "total communications" type appears to be beyond the general time-frame of this forecast. The ensuing discussion of paired cable and coaxial cable loops is extracted from *Telecommission Study 4(a)*.[81]

"*(a) Paired Cable Distribution*

"Three basic categories in paired cable technology offer solutions.

"(i) Regular twisted paired cable as found in the distribution today is inexpensive, and offers the potential of a much higher information rate than it is used for today. Each pair has the potential of one-way transmission at about 1.5 M bits/sec with repeaters over 1.15 miles. Subscriber carrier employing IC's and digital filters could prove

[81] Department of Communications, *op. cit.*, pp.44-5.

economical during 1975 to 1980 in providing a second line capability with much improved transmission quality. The concept of a new communications, set by 1975 to 1980, employing tone alerting tone supervision, and reduced loop current or even remote powering could drastically reduce the gauge of cable pairs and hence, the cost of the exchange facilities.

"(ii) Low capacitance paired cable, similar to that used in short-haul transmission facilities, could also be introduced to allow for higher information rate type of services. With presently attainable values, a 6.3 M bit/sec facility is possible with digital repeaters every 2.5 miles.

"(iii)Forms of highly balanced paired cable are also possible which would yield much higher bit rates or increased repeater spacings if higher bit rates are required. The common carriers have had many years' experience with highly balanced cables.

"In the past the costs of switching have been high in comparison with trunking. Today local switching costs are comparable with distribution costs. As switching units become smaller and less expensive in the 1980 to 1985 period it should be possible to decentralize the switching matrices. This may favour paired cable distribution as the subscriber distribution would become much shorter from the decentralized switches and their associated shared higher usage trunking. The shorter length of paired cable should mean no individual repeaters per subscriber loop for wideband facilities and would avoid the problems of longitudinal currents which are present on coaxial cable.

"*(b) Coaxial Cable Systems*

"Two basic layouts for coaxial cable distribution systems are possible, the coaxial loop and the dedicated switched coaxial system.

"(i) The coaxial loop distribution system could be achieved on either [a frequency-division or time-division multiplexing] basis. A broadband large coaxial tube would loop round a community connecting approximately 200 subscribers before returning to the originating point. Total one-way services such as CATV, FM and AM radio as well as two-way videophone, data and voice could be provided on the same facility. Present cost studies in progress may indicate that such a system is probably only economical for combined total services. Also in sparsely populated areas the system would not be as attractive as in metropolitan areas.

"(ii) The second possible coaxial system is the individual switched coaxial distribution. Coaxial cable in a miniature form would be used in place of paired cable in the distribution network. Unlike paired cable the coaxial cable is not as flexible for splicing and rerouting after placement. With decentralized switching and depending on the degree of decentralized switching which is attainable, this system may have application if distribution of all types of information — videophone, voice, CATV, FM, etc. — are provided.

"Either system will require cheap reliable electronics both for station and repeater use. Although improvements in cost and size will be made during the 1970 to 1980 period, the major improvements will be possible with LSI and digital filters in the 1980 to 1985 period."

A number of experiments have been undertaken (particularly in the U.S.) on the use of cable TV facilities to provide two-way communication. While this type of facility is not readily adaptable to arbitrary interconnections between subscribers, it is not overly difficult to provide subscribers with a link back to a central source (which can be a computer). Several experimental systems have been used for soliciting subscriber reaction to program material, and to enable subscriber participation to a limited extent. Guité[82] has described several experiments of this nature.

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[82] Guité, Jean-Michel, *Branching Out, Background Paper 4 — New Technology for Citizen Feedback to Government* (Ottawa, Information Canada, August, 1972).

The mean local loop length for Canada is probably in the range of 11,000-to-12,000 feet (extrapolated from U.S. figures)[83]. Average loop costs as a function of length for the General Telephone system are shown in Figure 16. The distribution of loop lengths is shown in Figure 17. The average local loop is 1.35 times the airline distance from the exchange to the user station.

4. Modems

Modems, or modulators/demodulators, provide the interface between computer systems and terminals and the common-carrier switched (voice) network. As a general rule-of-thumb, the purchase price of modems has been estimated at one dollar per b/s[84], so that a 2,000-b/s modem would sell for approximately $2,000. In fact, there is a wide variation regarding this price, depending on the particular features desired. Whether or not some of the features are necessary may be dependent on the condition of the common-carrier lines over which the user is transmitting or receiving.

In general, most data transmission over the Canadian switched-network is at 2,000 b/s or less. Transmission over leased voice-grade lines at 4,800 b/s is now quite common, and some transmission is now successfully carried out at 9,600 b/s over leased voice-grade circuits, although modems for this service are costly.

When digital transmission on the local loops is introduced (as is planned by TCTS starting in 1973 on a pilot scale), then modems, as such, will disappear in this particular service offering. There will still be a need for an interfacing device to protect common-carrier facilities and to provide the synchronization pulses. Some form of automatic dialing mechanism on non-leased lines may also be required. The cost of the interface should be considerably below that of a modem, but cost figures are not yet available.

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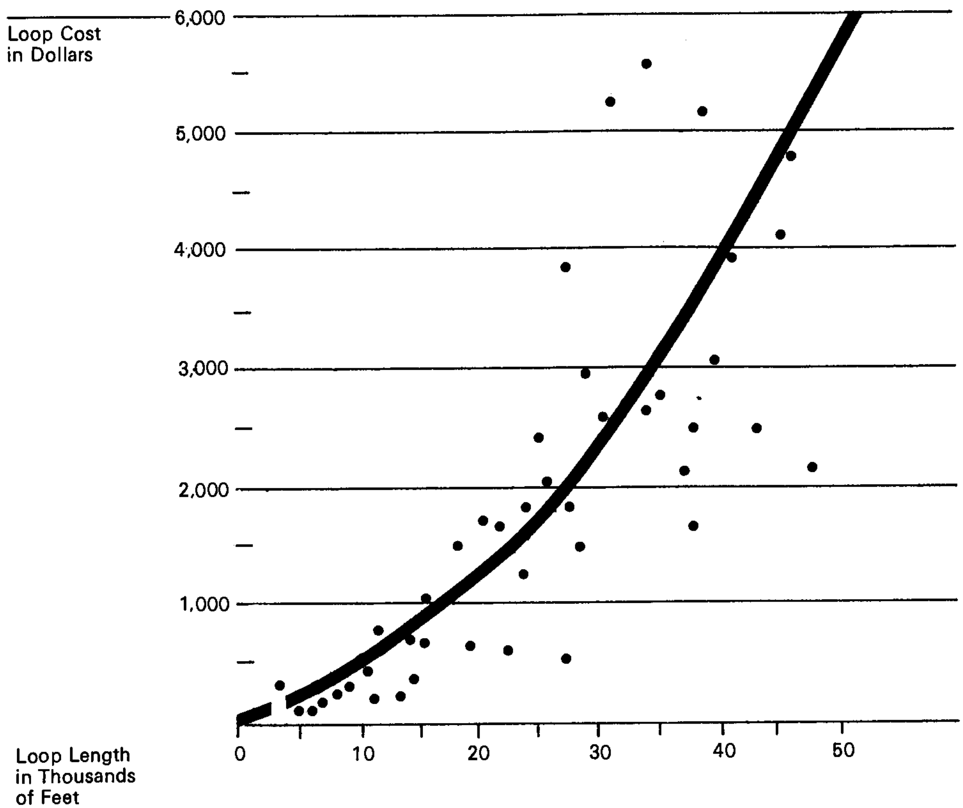
83 Davis, Clinton H. and Lally, William J., "Systems Engineering Survey of Subscriber Loop Plant", *IEEE Transactions on Communication Technology*, Vol.COM-19, No.1 (February, 1971), pp.71-9; and Gresh, Philip A., "Physical and Transmission Characteristics of Customer Loop Plant", *The Bell System Technical Journal*, Vol.48, No.10 (December, 1969), pp.3337-85.

84 Cronin, Frederick R., "Modems and Multiplexers – What They Do for Data Communications", *Data Processing Magazine*, Vol.12, No.12 (November, 1970), pp.31-4.

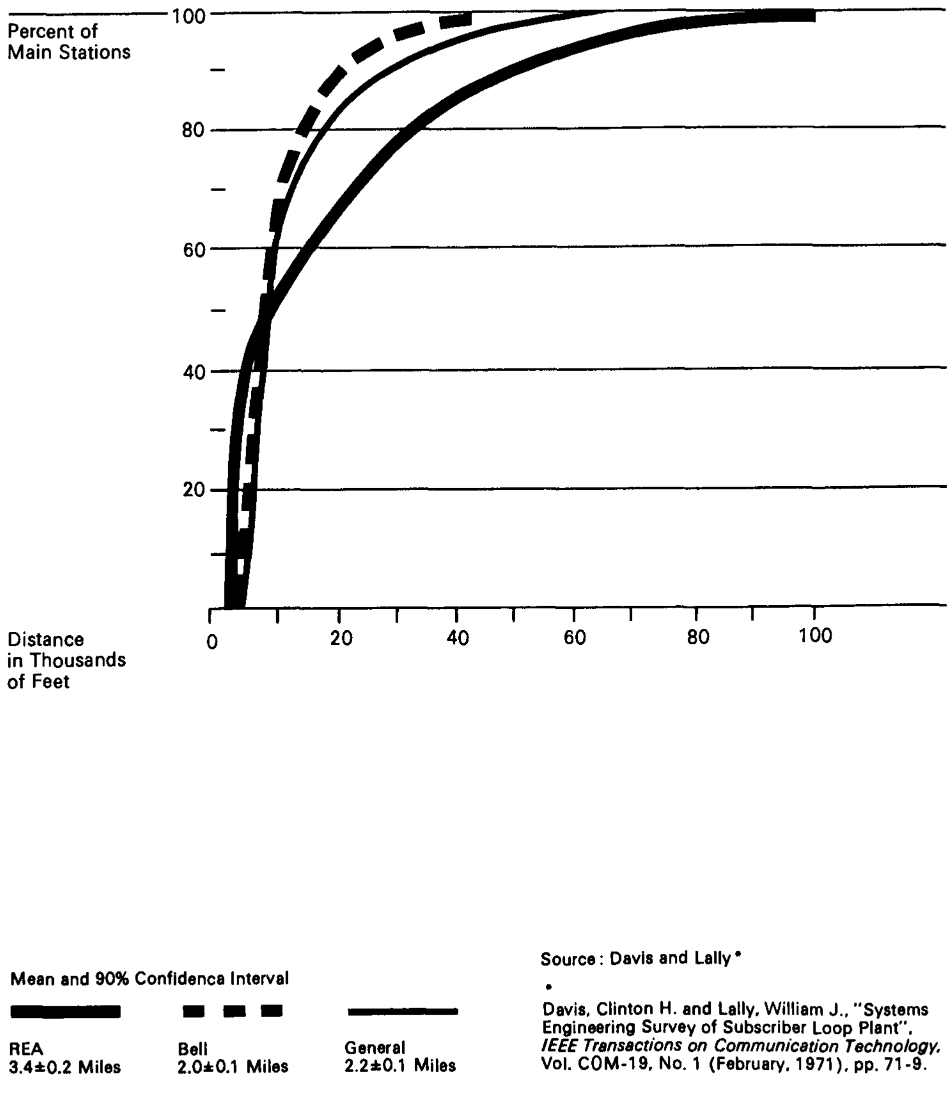
Figure 16
Cost per Loop



Source: Davis and Lally*

* Davis, Clinton H. and Lally, William J., "Systems Engineering Survey of Subscriber Loop Plant", *IEEE Transactions on Communication Technology*, Vol. COM-19, No. 1 (February, 1971), pp. 71-9.

Figure 17
Route Distance—Central Office to Sampled Telephone Station



Source: Davis and Lally*

* Davis, Clinton H. and Lally, William J., "Systems Engineering Survey of Subscriber Loop Plant", *IEEE Transactions on Communication Technology*, Vol. COM-19, No. 1 (February, 1971), pp. 71-9.

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