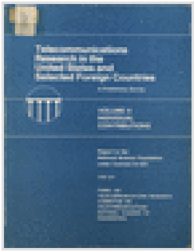

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Volume II

Individual Contributions

Report

to the

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Panel on Telecommunications Research

Committee on Telecommunications

National Academy of Engineering

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FOREWORD

The Panel on Telecommunications Research of the Committee on Telecommunications, with support from the National Science Foundation, made a preliminary survey of telecommunications research in this country and a comparison of it with similar research in other technologically advanced countries. The goal was to determine its adequacy, balance and relevance to U.S. national needs.

The Panel effort has resulted in a two volume study. Volume I summarizes the various aspects of telecommunications which the Panel reviewed and contains the Panel's conclusions. Volume II is a collection of original papers on a number of telecommunications-related topics which the Panel requested from its members and from outside experts in order to provide it with background material for its study. The Panel concluded that these individual papers should be printed so that other readers besides the Panel members could have access to them. However, the individual authors accept sole responsibility for the content of their papers. The views expressed therein are not to be attributed to the Panel, the Committee on Telecommunications, or to the National Academy of Engineering.

The Panel wishes to express its great appreciation for the thoughtful effort that went into these individual papers, both by Panel members and other volunteers. The latter included: G. C. Bacon, IBM; L. R. Bloom, GTE Laboratories, Inc.; P. S. Dauber, IBM; S. W. Dunwell, IBM; H. F. Olson, RCA Laboratories; E. F. O'Neill, BTL; E. N. Pinson, BTL; L. G. Roberts, ARPA; D. P. Rogers, NASA; S. N. Roscoe, University of Illinois; Jared S. Smith, General Electric Co., and P. D. Welch, IBM.

The Panel also wishes to express its great appreciation to the National Science Foundation for the financial and substantive support which the Foundation gave to make possible this study of the status and trends of telecommunications research in the United States.

PANEL ON TELECOMMUNICATIONS RESEARCH

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AN ANALYTICAL APPROACH TO THE STUDY OF TELECOMMUNICATIONS RESEARCH

In a survey of telecommunications research, what shall we include within the scope of the term telecommunications? We must take care not to limit the field to hardware technology, for communications is basically a human relationship. Similarly, we must recognize that communications can occur via many alternate forms - travel, books, magazines, and presentations before audiences. These are but a few examples of communications that might be overlooked by researchers searching for more sophisticated forms of communications.

In fact, a literal definition of telecommunications can be had from examining the origins of the word. Tele, from the Greek, means "distant." Communicare, from the Latin, means "to impart." "To impart at a distance," then, is the generic meaning of telecommunications. While that could include such archaic forms as notches on a stick carried by an aboriginal tribal runner, we shall limit our generic field to the currently popular use of the word. Chart I on page 7 provides a background panorama of what we are talking about when we speak of generic telecommunications. The reader with additional perspectives and creative thinking may be able to add more examples to the chart; what is already recorded, however, should suffice to emphasize the breadth of the subject.

The reader might question including the category of "information processing" under the subject of telecommunications. We are trying to illustrate that "communication" does not generally take place without some form of information processing. In our routine interpersonal communications, this processing is entirely within the two human beings involved, too intimately related to the human biological factors in the basic information transfer process to merit separate analysis. There are over six information processes between the brain of the speaker and the brain of the listener. In oral communications the brain initiates nerve pulses; the pulses control muscles to generate sound and to control oral resonances and lip noises to change the ideas to acoustic waves; the waves hit the outer ear drum which is connected by the impedance transformer (anvil hammer and stirrup) to excite the inner ear drum to stimulate the nerve pulses which reach the brain for interpretation. But there are some communications which do require a specific processing step outside the human participants; it is these that we have tried to identify as part of the total communications world.

Using Chart I as the broad picture background, let us examine a more practical structure for further study. Our

CHART I
THE GENERIC FIELD OF TELECOMMUNICATIONS (Transmission By Any Means)

COMMUNICATORS, SOURCES & SINKS	Current Information Transfer Modes						INFORMATION PROCESSING
	Graphic		Voice		Visual		
	live	stored	live	stored	live	stored	
Personal	telescratch pad teleprinters	mail cards telegrams	telephone	tapes voice gram	travel conferences picture phone	home movies slides videotape	mini-computers, adding machines
Mass (1 → N)	Dow-Jones AP wire	books magazines advertise newspapers	radio p.a.	records tapes	TV meetings shows	tapes films	option generation & display; Plato IV
Mass (N → 1)		pollsters voting	polling response at rally	tape interviews	TV news coverage CCTV monitor	tapes films	election prediction, battle mgmt.
Man → Machine	controls	stored prog. comp. image recogn.	voice/graph translator	voice prog. computer			Computer assistance to design by group
Machine → Man	teleprinter display	teleprinter display	vocoder	voice answerback	displays		
Machine → Machine	data comm	data comm					distributed computation
Environment → Mach. → Man	pollution sensors traffic sensors biotelemetry monitor	pollution sensors traffic sensors			radar	computer display	warning (multi-sensor correlation)

broad interpretation of the word, "telecommunications," has allowed us to examine a cosmos of information transfer, while, as a practical matter, the world of telecommunications is more generally understood to imply "means to impart information at a distance through the transmission of electromagnetic wave symbols."

Some explanation may be needed in a few of the terms:

1. The word "technical" is used to denote specialized professional activity. Just as medicine has its sensor (eye and ear) doctors and transmission experts (neurologists), communications also has its specialized areas of expertise which we have labeled "TECHNICAL RESPONSE ACTIVITY AREAS." Each of these areas can be a candidate for specific research projects.

2. In "Human Factors" we are attempting to find a term to cover those biological and psychological traits of man that are vital to the communication process. How do we perceive? What aspect of interpersonal communications is most significant to achieving interpersonal understanding of the subjects being covered? Can man be educated and trained to make better use of available man-made systems?

This category includes the concept of ensuring that the human interface to the communication system is optimized from both a hardware and a software standpoint. The hardware/human factors interface might include such items as adequate frequency response, level, fidelity, contrast, brightness and definition, as well as size and shape to fit the human hand, eye or ear sensors. The software/human factors interface might include time-study designed operator routines to structure telephone calls for a maximum transfer of information in a minimum time.

3. By "System Architecture," we are making reference to the fact that communication media used have a certain structure that determines to a large degree their utility in meeting new challenges. We feel that there are cases where a new structure might provide more effective means for the public to avail itself of the benefits of the new technology. Examples: the present means to handle intra-organization procedures such as internal mail, telex or a teleprinter system are thus far mere extensions of past ways of handling input/output and filing. The basic tools to do a much more effective job in office or interoffice procedures, including the generation, print-out, editing, filing, coding, message handling, etc., are on hand. The bottleneck is the need for the design of an entirely new "System Architecture" that will tend to be

standard. As another example, distribution of television and other information to the home might better be achieved for long run needs via cable, waveguide or fiber optics. Existing systems such as TV broadcast and the mail are vulnerable in any change. Hence a new approach, involving technical, economic, social and political inputs, is needed for progress.

4. In identifying the "Legal Factors," we are calling attention to the thought that, in progress toward meeting the cited communication needs, there are as yet unresolved legal questions needing study and reconciliation. Some of these legal questions are based upon needed legislative action; they may also thread back into basic socio-economic problems.

We have provided in Chart II a view as to the relative importance of research activities vs. needs. It is an attempt to respond to the question posed against the "needs" categories as to which of the response areas seems to hold the key to significant progress towards meeting that need. The reader may wish to develop his own appraisal. In any event, the chart can provide a framework for classification of efforts in responsive research.

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Jared S. Smith

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Lynchburg, Virginia

CHART II
IMPORTANCE OF SYSTEM COMPONENTS IN FUNCTIONAL COMMUNICATIONS

Communication Needs in Societal Systems	Technical Response Activity Areas					
	System Architecture	Human Factors	Terminals Sensors Displays	Transmission Mod/Demod Coding	Switching Routing Control	Processing Storage
Interpersonal Relations	2	1x	3			
Entertainment	3	2x	1			
Business & Government						
-Transactions	3	3x	1			2
-General	2	1x	3			
Polling	1	2x	3		3	3
Transportation	2	1	3	3	2	
Defense	1	3	2	1	1	2
Medical Care	1	3x	2			2
Education	1	2x	3			2
Public Safety		1x	3	2		
Explore/Experiment			2	1		3
Energy/Waste		3		1		2

Code 1 Very Significant
2 Moderately Significant
3 Significant
x Legal Factors must also be considered

INTERDISCIPLINARY RESEARCH AND DEVELOPMENT PROBLEMS IN TELECOMMUNICATIONS

I. Introduction

The National Science Foundation (NSF) is properly concerned about the status of telecommunication research in this country in order to establish if we are in danger of losing our technological lead to other nations. The intent is presumably to take whatever steps may be necessary to retain our technological superiority in the foreseeable future.

An important related question is, of course, how well and how rapidly we are applying the benefits of existing advanced telecommunication technology in the public and national interests. Are some of the foreign countries, in fact, taking better advantage of the existing technology than we are - in exploiting its social and economic benefits?

II. Real Concern

In the background is the real concern and uneasiness about our own industrial and commercial exploitation of this technology both for domestic needs and in international trade. We find ourselves all of a sudden in the early 70's with a substantial excess of engineering manpower and also at the short end of the balance of international trade. We are importing more products and services in telecommunications than we are exporting - a rather embarrassing position for the most technologically advanced country in the world. And this is happening at a time when our own engineering talents and production capacities are nowhere near fully utilized.

So let us examine the situation in order to see how improvements might be brought about from the standpoint of new research. What type of telecommunication research should get the highest priority from NSF if the public and national interests are to be served?

III. General Evaluation

The United States has done remarkably well in advancing the state of the art in telecommunications in the past decades. Our research and technology have been unexcelled. Industry has expanded tremendously. Meanwhile the telecommunications of other countries have also advanced, in most cases with our help.

We are still substantially ahead of them in pure technology, though not as far ahead comparatively as ten or twenty years ago. There is no tangible evidence that we shall lose our technological lead in the near, or for that matter, in the foreseeable future, if we maintain our present level of effort in the "hard" sciences.

From the standpoint of exploitation of the technology in our public interest, however, there is a general consensus that we are not doing so well. Many important areas of sophisticated telecommunications applications, such as education, health services, transportation, public safety and the general economy have not benefitted nearly as much from this technology as many of us believe they should. The advance in applications has many pitfalls and impediments and hence progress is slow.

Why is this? The reason, of course, is that in applying telecommunication technology to human needs and national needs, much more than technology is involved. In addition to vast and difficult system architecture and engineering problems, they give rise to conflicts of interests in industry and government.

The issues raised involve social, economic, political, legal, regulatory and related problems. These issues, not being sufficiently resolved, are inhibiting the growth of the industry and delaying advances in very important telecommunication applications, such as cable television, domestic satellite services, interconnecting data networks, public broadcasting, educational networks, etc.

IV. Interdisciplinary Problems

Thus the bottleneck is not technological exploratory research, traditionally of direct interest to scientists and engineers. Further advances in more technology may, in fact, embarrass us more because we do not effectively apply all the sophisticated telecommunication technology which is now available to us and probably will not apply it for a number of years to come.

The bottleneck involves problems in economic, social, political, legal and institutional areas where there is plenty of room, and need, for exploratory research. Such research and analysis, when carried out competently and objectively, would provide the basis for policy determinations in the public and national interests. Since it would include the "soft" sciences, in addition to the "hard" science of telecommunication technology, it would be very much of an interdisciplinary effort. It is this area that should get the highest priority from the standpoint of the National Science Foundation.

V. Present Efforts

It should not be construed that the issues and questions raised, and listed below, are receiving no attention at the present time. A reference to the current trade and professional press, in fact, will show that there is a relatively great awareness of many of these problems, some of which, particularly in the broadcast field, recur year after year. There is substantial effort on the part of many organizations, both public and private, with varying degrees of competence and objectivity, to resolve these issues in their own particular favor.

But most of these efforts, to date at least, cannot be classified as objective research and analysis to form a basis for sound long term policy determination. The shortcomings of these efforts may be summarized as follows:

a. too meagre, in view of the very substantial public interest involved

b. lack sufficient depth of professional competence on the part of the organizational units involved

c. not sufficiently free from industrial and political bias and pressures

d. lack appropriate institutional foundation to insure competence, objectivity, and continuity of effort.

The appropriate analysis and resolution of these issues should be a serious national concern. It is, therefore, appropriate that the NSF ponder seriously this problem with a view toward giving a higher priority to the needed basic interdisciplinary research.

VI. Interdisciplinary Telecommunication Research Center(s)

Since the requisite talents and capabilities are not readily available, where can they be reasonably mustered to do this research and become the focal point for this type of interdisciplinary telecommunication activity? The most likely place to find the necessary talents is in the larger university environment where the separate disciplines of economics, law, sociology and related areas exist, in addition to a good technical and scientific base. Then the appropriate interdisciplinary teams might be brought together to address these issues and explore objectively all relevant possibilities. Their findings and the result of their research could then be published with a minimum of political or industrial bias or pressure.

The question of promoting and establishing such interdisciplinary competency in one or several environments outside of government and industry is one that the NSF and NAE might consider seriously, because of the long range implications.

VII. Specific Issues and Problems

What are the interdisciplinary issues and problems which require and deserve significant research and analysis effort which the NSF may appropriately sponsor?

Following is a representative, but far from complete list. No priority is intended because of the listing sequence. There is considerable overlap between the various items, but that is the nature of most of the problems:

1. Nature of demand for broadband communication distribution system. Who needs it, who wants it, and how much are they willing to pay for it?

2. Impact of CATV on education

a. elementary schools

b. secondary schools

c. universities and colleges

d. adult education

If favorable, how can it be enhanced and speeded up?

3. Telecommunication technology and impact on social services - health, education, welfare, public safety, etc. Is the rate of progress satisfactory?

4. Relative merits of private ownership and exploitation of broadband telecommunication systems, versus municipal or public ownership.

5. Public versus private ownership in the operation of other telecommunication facilities, such as common carrier, broadcast, etc.

6. Regulation in the public interest. What are the necessary ingredients for effective and timely regulation? Does the regulatory body have an adequate source of unbiased technical and other relevant information necessary to do an effective job?

7. Federal, State and local jurisdictions in telecommunications.

8. What rate of growth of the telecommunication industry is in the public interest?

9. Impact of TV on society.

10. Censorship in telecommunications, including broadcasting.

11. TV programming - what alternatives are there? What are the merits of these alternatives?

12. Political use of telecommunications - Fairness Doctrine.

13. Advertising influence on TV programs.

14. Cost and pricing of telecommunication services. Marginal costs. Cost averaging. Effect on potential competition.

15. Savings and capital needs of the telecommunications industry.

16. Franchising of telecommunication services.

17. Copyright laws and their applications to TV, CATV and telecommunications in general.

18. Open channels - who pays for them?

19. Who pays for broadcast services? - What are the merits of alternatives to the present system?

20. Is competition in telecommunication necessarily in the public interest? Is there a good case for natural monopoly - with effective regulation?

21. Should the rate of technological growth in telecommunications be encouraged, restrained, or left alone? Is the rate of obsolescence of telecommunications equipment too rapid from the public interest standpoint?

22. Should CATV be regulated? Why and by whom?

23. Spectrum utilization policy guidelines, taking into consideration technical, economic, social, legal and international aspects.

24. International aspects of telecommunications. Dealing with foreign governments. Balance of trade considerations.

25. Since many issues are complicated by too many variable and unknown factors for accurate analysis, is there an effective mechanism to make significant pilot experiments in the social and economic areas before finalizing long range policies?

26. What are the short and long range implications of the interconnection decision?

27. Domestic satellite issues. Services in the continental USA. Services to Alaska and Hawaii. Impact on industrial growth.

28. Information pollution. Much of the information transmitted over communications facilities is irrelevant and wasteful. Should any limits be set to the amount of information transmitted? If so, who enforces it?

29. Compatibility and commonality between civilian and military needs in telecommunications. How much "hardening" and redundancy of plant is appropriate from the standpoint of possible natural disasters? How much for military emergencies?

30. Is there a good case for Federal subsidy to enhance the competitive advantage of the U.S. telecommunications industry over those in other countries - keeping in mind that telecommunications are government-controlled abroad?

31. Multi-national companies in telecommunication and electronics. Their nature and characteristics. Are they advantageous from the long range U.S. standpoint?

32. Are the U.S. patent laws as significant as originally intended, in the present telecommunication industry? Consider from the standpoint of industry, inventor and public interest. What improvements are in order?

33. Impact of anti-trust laws on the telecommunications industry and the balance of trade.

34. Impact and importance of the telecommunications industry on the U.S. economy.

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RESEARCH ON SPECTRUM, PROPAGATION AND RELATED AREAS OF TELECOMMUNICATIONS TECHNOLOGY

I. General

The electromagnetic spectrum is a very important resource which is vital to modern telecommunications in the broadest sense. Much has been written on the importance, use, regulation and exploitation of this resource in the public interest. From our standpoint it is only necessary to recognize that the demand for radio frequency spectrum is large and growing every day as individuals, industry and institutions find more users for this resource.

In some cases, the use of the spectrum resource is indispensable for the services rendered and no reasonable alternatives are possible. Such, for example, are the uses of the radio spectrum in navigation aids, mobile communications, satellite communications and certain broadcast applications. In other cases, there are alternatives to the use of the radio spectrum, but the alternatives may be uneconomical or awkward or both.

An NAE Committee on Telecommunications report* had the following to say on the growing overcrowding of the spectrum:

"During the past twenty years there has been a series of spectrum management studies ... The most general and the most basic consideration evidenced in all of these studies is the indisputable fact that spectrum usage is expanding and spectrum space is limited. This combination makes eventual scarcity inevitable. The question remains, however, as to exactly when this scarcity will reach critical proportions and what effects it will have on the nation."

Thus, with the resource limited and the demand growing, a serious challenge is presented to scientists and engineers to

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*The Application of Social and Economic Values to Spectrum Management, Committee on Telecommunications, National Academy of Engineering, June 1970.

delay and, if possible, postpone indefinitely, the day when the spectrum is saturated and no additional services can be provided without very serious interference problems between services.

Actually the use of the radio spectrum has evolved over the years in a rather haphazard manner and the method of assigning spectrum and allocating channels for the various services is far from optimum from the standpoint of the present state of the art.

II. New Research

With additional research and improved technology it can be said with some confidence that perhaps another order of magnitude improvement in density of services is possible within the presently allocated spectrum without undue destructive interference between services. With further expansion of the spectrum to shorter and shorter wave lengths, much more usable spectrum space can be available for telecommunications and related applications.

Significant research effort which would help postpone indefinitely the extreme scarcity or saturation of the radio spectrum may be classified under the seven headings listed below. The National Science Foundation (NSF) might consider soliciting creative research ideas in each area and sponsoring the best of these not duplicating ongoing work.

1) Spectrum extension
2) Modulation theory
3) Propagation
4) Antenna systems
5) Noise and interference
6) Social and economic aspects of spectrum utilization
7) Management of spectrum

Following are some general comments on each area followed by a list of research topics submitted by knowledgeable workers in the field.

A. Spectrum Extension

This type of research is basic. The object is to have more of the valuable resources by expansion of the usable upper limits of the electromagnetic spectrum. This would include the generation, precision measurements, component developments of means for modulation, transmission, reception and general control of radio frequencies through the infra-red, optical and ultra violet regions.

Much of the upper reaches of the spectrum may actually have more important uses for medical and industrial applications, in addition to communications.

A great deal of this type of research is actually going on in various industrial and university laboratories. It may only be necessary for the NSF to do a watchful monitoring of these activities to ensure that vital gaps are not left in the general knowledge and that what data is developed is not monopolized unduly for proprietary advantage, but becomes published or generally available in the public interest.

B. Modulation Theory

The overall objective of this area of research is to find more efficient modulation schemes which will permit maximum information transmission and reception per unit of spectrum occupied. This involves information theory, adaptive communications techniques and more sophisticated modulation methods than used in much of the crowded spectrum at the present time.

Though there is the possibility of substantial improvement in the efficient use of the spectrum following this line of research, it must be kept in mind that it will not be practical to implement this potential improvement because of long standing channel assignments and investments in systems and equipment.

However, the results will be applicable to new services in the not yet crowded portions of the spectrum, and in due course may provide a basis for revision and more efficient assignments in the presently well established areas.

C. Propagation

The propagation of radio waves in the earth's atmosphere is an extremely complex phenomenon which has attracted researchers from the time of Marconi and Heaviside. Much has been discovered over the years, but much still remains either unknown or not fully predictable.

At the low end of the radio spectrum there is need for detailed data to be able to evaluate controversial huge programs like Sanguine. At higher frequencies, in the HF band, the propagation is still not as predictable as we would like for many important applications. There is, however, the very intriguing fact, experimentally established, that the ionosphere can be modified artificially by high power directed beams to enhance desirable properties for special applications. More intensive work in this area is almost certain to be productive.

In the UHF, SHF and the higher regions of the spectrum there are unknowns with respect to the effects of different types of rain and also refractive index layers in clear atmosphere which in some bands raise havoc with the "expected" line of sight propagation.

There is need to gather and coordinate worldwide experimental data on propagation as a function of time, wavelength, weather conditions, and geographic area. There is also need to record and establish how effectively the spectrum is in fact used, as against how it is legally assigned and intended for use.

On the theoretical front it would be very useful to develop an overall unified engineering theory of propagation to encompass all important physical phenomena such as refraction, diffraction and scatterings.

D. Antenna Systems

The state of the art in antenna systems is sufficiently well advanced so that any reasonable requirement can usually be met. However, for the sake of completeness it should be mentioned here that further work may be necessary in certain important applications to confine radiation to the desired path and avoid or minimize minor lobes and back and side radiation. Related to this is need for very precise stabilization of antenna beams to prevent extremely narrow beams from shifting off target, a capability particularly important in satellite communications.

E. Noise and Interference

In any telecommunications system, the ultimate limitation of the sensitivity is determined by the nature and general level of the circuit noise in the frequency band used.

Noise may have many sources including the ever present thermal noise, along with atmospheric, solar, galactic, as well as man-made noise.

Considerable research has gone into the study, measurement and characterization of the different types of noise. But more will be required if we are to optimize telecommunications systems. It is particularly important in some rather unusual applications, such as at very low frequencies in submarine, deep water and deep mine communications circuits.

F. Social and Economic Aspects of Spectrum Utilization

The proper use of spectrum resources in the public interest obviously involves some continuing research in technology as discussed above. But public interest implies evaluation and trade off analysis involving social, economic, legal, regulatory and other factors. This calls for some objective interdisciplinary research where there are no established yardsticks or criteria for optimization. So it is doubly a research problem.

Research of this type could best be done in universities, where the requisite talent in the social, economic, legal and other fields (in addition to the technical talents) are available and can be brought together to address specific research problems. Hopefully they can be fully objective and not be swayed by political and industrial pressures, and the results of their analysis can be made fully available to everyone.

G. Management of Spectrum

Finally, the method of managing the spectrum, in both its commercial and government aspects, has in fact been carried out fairly effectively in the past, as evidenced by the phenomenal growth of spectrum use and the telecommunications industry.

However, as the spectrum becomes more crowded with users, the problems multiply. It is important, therefore, to study and consider critically the desirability of some new and improved approaches to the assignment of the spectrum, its use and management. Such research and studies might anticipate problems and find innovative solutions before the difficulties get hardened by large investments and established positions which will be very difficult to modify.

III. Research Topics*

Following are some specific research items suggested for consideration by workers active and knowledgeable in this field (no priority is intended by the sequence of the listing):

1. Characterizing propagation through dense, random, inhomogeneous media, such as re-entry plasmas.

2. Multiple scattering in random media composed of many coupled discrete objects, such as heavy precipitation.

3. Coupling of large antennas to the propagation medium, such as in tropospheric microwave links.

4. Development of a unified engineering theory of propagation to encompass all important physical phenomena, such as refraction, diffraction, and scattering.

5. Signal distortion and bandwidth limitations of various propagation media, such as tropospheric line-of-sight, over-the-horizon scatter, ducting, optical and micro-wave guides, and thru-the-earth.

6. Non-linear effects in wave propagation with regard to high power transmissions and inter-modulation effects.

7. Analyses of wave propagation on optical fibers, taking into account boundary roughness, bends, kinks, and inhomogeneities of the dielectric.

8. Consideration of non-electromagnetic methods in communications, such as seismic signaling.

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*Research is underway in many of these areas. The listing means that additional effort may be productive, particularly to maintain the U.S. technological leadership. Many of the suggestions are from staff members of the Institute of Telecommunications Sciences, Department of Commerce, Boulder, Colorado.

9. Ionosphere modification and applications.

10. Radio technology applied to seismology and earthquake prediction.

11. Radio technology applied to tornado detection and prediction.

12. Research on clear atmosphere refractive index layers. (Applicable to radio propagation and air navigation)

13. Rain and water vapor classification and effect on transmission.

14. Surface reflection, roughness and vegetation, and influence on propagation ducts. Propagation in modern urban environment (tall buildings) and dependence on frequency band. Air-sea interaction.

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THE EFFECT OF STANDARDS ON RESEARCH AND DEVELOPMENT IN TELECOMMUNICATIONS

I. Introduction

The setting of standards in any industry is intended to simplify equipment, to make it less costly and to use resources more efficiently. There are many cases, however, where standards are a difficult compromise and where the techniques for standard setting are not always optimized. If one studies the effect of setting standards on the research and development process as it applies to the telecommunications field, it is quite obvious that standards have a noticeable effect. On the positive side, the establishment of standards narrows the areas for productive research and thus permits a concentration of effort not otherwise possible. On the negative side an agreement on standards can close off a fruitful technical approach before the value of that approach may have been demonstrated. One therefore hopes that standard setting bodies are technically well informed, have a world-wide knowledge of developments and are truly objective in the establishment of any new telecommunications standards.

A renewed attention is being given to the establishment of a one-world concept in telecommunications. The ever increasing availability and constantly decreasing costs of international communications present a startling new challenge to evolve and optimize a one-world system. Satellite transmission and other recent technical developments are creating a new urgency for a stronger attack on the problem. Because of the advanced technology already available in the United States and our posture of continuing leadership in telecommunications research and engineering, the balance of trade could be favorably influenced by fostering the one-world concept.

Speaking as part of a technical community, the scientists involved with research and development usually establish their own criteria for effective standards. Those criteria involve, at the very least, seeking a standard which incorporates the best technical solution known at the time. In addition, that best technical solution should be the basis for further growth and not stand as a roadblock against continuing development or the introduction of evolving newer technologies. It should also permit the efficient use of technical manpower, avoiding duplication of research and engineering, and should, by engineering guidelines, be considered logical.

There are often many other interests -- political, commercial, national, regional -- which have vested interests in the establishment of standards. In many cases these considerations lead to standards which are less than effective as measured by logical R&D criteria, or by the one-world criterion. Standard setting can be utilized as a means of restricting markets, or conversely of promoting world trade. Standards can be used to restrict communications, to hinder further growth, or to foster regionalization.

Often, standards setting bodies involved in the telecommunications field are confronted with the need to arrive at a compromise solution which best reflects the many interests which they perceive. It is often true that the resulting standards have significant effect upon the R&D community and sometimes appear contrary to the best technical and engineering practices. Added to the above factors is the dilemma of setting standards too early, in which case the best technical solutions have often not yet been demonstrated. On the contrary, setting standards too late has a tendency of obsoleting investments that have been made in behalf of a system which was not adopted. The too-early-too-late problem can stifle innovation on the one hand and waste resources and investments on the other hand. Weaker groups often conclude that, in the absence of a standard, there are advantages to deferring research and development just to avoid that potential obsolesence.

Sometimes because of the non-technical interests that are reflected in the final standards, a situation eventually arises where multiple standards are adopted which conflict with one another. Although such a result is technically undesirable and often economically disadvantageous, it does arise in satisfaction of political, commercial or other interests. When it occurs it is contrary to the one-world concept of telecommunications evolution and it offends the logical sense of the engineering community.

Most of the circumstances surrounding the development of standards which have been outlined previously are found in case studies which may be used as examples. One case study centers around the development and adoption of the standards for the format for Pulse Code Modulated (PCM) Telecommunications Carrier Systems. This particular example also illustrates one other factor unique to telecommunications standards in the United States. The Bell System as the dominant force in telecommunications in the U.S.A. can, and often has adopted standards which, of necessity, are copied by other carriers and organizations which must provide compatible equipment. This puts a special burden upon the Bell System to consider carefully the effect of Bell standards on the remainder of the U.S. common carrier network, and additionally, the effect upon world standards.

In the PCM case study a number of these points are apparent. From this case, it is possible to draw the conclusion that a more thorough study of the process by which standards are established might be helpful. It is possible that a thorough review of the interrelationships between the American National Standards Institute (ANSI), the Electronic Industries Association (EIA), the Federal Communications Commission (FCC) in the U.S., and Consultative Committee on International Telegraph & Telephone (CCITT) and Conference Europeenne des Postes et Telecommunications (CEPT) would be useful. And, of course, it is important to factor in the various standards committees of the Institute of Electrical & Electronics Engineers (IEEE) and the scientific and technological know-how they can bring to bear on standards. The problem is clear - a more orderly procedure would be helpful and would improve the effectiveness of Research and Development. It could have a substantial effect upon the balance of trade problems. The steps leading to a solution are not entirely clear and should be the subject of further study.

II. Telecommunications Standards in the U.S.A.

The telecommunications industry in the United States, dominated almost entirely by the common carriers, has been able to manage its own standards activities very effectively. Standards and specifications for transmission and for equipment have been established primarily by the Bell System and have been sufficiently flexible so that interface problems between operating companies have usually not been overly difficult.

Under this system, an obsolete crank ringer telephone connected to a hand switched 20-party local switchboard can talk to the World Trade Center in New York City. The interconnects take place for the most part automatically through long lines trunks and then into the receiving exchange. The two parties are totally unaware of the sophisticated system through which their conversation has been directed to provide them with this ability to communicate. Until recently, interconnection of any equipment or system into the common carrier has been only with permission of the common carrier. With the new interconnect rulings, however, additional standards will have to be developed in order to protect the common carrier network.

As noted above, internal standards for the telephone industry have gradually evolved through the years - and the system has worked well. Since most of the advanced communications technology has come from the Bell System, it was natural that Bell's specifications were adopted. In a few cases Bell specifications did not become industry standards where they did not affect performance or interconnect capability, or where an independent manufacturer or user found a more efficient or economical approach.

In the non-telephone communication industry we have a different situation. Lack of an adequate set of TV performance standards, or lack of agreements between broadcasters on color standards even today give marked differences in quality from station-to-station or even from camera-to-camera. The viewer often has to become his own "standards" monitor by adjusting dials to make green faces natural only later to have to readjust at the next commercial.

For cable TV systems, there are no standards governing CATV operations. Local communities must accept whatever the operator provides in the way of signal level, signal-to-noise ratio, color quality, cross-talk, without any recourse to a set of standards for performance. IEEE has committees working in this area, but standards have not been established. This is an example of where late standard setting can be costly. A few years hence when installations become large, the late adoption of standards might obsolete terminal and transmission equipment and everybody could suffer -- manufacturer, operator, and user.

III. Telecommunications Standards in Europe

European countries have taken telecommunications standards quite seriously. Although not often the case in telecommunications, standardization in Europe has sometimes been used to protect national markets from outsiders, and there are cases where the introduction of unique national standards have perhaps been a matter of national pride. Television broadcasting in Europe now has three standards, the PAL system, the SECAM system and the 405 line system, none of which are compatible with the U.S. Standard NTSC system. Television broadcast ranges usually span several countries so that signals from a number of stations having different standards are available for reception in many places. However, to take advantage of the variety of channels, a more expensive multi-standard receiver is required.

In the point-to-point telecommunications area in Europe, there would appear to be a great deal of standardization with both CCITT and CCIR having many years of experience behind them and some significant body of creditable technical achievement. In fact, however, there are still many small differences from one country to another within Europe. Although it is possible for a competent manufacturer to build equipment for use in more than one country, it is no accident that the multinational telecommunications manufacturing companies do have manufacturing facilities in more than one country. Even in frequency division multiplex equipment, used for long lines that cross national borders, there are significant differences. Often these will appear as alternatives given in the CCITT documentation. In addition, there are many details inside a system which are not standardized at all by CCITT. These are handled by the National PTT Administrations and they vary from country to country. In spite of the variances, a worldwide automatic telephone network is taking shape,although probably at greater cost than would be the case if uniform standards were a reality.

IV. Pulse Code Modulation - The Case of the Multi-Standard

Pulse code modulation carrier may become a classic example of the problems of adopting standards. Early standardization by Bell began in the U.S. and eventually there evolved the present T1D1,D2,D3 24 channel digital carrier system and its hierarchies. Its initial use by Bell was intended primarily as an economic and efficient alternative to FDM carrier in exchange trunking systems for short haul trunks (up to 50 miles) between exchanges in a major city to permit more voice channels in such metropolitan areas over existing cables.

In Europe where early decisions were not necessary, digital standards were ultimately studied as part of an overall digital switching and transmission system, rather than as a carrier technique. Largely as a result of different philosophies, Bell for the U.S. and later CEPT for Europe adopted different standards for PCM transmission.

A. Bell System PCM Standards

In the U.S., the Bell System pioneered in digital communication with the introduction of the T1 carrier in the early 1960's. This PCM system proved quite successful, and large quantities were installed during the 1960's, thus setting, through large committed investment, the first U.S. "standards" for PCM. Compatibility with this initial equipment dictated standards which had then to be followed by succeeding transmission equipment. The T1 24 channel system was developed solely for use on short haul exchange trunks, but field experience quickly proved the equipment had much longer distance capabilities. Therefore additional development occurred and led to the planning of a PCM hierarchy to include an entire family of compatible transmission equipment. The family includes a 4 x 24 channel group of 96, operating at 6.312 megabits/sec. designated as T2, and higher multiples for T3 and T4 and T5. In the planning of the digital hierarchy it was quickly recognized by Bell that the D1 coding format first used with the T1 did not provide a sufficiently high grade of transmission for toll service. The principal problem existed in the quantizing noise produced by the 7-bit voice encoding pattern of the first version (D1). For this reason, a major change was made to an 8-bit code, and the improved equipment and new "standard" was assigned the nomenclature "T1/D2," for reference to the D2 channel banks encoding the 8-bit code. For both versions digital transmission on the existing 22 gauge line is at the rate of 1.544 megabits per second, with digital pulse repeaters introduced in the line at the normal loading coil spacing of approximately 6000 feet. Thus, the pulse rate was made the same for either T1/D1 (7-bit) or T1/D2 (8-bit) standards. The T1/D2 may be used not only for the original short haul exchange trunks, but with the 8-bit format it is acceptable for long haul, and thus it becomes the basis of planning for the nation-wide switched long distance digital network in the United States.

B. Other PCM Standards

Elsewhere in the world PCM digital carrier equipment is now starting to be installed in quantity, though at a lower pace than in the United States. Canada is adopting the Bell System's standards and this will provide end-to-end compatibility with U.S. equipment. Japan has standards which are quite similar, but not identical to the United States. European countries have recently adopted a standard of encoding and grouping which follows a format different from that of the Bell System. As contrasted to the U.S. standard (Bell) of 24 voice channels for the T1 carrier, a European standard worked out by CEPT (Conference Europeenne des Postes et Telecommunications), uses a grouping of 32 channels of which 30 are voice, and a transmission rate of 2.048 megabits per second. In the Bell System T1/D2 standard, signaling information is added in place of one voice bit in every 6th frame, permitting all 24 channels to be voice channels, each carrying its own signaling information. The European CEPT standard grouping, on the other hand, uses 30 out of its 32 channels for voice, reserving one for framing, and the remaining channel for carrying signaling information for all 30 voice channels. This basic difference between U.S. and European standards results in equipment which is not compatible on an end-to-end basis. There are also other significant differences. At the present time, this does not create a problem since there are no PCM transmission links between North America and Europe. In the future, however, this incompatibility will cause unnecessary expense for international PCM calls and will result either in reduction to analog and reencoding, or complex automatic translating and buffering ("transcoding") schemes.

A number of other standards have also been proposed. England's BPO tried a 24-channel system, but has recently decided to go CEPT. Both France and Switzerland have tried other standards. At the present time it seems probable that both Eastern and Western European nations, including England, will gravitate toward the CEPT 32-channel standard, while North America has adopted Bell's standard, with Japan using its own scheme which is similar, but not identical to Bell's standard.

C. International Standards in Telecommunications

International standards are finally recommended by CCITT, an organization within the UN created for the purpose of facilitating international telecommunications, and of which the United States is a member. CCITT has reached a point where both Bell T1/D2 24 channel and CEPT 32 channel systems will be approved as standards, although they are not compatible.

D. The Dilemma

The example of multistandards in PCM points up the dilemma of international standardization and the atmosphere for research and development. One can argue that PCM is an invention ahead of its time. It was born in the vacuum tube era, but became practical with semiconductors. Its introduction in the U.S. was directed toward increasing the utilization of existing short haul multiconductor cables. Its adoption in this country by the common carriers for this application required early choice of coding format and number of channels. When the Bell standards were adopted, digital long distance networks, digital local and toll switching equipment, international PCM, and satellites were not first priority considerations. In Europe, when digital transmission began to be considered and their early equipments developed, no great consideration was given to the long range requirement for simplifying the eventual interface with the North American continent and with Japan. Now another requirement appears, the PCM satellite system shortly to be established will span the world and will reinforce the desirability of common standards.

V. The Challenge

Two new areas in which telecommunication standards can be expected to have a major effect are video telephone services and data services. In the former, as was the case with PCM, the first unofficial "standards" are those of the Bell Systems' Picturephone, a service which is likely to be modified and improved with changes to be expected in the standards, as customers gain experience with video systems. It is vital that CCITT, Bell and other interested groups aim for uniform worldwide standards for this service in anticipation of international traffic. The cost of failing to do so can be a delay of many years in the availability of international video telephone service, as well as a more expensive service.

Perhaps an even greater challenge lies in the area of pulse data transmission standards. Considering now solely the U.S. situation, we find the common carriers presently providing for pulse data transmission on the voice network through the use of modems. These devices at the sending end convert data pulses to tone bursts. The tones are transmitted in exactly the same way as analog voice signals; then are reconstituted into the pulse data at the receiving end. Modems are currently in use or under development for many different pulse rates up to 50 kilobits per second. The lower rates (up to 4800 bits per second) can be accommodated on the switched network, the higher rates are non-switched services. There are already nearly 300 versions of modems and the number is growing. Additionally, provision is being made by the common carriers for a digital data network which will not use modems and which will transmit pulse data at even higher rates; 56 kb/sec in 1974 and higher rates approaching about 1 megabit per second in the future. When one considers the anticipated problems of computer interconnection, taking into account the variety and numbers of I/O devices and peripherals, together with the growing legions of different computers, all steadily demanding higher operating speeds, the challenge for standardization is clear.

It should be noted in passing that, in addition, the modem approach, and the digital data network which the carriers offer to subscribers for pulse data service, the carriers transmit pulses for internal use. Dial pulses at 10 per second and PCM carrier pulses at 1.544 and 6.312 megabits per second are standards relating to the operation of the network and are not offered to, nor are they suitable for, direct customer use.

Finally, we must eventually face the computer interconnection problem. If computers in different locations around the country are to talk to one another efficiently at very high bit rates with minimum buffering, it is apparent that standards should be developed which make computer cycle rates compatible with communication system bit rates. No agreement now exists even among computer manufacturers for standardizing at these high rates, and the communications compatibility problem is therefore moot at this time. It would appear, however, that the best interest of the nation will not be served by the computer manufacturers adopting one set of standard rates for high speed synchronization, while the common carriers independently optimize the data communications network against a different set of requirements.

VI. Conclusions

With the rapid growth of international telecommunications facilities there is need for improved procedures for standardization. What was at one time purely a U.S. problem, or purely a European problem, now becomes a world problem. International direct dialing standards are only a minor example of the growing requirements for a one-world basis for telecommunications standards. The standards for satellite communications have not yet proven a major problem, but the introduction of PCM techniques can change that situation. Planning for video telephone and data standards presents a challenge of the highest order. Finding a more objective procedure for setting standards is a most desirable goal. The procedure itself is subject to study and recommendation and merits the attention of U.S. interests. A method for the channeling of worldwide R&D results to the groups responsible for establishing and coordinating standards should also improve the quality of the standards. With improvement in international standards, the U.S. technological leadership in telecommunications could be better reflected in a more favorable U.S. balance of trade.

Three potential areas for study might prove fruitful in supporting U.S. representatives in future telecommunications standards discussions.

1. Investigate the possibility of determining the key elements in a proposed standard.

2. Investigate methods of better utilizing key element information and other resources.

3. Investigate the estimated extra costs of multiple standards to include: duplication of R, D & E, interface equipment, and the like. Determine also the penalty in fidelity arising from the adoption of multiple standards.

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BIOMEDICAL AND SOCIOLOGICAL IMPLICATIONS OF U.S. TELECOMMUNICATIONS RESEARCH

I. Introduction

Research in telecommunications technology has attracted engineering talent of the highest calibre in this country and overseas. The record over the past quarter century has been one of unremitting pursuit of excellence. With such outstanding intellectual resources, and with such highly motivated individuals and teams, it is therefore to be expected that the telecommunication field itself would competently establish long and short-term goals appropriately related to national and international needs.

That these internal judgments and assessments have been highly successful in promoting technological development is without question. What is now becoming less clear is the extent to which the application of current arts of telecommunications has been most effectively carried out for general betterment over the widest range of economic strata within our own and other societies.

In this context, the one question immediately takes on a dual and pressing character. On the one hand, there is the problem of diffusion into society of communications devices and systems poorly understood by the user. In turn, this lack of understanding breeds a paranoid reaction against acceptance of further technology, no matter how carefully devised or responsibly applied by expert innovators. On this problem, Murray Gell-Mann recently stated that "these are the unfortunate effects of carelessly deployed or carelessly diffused technology." On the other hand, there is a separate but related goal of optimizing the quality of life for the majority of our citizens for as long as possible in their life span. This is a question clearly separate from user acceptance of a particular device or system. It is a question in which society's broadest and best evaluation of its own goals must encompass the technologies of communications systems as such, and endeavor to build them into the most effective forms of needed human communications.

Clearly, we have reached a position where all current forms of communication are not needed. Their very existence, or at least their trivial application, has been and may continue to be detrimental and even disastrous to human society. Therefore, it is necessary in future planning that we discard or suppress those forms of communication which have adversely affected the quality, as well as the breadth and depth of human communications. It is equally important that we nurture and foster communications techniques that promote our social development. We should seek by their implementation and growing sophistication to prevent the tragedies in human relations that so commonly follow a failure of needed communications.

Health care delivery, biomedical research, and child and adult education are representative areas which will depend increasingly on the full gamut of telecommunications development to broaden and increment man's unaided capabilities. Many of these areas present problems that are unique to the United States. These problems are often complicated rather than helped by high levels of technology in the general community, and the associated "careless diffusion and careless deployment" cited above.

Man's capacities in telecommunications reflect the special development of his hand and brain in toolmaking. In the past 20 years, he has strikingly augmented his capacities in perception and decision-making with the electronic computer. These new tools which extend man's senses are already inextricably interwoven with many forms of telecommunications; and as they have evolved, we have recognized major new areas of needed psychophysiological and telecommunications knowledge that would optimize man's interactions with computing devices.

How well equipped is the U.S. to undertake such a substantive range of tasks in the coming decade?

In particular, granted our technical superiority in both telecommunications and computer sciences, does it necessarily follow that our society will apply them to the most effective solutions of socially pressing problems? Or will others make more effective use of U.S. technology? The following paragraphs will attempt an evaluation of some major issues, based on domestic and foreign developments.

II. Health Care Delivery

This Administration has committed itself to the concept of universal health care. We are now clearly far removed from this desirable goal, in terms of medical manpower and of clinical facilities. Moreover, the training of more doctors may not of itself offer an economically feasible solution. Instead, we may anticipate development of teams of paramedical professionals, heavily dependent on modern telecommunications, and entrusted with much of the health care delivery in both urban and rural areas.

A. Logistics of Communication Systems in Health Care Delivery

The unfortunate inhabitant of a city ghetto may be as isolated from medical care as those living in remote rural areas, if he were to rely on available forms of medical practice. For both groups, prompt availability of medical care may be a matter of life or death.

In city areas, traditionally served by large city or county hospitals, there will be trends toward many small clinics distributed through the community, and delivering "minimal health care" in areas where none now exists. These clinics would operate under the direct surveillance of qualified medical staff at a regional medical facility. Staffed by paramedical personnel, they will require two-way color video links with one or more central medical facilities, including a capability for transmission of light microscopy images from the field station. They will also have facilities for transmission of graphic medical data, including the electrocardiogram, respiration, electroencephalogram, and a variety of data on the muscular systems.

In rural areas, there are numerous minority communities, in addition to isolated farming groups, for whom local medical care is non-existent, and a visit to the doctor entails a long and often hazardous journey by road. Here, too, future plans for medical care envisage both mobile vans and regional clinics operated by paramedical personnel in close communication with regional medical centers.

B. Principles of telemedicine

The traditional examination by the physician has been heavily dependent on his perception with unaided senses of significant aberrations in structure and function. The great advances in biochemistry over the past 25 years have brought about a veritable revolution in ancillary tests that have added orders of magnitude to the precision of the clinical examination.

Space age technology added a further dimension. Biomedical data acquisition systems have made increasing use of microminiaturized transducers, signal conditioners, and biotelemetry systems that are a direct spinoff from the space effort. Early experience with these techniques has indicated the feasibility of a remote medical examination.

The arts of telemedicine will evolve slowly. Feasibility studies have involved a medical technician working under instructions from a physician. We may anticipate bold steps into the use of telefactors, of types that will evolve from lunar and planetary exploration programs. These may ultimately substitute in some circumstances for the medical technician in assisting the physician in his remote examinations. On the other hand, the major thrust of telemedicine programs will continue to be by the extended use of paramedical professionals, a group for which needed training programs are only now emerging.

C. Communications channels for telemedicine

Telemedicine schemes will make full use of all current forms of telecommunications. Patient medical data, such as LKG, EEG, etc., can be effectively transmitted over voice grade telephone lines in an IRIG narrow band FM multiplex format. They can be demodulated in real time and subjected to further computer analysis and pattern-recognition techniques. Already, feasibility has been established for such transmissions on a routine basis over international voice-grade telephone circuits. These same voice circuits are also invaluable in their traditional role of patient or paramedic interrogation by the physician.

Video information further enhances quality and quantity of medical information transfer. Where channels are restricted to voice bandwidths, slow-scan techniques are thoroughly feasible, and sequential optical filtering with color photography now allows transmission of color images.

Radio transmission in H.F. portions of the spectrum is already suited to these narrow band requirements for distances beyond VHF or UHF coverage. The latter, however, will be increasingly used, both for direct communications between outlying fixed or mobile clinics and regional medical centers, and also in providing links to satellites. At UHF frequencies, high resolution two-way TV coverage can be planned.

In summary, organizational schemes in telemedicine will remain flexibly related to varied capabilities of each geographical unit -- the intellectual capacity and training of lay or professional operators in the field, the channel capacities in data transmission, and the sophistication of central or regional medical facilities and personnel. A substantial period of trials for prototypes of these systems will be necessary before blueprints can be offered that would assure high cost-effectiveness as well as efficient delivery of health care in typical urban and rural communities. We do not yet know the essential verbal communications that would be part of the examination protocol; nor do we know how best to use mechanical sensors as substitutes for the physician's eyes, ears, and hands.

With increasing use of cable TV (CATV) systems, there have been proposals for use of these systems for transmission of medical data from the home to the doctor or hospital. Although there appear to be no insuperable technical obstacles, there may well be certain social problems. Transducing equipment that would transmit a major body of needed medical data would probably be expensive, require regular maintenance and calibration, and be used only intermittently. Moreover, the user would undoubtedly need training in its use, and these technical skills may well be beyond the capabilities of the elderly, the infirm, and those whose lives are typical of the majority in this country in being "technologically deprived" in terms of a reasonable understanding of instrumentation systems.

D. Specialized Telecommunication Needs within Hospital and Medical Center Environments

Intensive patient care in medical and surgical emergencies, including the immediate postoperative phase following major surgery, has placed great emphasis on sophisticated laboratory analyses, as well as in monitoring vital signs. Much of the recognition of complex patterns in these analyses has become, and will be increasingly dependent on computer-based analyses. Video monitoring of walking patients, or as an adjunct to bed care, is increasing. For these reasons, a veritable network of internal communications is essential in hospital practise.

Shock hazards from multiple lead attachments, including low impedance paths through renal and vascular catheters, have led to use of radio biotelemetry and fiber optic techniques to eliminate dangerous leakage paths in intensive care procedures. The present state of the art may be regarded as intermediate between older "hardwire" transducing methods and future developments in "no contact" sensing devices. As a genotype of possible future developments, devices of the type using Josephson junctions have shown great promise in remotely sensing magnetic components of cardiac contraction and brain activity. Not only will developments in this area avoid present problems of shock hazards, etc., but the improved mobility of the critically ill patient has significant therapeutic advantages and makes nursing care easier and more efficient.

E. Comparative Evaluation of Overseas Developments of Telecommunications for Health Care Delivery

There can be little doubt that, in the elements of sophisticated technology, the United States possesses both prototype techniques and fully evolved systems that are substantially in advance of similar developments elsewhere for health care delivery.

On the other hand, there are important factors that may limit the deployment and efficient evolution of these systems in furtherance of health care in the U.S. Foremost is the extremely high cost of our existing health care system, in which expenditure has grown from \$50 to \$100 billion in the past five years, and which may continue to grow exponentially unless it is drastically restructured. Creative application of telecommunications technology may hold reasonable hope of holding some of these costs in check; it may even contribute to reversing the current exponential trend.

There is the further prospect that adaptations of this U.S. technology to medical care in overseas countries may produce good models of system applications before they are available in the U.S.A. For this reason, it may be desirable to view future developments on a collaborative basis with foreign investigators, rather than competitively. This may be a highly productive route to needed knowledge. It would be expected that some foreign applications would bear a unique stamp reflecting local needs, but that much of their new knowledge would be valuable by extrapolation to U.S. problems in medical care. Moreover, developments in satellite communication will clearly allow extensive medical data transmission over international circuits, with the potential for use of sophisticated pattern recognition and image processing methods at U.S. medical centers. These techniques are not likely to be widely available abroad in the foreseeable future.

III. Telecommunications Research in Child and Adult Education

Classroom education has been relatively little changed by available telecommunication technology. It is an area lacking the unified approach now possible from new knowledge gathered in the separate fields of brain physiology, the psychophysiology of perception, and the arts of telecommunications and computation.

Studies in brain physiology have revealed substantive correlates, both for individuals and for groups, of the processes of alerting, attention, and in some degree of decision-making. Psychophysiological research has indicated some of the ways in which we may optimize the environment, and in turn, optimize the learning rate. Recognition of states of high attention, and of the waxing and waning of levels of alertness, demands interactive relations with sophisticated computing systems. For the instructor, these methods would offer an opportunity to regulate the informational flow and provide him with more positive links with class members than is now possible.

From preliminary studies in these areas, exciting prospects are emerging. For the normal child, there is the possibility that conventional teacher-student interactions will be usefully supplemented by complex audiovisual displays that may be temporally segmented to meet cyclic changes in levels of subjective awareness. For mentally retarded children, numbering about 1 percent of the U.S. child population, there is the prospect that electrophysiological signatures of brief moments of attention may be well enough recognized to enable presentation of learning tasks at these times.

To be effective, these methods applied to both normal and defective children will rely on complex two-way telecommunications with the instructor. Our knowledge of the physiological signatures of brain actions continues to grow rapidly, but this growth is dependent on further major research in telecommunications and computing sciences.

Much research in perception, models of brain action in the perceptual process, and research in interactive computer processing is now proceeding in the Soviet Union and in Soviet bloc countries, particularly in Czechoslovakia. On the biological side, this work is of high quality, but is technologically limited by available computational capabilities. It is backed by a long history of mathematical modeling of biological and psychological processes.

IV. Man-Machine Relations that Extend Human Perception and Action

The ability of the digital computer to function as a pattern recognizer has opened new vistas in man's social and environmental interactions. There remain substantial problems, however, in the effectiveness of human communications with computing devices, and in man's ability to interpret complex computer output displays.

In part, these relate to inherent differences in operational modes in brain and computer; the brain functioning as a highly parallel processor, with relatively slow internal bit rates, and significant error probabilities that may relate to "noisy" or pseudorandom internal behavior; the computer characterized by a single address format and very high internal bit rates. These constraints in the computer may account for a quite rigid adherence to alpha-numeric displays that probably offer a considerable informational mismatch in interactive processing with a human operator.

Yet the alternatives in computer organization that might optimize human interaction are not immediately apparent. Nevertheless, the rewards for improvement of input-output organization would be sufficiently great that it would be well worthwhile to consider a direct "brain-computer interface," in which we might take advantage of a "perceptual shorthand" in the computed display format, as well as finding ways to relax rigorous descriptions in input data sets, as proposed in the theory of "fuzzy sets."

Future developments may extend the capability of the computer as an adaptive filter in recognition of electric brain patterns. Preliminary studies have indicated its possible application in this way to control of a variety of prostheses.

Clearly, future developments in telecommunications will envisage these very complex pattern recognitions as occurring at the terminals of long communications links, at first over terrestrial paths, and perhaps later over interplanetary distances in space exploration. The value of reliable communications links to these automated pattern recognizers and decision makers would clearly be paramount.

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EXCESSIVE COMMUNICATION

The development of civilization has been marked by milestones in the art of communication. Such markers have included the development of language, its retention in written form through picturegrams and alphabets, the invention of paper which makes written information transportable and retainable, the art of printing which greatly multiplied knowledge available to all men, and more recently the contributions of telecommunications, the telegraph, the telephone, television, and the computer.

Each of these developments has added to the quantity and the rapidity with which information is presented to the human recipients who are the ultimate users. A small proportion of information must be decoded and used by machines, but the amount presented to a machine is usually limited in the design of the system incorporating such machines, and hence is within their capacity to handle. Such is not the case with the present flow of information terminating on the individual human being.

While telecommunications, i.e., the coding, processing, transportation and decoding by electrical means, represents only a portion of the total information processing in modern life, the developments of telecommunication theory and practice have made major contributions to the philosophy and action involved in all communication processes, including publications and just plain talk. Examples of telecommunication theory which have carried over into other fields of thought have been the recognition of the universality of the concepts of feedback, signal-to-noise ratio, redundancy, coding and decoding and impedance matching to achieve optimization, channel loading, etc.

The human intellect must be regarded as the most important receiver for most messages. Information theory has proposed that when any communication channel becomes overloaded, communication deteriorates rapidly, or even ceases abruptly. Modern men, especially those charged with making the most important decisions, are being presented with information at an ever increasing rate.

It is proposed that more effort should be applied to research to determine quantitatively just what are the limits in information processing inherent to human beings immersed in our social structure which floods them with oral, visual, written and printed information, some relevant (signals) and much irrelevant (noise). Information of this type is particularly important when the recipient is expected to use this information to make appropriate decisions and take action, or when rapid decisions affect human safety and well being.

Such research will require the correlation of several disciplines in the design and implementation of experiments which will involve psychological, social, and physical theory and practice.

I have asked Dr. Stanley N. Roscoe, who is both a psychologist and an engineer to comment on the need for such research. His remarks entitled "The Determinants of Cognitive Channel Capacity," follow this article as Appendix A. His professional field involves particularly the problems of the instrument-pilot interface in the airplane cockpit. He has conducted some experiments which are described in his report, "Assessment of Pilotage Error in Airborne Area Navigation Procedures."* This is a "for instance" example of how such problems can be reduced to quantitative measurement. The details of his experiments excerpted from the report are attached as Appendix B.

It is the theme of the report that many more experiments in the area of human communication overload should be developed and supported to determine the effects of overloading of the message channel in the presentation of information to human beings in the presence of noise, using the word "noise" in its broadest sense. A knowledge of the deterioration in the quality and quantity of usable information under these circumstances can have important social and economic values.

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Attachments (2)

*Prepared under the auspices of the Aviation Research Laboratory, Institute of Aviation, University of Illinois-Willard Airport, Savoy, Illinois for the Air Force Systems Command (Technical Report ARL-72-24/AFOSR-72-13, October 1972).

APPENDIX A

THE DETERMINANTS OF COGNITIVE CHANNEL CAPACITY

In the realm of intelligent behavior, each individual has a time-variant momentary cognitive attention capacity and, to varying degrees, the ability to distribute that capacity to attend to different matters as a function of time. In many respects this cognitive channel capacity can be likened to the channel capacity of a communication system; in some it can not.

The differences between animate and inanimate channel capacity are most noticeable as the two types of systems approach saturation. When an inanimate communication channel becomes saturated, communication breaks down -- the flow of information stops; when an animate communication channel becomes saturated, it exhibits more or less graceful degradation -- some messages continue to get through.

Typically human cognitive behavior approaches saturation in situations requiring the rapid time-sharing of attention among competing stimulus inputs having associated action priorities that vary as functions of time, ambient circumstances, or the changing objectives of the individual. Examples of complex activities requiring rapid time-sharing of attention to a wide variety of stimulus inputs are flying an airplane under instrument flight rules in a congested air traffic situation, calling defensive signals while linebacking for the Washington Redskins, or serving as President of the United States. In each of these examples, an abrupt breakdown in responses to stimuli could be tragic.

The experimental study of animate cognitive channel capacity at or near its saturation level may lead not only to the psychological discovery of the determinants of human performance in complex stimulus-decision-response situations, but also may yield bionic transfer to the design of inanimate communication channels that exhibit graceful degradation.

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Aviation Research Laboratory
University of Illinois

APPENDIX B

A COMMON METRIC FOR RNAV* EQUIPMENT CERTIFICATION

The categorical assertion that a system's blunder proneness can be assessed by measuring a pilot's residual attention while using it is based upon an experiment recently completed at the University of Illinois (Kraus, 1972; Kraus and Roscoe, 1972). The purpose of the experiment was to evaluate a reorganized manual flight control system in a realistic, complex mission environment. A Link GAT-2 general aviation trainer, interfaced with a high-speed digital computer, simulated procedural and performance characteristics of a representative airborne area navigation system operating in an IFR air traffic environment.

In the experiment, three variables were manipulated, the type of manual control system flown, the waypoint storage capacity of the simulated RNAV computing system, and the level of side-task loading to which the pilot subjects were submitted. A saturating level of side-task loading served both to induce a stressful flight situation and to provide an inferential measure of each pilot's residual attention as a function of the equipment variables being investigated.

The results of the experiment are reported in the papers cited; their relevance to the certification of equipment lies in the fact that each pilot's residual attention, as measured by the rate at which he could cope with the information-processing side task, varied in a sensitive, orderly, and statistically reliable manner with each change in equipment characteristics, despite the widely differing levels of residual attention exhibited by different pilots.

The computer-controlled side task was automatically adaptive; the faster the pilot responded, the faster information inputs were presented. A horizontal array of transilluminated numerals, 0 through 9, was mounted immediately above the primary flight group on the pilot's instrument panel. Numerals 1 through 8 were illuminated in a random sequence, and as each appeared the pilot could extinguish it by pressing the corresponding numeral on a scrambled keyboard mounted above his right knee and out of his normal field of view.

During operation, when a pilot extinguishes an illuminated numeral, another appears after a 0.75-second delay; thus, if

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*Area navigation is any system of navigation that allows use of all the airspace, without restriction associated with the geographic locations of radio navigation facilities.

he were to respond to every stimulus with no delay, he would be processing a theoretical maximum of four bits of information per second (three bits per response). However, if a pilot fails to respond within six seconds, the stall warning horn starts sounding with rapid intermittence, calling his attention to the side task. The effect of the blasting horn can be dramatic. If difficulty with primary flight control or confusion over RNAV procedures were the cause of the pilot's original failure to respond within six seconds, the onset of horn blasts can be followed successively by annoyance, frustration, hostility, and panic.

In the experiment, the stress created by the side task was accompanied by a doubling of the frequency of pilot blunders, regardless of the manual control system in use. Despite the stressful effect of the elevated task loading and the four to one range of residual attention among professional pilots (approximately 0.25 to 1.00 bits per second), well-designed systems approached freedom from blunder proneness, indicating that it would not be unreasonable to require demonstration of a specified level of blunder-free residual attention by a group of properly qualified pilots for RNAV system certification.

The particular information-processing side task described is only one of many that might be employed. It was used because it was simple to implement and score and because it was found to work during preliminary experimentation. A more complex cross-adaptive logic in which side-task stimulus presentation depends upon concurrent performance on the primary task has also been investigated (Damos, 1972; Damos and Roscoe, 1970). It also works, but not so well as the simple self-adaptive task just described.

The measurement of residual attention in a standardized manner under specified flight situations, whether in actual or simulated flight, offers a promising common basis for establishing the workload demand and blunder proneness of area navigation, vertical guidance, and other types of flight directing and control systems. As such, it represents a potential method of demonstrating compliance with objective performance standards for airborne equipment certification.

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INTERFACE MAN-COMPUTER DATA ENTRY

I. Scope

The purpose of this study is to assess long range needs in the interface between the internal digital manipulation of the electronic signal and the outside world. For want of a better terminology, we shall call the communication which crosses this interface "data". Such data is generated by people, physical processes, transaction documents, pictures and miscellaneous other source documents. As well as the physical transduction of the data itself, the study is concerned with human factors, formatting, and programming support issues which facilitate the generation of entry of data.

The data entry area is not a cohesive body of technology. More importantly, the value of a technology is largely determined by the system and operational environment within which it resides. Thus, there is no attempt to draw a sharp definition of this area. Rather, this report attempts to cover the interesting approaches of physical data entry and a look into problems of data generation that the user faces in dealing with the hardware. The latter subject leads into a large number of programming and human factors issues. In the long run, these will become the dominant considerations in designing an entire man-computer system.

II. Perspective

Historically, the major impedance to the growth of the computing business has moved outward. Until the present era the cost of hardware, especially online storage, was a major factor in the customer's decision to put an application on a computer. With present computers, the complexity and stability of the software system have become the first consideration in a new application, or the expansion of an old one. The present development emphasis is to clean up the system structure and make it much more permissive of application expansion and the programming of new work. It seems reasonable then that growth in function and facilities will be strongly dependent upon our ability to interface the computer with an enormously expanding variety of day-to-day endeavor. Consequently, our ability to insert the computer transactions in a natural way must be a major focus of research effort.

Whenever a person is directly involved, data output is an integral part of the data entry functions. For example, conversational interactive data entry requires some degree of data display. The system must enable the person who is monitoring automatic data entry or executing manual data entry to supply missing data or to re-execute part of the entry process. To the extent that intervention is required by the nature of the data entry task or by the nature of the system, the monitor/enterer must be provided with a context in which he can determine the occasion for and degree of exception-handling needed. The system must either be configured to recognize the error, or display a subset of data which enables the user to recognize it. This is one of the factors which makes the successful configuration of entry and display techniques application-dependent.

III. Trends

There are a number of major trends which could dominate the theme of data entry for the period of interest. These are:

A. The economics and logistics of handling data several times before it gets into the machine yields strong emphasis on capturing data as near its source as possible. While this direction seems to pervade all applications, there are two principal keys to its rate of progress. First, as the data capture hardware gets further from the central system, its duty factor of usage tends to decline. Consequently, the absolute cost of the capture device must go down correspondingly. Secondly, even in instances where the duty factor of usage is high, such as in gas station credit card transactions, the cost of communication to the central system becomes a major component of over-all transaction cost. While many applications will allow remote buffering of information in machine readable form, it is highly desirable in most financial transactions to have two-way communication with a computer in order to obtain positive authorization for the transaction and to minimize float.

B. The fastest growing segment of data entry is in the consumer area. Here the principal requirement is to read a credit card, identify a piece of merchandise, or accept a simple query. The problem is to prestructure the transactions in such a way that the general public's interaction with the computer is extremely simple.

C. Optical character recognition (OCR) will continue to grow as an input mechanism, especially where reasonable volume is involved. The principal trend in OCR equipment is to reduce the threshold cost and to reduce the constraints on its usage, principally in the area of alpha-numeric hand printing.

IV. Summary

1. The major hardware needs in the data entry area are for better terminal printers and large screen displays. Both of these components are currently major cost problems.

2. Optical character recognition will grow in importance in the future. Technical advances are needed here to permit a broader expansion of data entry capability to hand prepared documents.

3. Improved data entry technology is desirable in applications such as retail check-out systems.

4. Human factor studies and improved speech recognition capability is required to expand voice communication capability with computers.

5. Other than the need for better graphic display, the principal need in graphical data entry is for better human factored software.

6. At the man-machine interface, we understand the machine much better than the man. There are both hardware and software design issues, but software issues are dominant and growing. We have almost no predictive design technology in this area.

7. For purposes of security and authorization, systematic studies of ways to positively identify a person at a terminal are desirable.

8. A cursory investigation of physiological phenomena yielded no practical data entry mechanisms. There are more scientifically oriented investigations that might bear fruit later.

9. "Data Entry" is not a cohesive body of technology on system function. It should be viewed as part of the organic whole of an application. There always are several alternative data entry technologies for the same application and their relative value can be determined only in the context of the entire application environment.

V. Technology Issues

A. Key Entry

Stand alone keypunches, clustered key entry stations and terminals will be included in this category. The trend is away from the stand alone units to clustered and on-line entry.

Key entry will remain an important computer interface for the foreseeable future. The trend in OCR is toward lower cost and fewer constraints on the input document. Thus, the impact of OCR on key entry will continue to increase, but not enough to remove key entry as the dominant data entry mechanism.

Keyboard design today lacks discipline. Not only are many mechanical aspects still open to investigation, but the logical structure seems to require new study each time a new application is considered. The following list outlines some of these issues.

- Size of keys
- Key spacing
- Operating force
- Displacement
- Keyboard shape (Concavity)
- Keyboard slope
- Feedback (kinesthetic, auditory, visual)
- Keyboard format
- Key interlocks
- Application sensitivity

B. Character Recognition

1. State of the Technology

Machine printed and handwritten documents or pages are pervasive in our society, and OCR is a candidate for data-entry whenever information from documents is now done by manual keying at a cost (mostly labor) which approaches one-fourth the total cost in contemporary DP (data processing) installations.

Replacement of a major part of this labor with labor saving OCR equipment is desirable. There are other alternatives to OCR, such as placing key entry terminals at the source of data, or recording data in machine readable (coded) form at the source. OCR is likely to have a significant role as long as paper documents are a commonplace medium for storing and transporting information. To date OCR has not had wide acceptance. The reasons are:

1. The machines are expensive.
2. Installation costs are high.
3. Inputs are relatively constrained and on special forms.
4. Potential users have not been adequately aware of the benefits of OCR.

Although the rate of growth of OCR is uncertain, there is strong intrinsic motivation for OCR as a direct and obvious method of capturing data at the source. Growth of OCR is limited because we haven't adequately solved the problems associated with OCR, not because the potential application area is small. It is probable that certain mild constraints on the input will be necessary and acceptable for some time in the future.

The problem of machine recognition of cursive handwriting has been recognized as very difficult - in a league with complex pattern recognition and speech recognition. Work is in an exploratory stage. There is need for innovative and imaginative approaches to make progress in this area.

2. Technology Problems in OCR

Solid-state scanners are now feasible, and reductions in memory and logic costs allow a shift toward programmable machines rather than hard-wiring.

a. Current document transports for OCR and MICR (magnetic ink character recognition) handle a wide variety of documents at high speed remarkably well. There do not appear to be specific technology barriers in this area, but we can assume that cost would be a problem in any system aiming toward the low-cost end of the market.

b. Current scanner approaches (LED or Photo-FET arrays) appear quite good.

c. With relatively unconstrained input, finding the desired field of characters is a major problem. Algorithms are needed for performing this function in memory.

d. Measurement design is still largely a manual process without formal guiding principles. Measurement selection and design of decision functions is computer-aided, but the procedures don't have a strong theoretical foundation.

e. Post-processing to apply contextual rules to fill in characters that were rejected is currently an application dependent art. General principles or procedures would be desirable, but may not exist.

f. The low-volume user may best be served by a scanner terminal with centralized recognition. With telephone lines, some form of compaction is required to get enough throughput. It might be desirable to do recognition on the data in compacted form if properly coded. Another alternative is to push toward broad-band transmission in the first place.

C. Credit Cards

While the embossed card will remain for a long period of time, magnetic stripe credit cards could offer significant advantages. This approach allows the encoding of a great deal more information on the card and additionally allows the system to record back credit or other status information.

In addition to providing more user data on the card, the need for security against theft and inadequate credit balances causes a trend toward online systems. The principal thrust seems to be the use of the credit card in connection with a memorized four-digit personal code. Some systems have additionally gone to cryptographic approaches of coding the data before transmission across telephone lines in order to further protect the personal codes.

While it is believed that the four-digit code and credit card serial number will be sufficient to drastically reduce the current losses, this may not yield a sufficient identification for some transactions. Therefore, it is worthwhile to consider more positive, but also simple means of additional personal identification.

D. Speech Recognition

Speech recognition has the potential for greatly enhancing the man-machine interface. Examples would be giving an astronaut additional control capability when his hands are occupied, or giving a mail clerk the capability of voice control to supplement manual control of a mail sorting system. Speech control successfully implemented could supplement, and in some cases, replace the keyboard as an input device.

1. Classification of Speech Recognition Problems

There are four basic dimensions to the speech recognition problem: the range of speaker variability; the complexity of the material spoken; the background noise level; and the channel distortion between the speaker and the A/D converter. Constraints placed on each of these dimensions give rise to a classification of speech recognition problems and speech recognition capability.

The basic alternatives as concern speaker variation are single speaker and multiple speaker. Multiple speaker breaks down by dialect, by sex (women have proven more difficult than men), and by age (particularly children). Thus, we can talk about the capability to recognize the speech of a single dialect, of all female speakers, of any American dialect, etc.

The basic alternatives as concern the complexity of the material spoken are isolated words and continuous speech. The problem of recognizing isolated words is called word recognition. Word recognition capability is roughly measured by the number of words recognized. Continuous speech capability depends upon the vocabulary size and upon the language. It varies all the way from continuous sequences of a few words, through artificial languages with limited vocabularies and a simple syntax, to natural English. The background noise level varies from essentially zero to a factory environment.

The channel distortion practically breaks down into two alternatives: input over the telephone, or over a higher fidelity channel.

2. The Difficulty of the General Speech Recognition Problem

The general problem of the machine recognition of the spoken vernacular of an unknown American speaker is a problem of immense complexity. It is a pattern recognition and linguistic processing problem par excellence. The acoustic correlates of the basic phonetic elements of speech vary dramatically; with dialect, with speaker, with linguistic context, and with emotion. Even at the word level for a single speaker there is great variability. There is strong co-articulation between words, and the total acoustic correlate of a word depends strongly upon sentence context. There are no word boundaries except at pauses.

Further, syntactic and semantic "knowledge" sufficient for the understanding of utterances in a language is a requirement for accurate human phonetic transcription of that language. People only speak carefully enough to be understood by other people, which means that any general speech recognition device must be able to capitalize on the redundancy in speech and hence cannot operate as an acoustic processor alone, i.e., it must do sophisticated syntactic and semantic processing.

The achievement of this acoustic and linguistic processing function in an effective way short of the sensing and processing capabilities, as well as experience of a human being, is a major research challenge.

3. State-of-the Art

a. Word Recognition

Present capability for word recognition for multiple male speakers is twenty to fifty words with 95% accuracy. This has been achieved in a number of places. This capability has not changed substantially during the last ten years. The problem is solved by applying various standard pattern recognition techniques to the entire word. It is not solved in any fashion which is likely to be extendable to continuous speech.

Present capability for word recognition for a single speaker is fifty to one hundred words with 95% accuracy. This has also been achieved in a number of places and is done in the same fashion as for multiple speakers. In both cases the performance is somewhat less over the telephone. This one hundred word capability can be compared with the 10,000 or more word recognition capability of the human being.

One company, Scope Inc., markets a word recognizer. It is a single speaker device and recognizes 10 to 54 words. The only other system in actual use to our knowledge is the IBM Raleigh FE system. It has a multiple speaker capability which can recognize 13 words from a telephone input. Message accuracy is measured by the discrimination between yes and no which is done with 98% accuracy. The thirteen words are recognized with 95% accuracy.

b. Continuous Speech Recognition

The system put together at IBM Raleigh with Air Force support is the only non-trivial complete continuous speech recognition system. It operates on a 250 word vocabulary with a simple, fixed syntax language spoken by multiple male speakers. The 250 words are the most commonly occurring 250 words in English text. The system has processed 34 sentences and recognized 9 of these perfectly. It can recognize 75% of the words, and, depending upon the class, 50% to 70% of the phonemes in these 34 sentences. This work is noteworthy because it is the first time a complete system (with both acoustic and linguistic processing) for continuous speech has been assembled, and because it gives surprisingly good performance for an initial attempt.

A system put together by Reddy at Stanford operates as a limited continuous speech recognizer. It recognizes commands to the Stanford block stacking programs.

Both of these programs (The Raleigh and the Stanford) would require about 5 MIPS* to operate in real time on a general purpose machine with no special hardware of any kind. The Raleigh system includes context-dependent phonetic segmentation and recognition and linguistic processing. These two ingredients were recognized as essential, in the intervening period, to any successful program.

4. Nature of Speech Recognition Research to Date

Research on the automatic recognition of speech began over fifteen years ago. There have been a number of efforts including Bell Laboratories, RCA, Litton, Lincoln Laboratories, IBM, and others. The initial activity (1955-60) was concerned with continuous speech recognition and was a slow process of disillusionment because of the general difficulty of the problem.

*Millions of instructions per second

Subsequent projects were mostly concerned with word recognition and resulted in the widespread uniform level of achievement cited above. Up until the present ARPA program discussed below, there have been no large scale federally financed efforts in speech recognition.

In addition to the activity in industrial and defense laboratories, there has been continuing work at universities and a substantial number of graduate theses. There has also been considerable research activity in linguistics, speech science, and pattern recognition, which is pertinent to speech recognition.

5. The ARPA Program

ARPA has undertaken a five year program in continuous speech recognition at a projected cost of approximately 15 million dollars. Ten million of this is a re-orientation of old costs, and 5 million represents new expenditures. This effort follows the recommendation of a study committee which met during the Summer of 1970 and which produced a report "Speech Understanding Systems", May 1971, which is available from the National Technical Information Service, Department of Commerce, Springfield, Virginia.

The goal of the ARPA effort is a system for the recognition of continuous speech from multiple speakers in a quiet room with high fidelity input.

The language would be a command language, generally not Englishlike, with a highly constrained syntax and a vocabulary of approximately 1000 words. ARPA is interested in a complete system which integrates speech recognition into the solution of a reasonable and well specified task. The goal is a demonstrable system by 1976.

There will be a number of parallel efforts over the first two years. The major groups involved are SDC, SRI, BBN, Lincoln Laboratories, and Carnegie-Mellon. The Speech Communications Laboratory at Santa Barbara, the University of Michigan, and Univac in Minneapolis are also involved; the latter under a subcontract with BBN. At the end of two years, if the results are sufficiently promising, one or more of these contractors will be selected for a subsequent three year effort yielding a complete system with viable applications.

Other features of this program are: a steering committee to coordinate the effort; a summer institute to promote technical interchange among the individual projects; use of the ARPA network to facilitate sharing of hardware, software and data; a common data bank (maintained by the Lincoln Laboratory) to insure a valid comparision of results; and continued financing of university research.

6. The MITI Program in Japan

The Japanese government has embarked on a 100 million dollar joint government-industry program for a "Pattern Information Processing System" (PIPS). This program is directed toward character recognition, two-dimensional image processing, three-dimensional image processing, and speech recognition. Their present goal in speech recognition is the recognition of 100 isolated words. However, the detailed planning of the speech effort does not begin until next year and this goal will likely be modified. There has been no decision as to the amount of money which will be spent on speech. The plan is to have a pilot speech recognition system in five years.

7. References

The following is a brief list of references for obtaining general background in the speech recognition area.

"Speech Understanding Systems", A. Newell et al, May 1971, ARPA Report, National Technical Information Service, Springfield, Virginia.

"Approaches to the Machine Recognition of Conversational Speech", K. W. Otten, Advances in Computers, 1971, pp. 127-163.

"Man Machine Interaction Using Speech", D. R. Hill, Advances in Computers, 1971, pp. 175-230.

"Automatic Speech Recognition: Literature, Survey and Discussion", S. R. Hyde, 1968, Research Dept., Report No. 35, P. O. Research Dept., Dollis Hill, London, N.W. 2.

"Machine Recognition of Human Language", N. Lindgren, IEEE Spectrum, No. 7, 1968.

"Whither Speech Recognition," J. R. Pierce, Journal of the Acoustical Society of America, 1969, pp. 1049-1051.

E. Image Entry

Images, two-dimensional or three-dimensional signals, constitute a significant class of data. There exist enormous quantities of information in the form of visual images which are now processed manually. The automatic or semi-automatic acquisition and processing of this information could substantially reduce this manual task. Generally the processing of images is complex, and to date, except for the simplest tasks, computers have not been effective and efficient. However, it can be expected that the rising cost of labor, shortage of trained personnel, the decreasing cost of computation and memory, progress in methodology, sensors and effective man-machine interaction would bring about a major penetration of the computer into these areas.

1. Data Types

To provide a perspective, a list of data types for entry to the computer other than the keyboard entry is given in the following:

a. Time Signals

1. Voice
   Speech recognition
   Speaker verification and identification

2. Seismic
   Discrimination (nuclear explosions, earthquakes)
   Exploration

3. Biomedical signals
   Electrocardiograms
   Electroencephalograms
   Etc.

4. Sonar and radar

b. Two-dimensional patterns

1. Characters
   Stylized fonts
   Mixed fonts
   Hand printed characters
   Cursive writing
   On-line character recognition

2. Fingerprints

3. Maps

4. Text
   Format recognition combines A/N and line drawing

5. Bubble and spark chamber photographs

6. Aerial photographs/satellite images
   Clouds/weather
   Crops
   Targets, reconnaissance
   Pollution control
   Earth resources

7. Electron micrographs
   Material and integrated circuits
   Biological specimens

8. Biomedical images
   Scintigrams
   Chromosome
   Bacteria
   Pharmaceutical
   Smears
   Cells and Tissues
   Brain Sections
   X-ray films

c. Three-dimensional patterns

Scene analysis
Robotics/artificial intelligence
Manufacturing

The types of data in the first part of the list are either one-dimensional or intrinsically binary (black and white) patterns, and only those on the second portion of the list are images with grey scale.

2. Environment

There is growing interest and activity in pattern information processing, not only in USA, but in other countries, and notably in Japan. The Japanese Government decided in 1971 to invest over $100 million for a period of eight years in research and development of a "Pattern Information Processing System" under the National Research and Development Program, with active industry and university participation.

Indicative of the prevailing general interest in the U.S., the National Science Foundation held a conference in February 1972 to discuss research opportunities on "pattern information processing."

However, as yet there is little commercial impetus to develop image entry and/or processing capability. This apparent lack of commercial interest can be, in part, attributed to the fact that almost all successful computer applications have so far been in the areas of business data processing, management information and scientific computation, and that the major sources of images are in medicine, science and applied technology.

The impetus and motivation for acquisition and processing aerial photographs and satellite images are being provided by the government. A few major image processing centers will be established and tasks performed on national and state levels.

There are over 40 known groups at universities, medical centers, government laboratories, independent research institutes and industry laboratories which are engaged in computer processing of biomedical images, electron micrographs and 3-d patterns. The efforts range from academic inquiry, research, development, and feasibility studies to clinical implementation.

3. Needs

a. Image entry
b. Image processing

In order to make computers effective and efficient in handling visual images, it is necessary to provide adequate means for image acquisition and display. But this is not enough; one has to provide image processing methodology or programs. This is especially true in medical applications. It is not realistic to expect practicing medical doctors to develop their own processing algorithms and programs. As a group, medical doctors are skeptical about the usefulness of computers in their profession other than for keeping track of patient information and bills. In order to penetrate successfully into the handling of biomedical images, it will be necessary to develop basic processing software, as well as to solve the problem of image entry.

This dependency upon development of processing techniques and algorithms is a key difference between image entry and other types of data entry, say character recognition. In the latter, once the characters are recognized, the processing of this information is well defined. Unfortunately, it's generally not the case in handling images. Merely to get images in and out of the computer is not sufficient; how to process them in many cases is not understood. The user may say "enhance the picture" or "find the ventricle"; how to achieve this is usually not a trivial task.

F. Graphical Data Entry

Graphic Data Entry is the creation and maintenance of a coded graphic data base representing both the image and the inherent structure of the information on documents containing combined alphanumeric and graphic data. The emphasis here is not on highly interactive graphic design, but rather, on the efficient entry of large volumes of graphic data.

Unlike the image processing problem, graphical data admits to an explicit, albeit complex, relationship between the computer representation of the picture and the semantics of the object. Thus, the issues of recognition and manipulation are enormously simpler. Correspondingly, the costs associated with processing and storage cease to be dominant. The focus thus moves to the entry interface. At this point, the dominant aspect is the human factors of the programming which supports the creation and entry of the data. Secondarily, the entry hardware is an issue.

Applications fall into two categories: (1) Mapping - The processing of documents which represent geographic boundaries or areas and the location of facilities relative to this geography; and (2) Drawings - Combined alphanumeric and graphic information usually relating to the production (or building) and maintenance of products, processes or procedures.

A list of typical applications follows:

- Mapping and cartography
- Computer-aided drafting
- Page layout and composition
- LSI Chip design
- Numerical machine control
- Electrical circuit diagram
- Piping layouts
- Plant floor plans
- Pert charts
- Truss design
- Chemical structure diagrams
- Architectural drawings
- Program flowcharts and documentation

The data base generated as a result of graphic data entry is the key to the success of these applications. It is used for two purposes: (1) Computer-produced documents at a level current with that of the coded data base; and (2) Processing and manipulation, by application programs, of information represented on the documents.

The principal value of such systems is to increase greatly the productivity of the people involved in design and drafting. Thus, it is necessary that the device "feel right" to people skilled in these fields.

In the software area, the major need is for a customizer which will allow the non-programmer to fit the system to his particular needs. This would include special symbols, drafting conventions, etc., as well as the facility to incorporate processing macros particular to the application.

G. Human Sciences

There seems to be little doubt that the focus of commercial and technical interest is moving outward from the Central Processing Unit (CPU) toward the customer's work and the user himself. As we make this movement outward, more uncertainty is encountered in the product strategy and design process. Not only is it more difficult to discern what is needed, but it is much more difficult to determine if a particular design meets the stated requirement. It is easy to compare arithmetic units, but more difficult to compare information systems.

There is no technology to allow the comparison of conversational languages. A cursory look at our scientific and technical resources shows why we understand much more about what goes on inside a semiconductor device than we do about what goes on in the mind of a user as he attempts to get his work done in a computer. The latter issue is becoming more important than the former.

From the perspective of data entry, work is needed to develop a design and evaluation methodology for those components of hardware and software through which data is entered. Classically, such work has been called human factors or behavioral science. While this work is heavily dependent on those disciplines, there appear to be a number of areas which have not been confronted by these fields, but are of growing importance. The following issues define the scope of some of these.

1. Issues

a. Technology Evaluation and Design

As we develop new I/O technology components, a comparable amount of effort is needed to understand and synthesize the man-machine systems within which they reside. The value of the technology can be established only in that context.

Current technology, itself, is not well understood from a human factors viewpoint. Other than the aspect of noise associated with the typewriter terminal, there is little agreement on whether hard copy or Cathode Ray Tube (CRT) display is better for conversational computing. Perhaps this issue is unresolvable, but work is required to understand what factors make it so.

b. Human Factors of Programming Languages

As we proceed to design new languages which will facilitate more users, there is no technology which will predict how people will like them. Which commands, for example, correspond naturally to the way people want to think about their problem and which are there because the system programmer put them there to make his job easier. Field studies show that one of the major costs in application development is in the area of debug and checkout. It has further been shown that the bulk of errors are errors in program structure (as contrasted to coding) and application concept.

A major issue is the design of effective languages that will encourage the layman to bring more of his data processing work into the system. The intent here is to eliminate the application programmer from a broad class of simple transactions and at the same time facilitate the user in his task of data generation.

A striking example of a system which facilitates data entry is the display oriented project led by Dr. Douglas Engelbart at Stanford Research Institute. Here the users are expected to undergo a great deal of training. The payoff is an extremely powerful data and text manipulation capability with which the information can be sorted, indexed, retrieved, cross-referenced, structured, etc.

The system also provides excellent capability for communication among users. The key to the power of the system and also the source of the training need is an extensive use of context. A great deal of attention is paid to anticipating what the user might do next. By taking account of the context of the user's current state, extremely brief (one or two characters) and powerful commands are the most commonly used.

A very interesting issue raised here is the tradeoff between the user's throughput obtained from an extensive support structure versus the training required to make use of it. There does not seem to be much understood about this issue as well as the larger issue of why there is such a large variability among the productivity of programmers. Systems such as these are invented rather than synthesized from fundamental principles. They are successful to the degree that they align with the way the user wants to think about his work.

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INTERACTIVE CABLE TELEVISION SYSTEMS

Over the past twenty years cable television systems in the U.S. have grown from 14,000 home subscribers in 1952 to a total of about 7 million as of the end of 1972. Current subscriber growth is at a 20% annual rate.

From their early function to provide TV reception in remote areas not reached by over-the-air television, cable television applications have moved rapidly to higher quality color reception, to greater availability and choice of programs, and to local programming. Additional applications have come under consideration as it has become apparent that this significant growth of cable systems will enable them to reach large numbers of subscribers with many channels for use in education - training, health care, specialized information, shopping, premium movies or other entertainment at an additional fee, and other specialized services.

It has become evident that many more applications are possible, but that they would necessitate a two-way system either to collect automatically organized information on a home terminal, to enable the home terminal to interrogate information centers, or to answer questions.

The following list illustrates some of the possibilities:

In addition to the usual line-up of cablecasting news and weather, CATV operators will be able to offer the broadband "wired city" such new two-way services as:

For the home -

burglar and fire alarm service; banking; shopping; electronic newspapers; electronic mail; special interest programs on order; opinion polling; and meter reading.

For business -

electronic mail; data retrieval; computer time-sharing; document transmittal; video conferencing; market testing; credit card validation; and facility security.

For education -

computer-aided instruction; data retrieval; computer time sharing; and access to centralized library services.

For government -

video conferencing; training courses; computer access; fire and burglar detection; picture and fingerprint record retrieval; remote "line-up" of suspects; and automated traffic control.

Some of these services can also be provided by the telephone system. It is not yet clear which communication system will be found most convenient in the future for various of these present and future applications. It may be that the telephone system can best take care of some services and the cable television systems can most effectively handle others. Because of their great capacity and flexibility, cable systems, which will develop substantially on the basis of a few major applications, will have the capacity for many additional ones.

In order to open the door to all these possible applications, many systems are already being planned and built with upstream capabilities in the form of an additional cable, or by reserving a part of the bandwidth in the single cable for the return signals. The additional terminal equipments, at the home or at the cable system headend can be installed later as they are required.

Several such interactive cable systems are in being, i.e., New York City; Spartanburg, South Carolina; Orlando, Florida; Irving, Texas; and El Segundo, California. Some 1,000 FCC authorization certificates have been issued through April 1973 for additional systems with this capability.

Future FCC rulings will determine many of the cable developments and may have to settle the conflicts between the use of the narrow bandwidth (telephone) and the broadband cable systems. Thus, broader bandwidth on the home telephone system will help to stimulate two-way video phone applications which may well compete with some of those permitted by the cable.

Many studies of these problems have been made by foundations, industry, the FCC, and much has been published already. A few illustrative references are attached.

There is no point in covering extensively in this report the contents of all these studies. However, a number of preliminary conclusions will be suggested, keeping in mind that our interest is in attempting to identify some areas where research could be pursued or expanded to benefit additional broadband applications.

While some of the two-way applications using signals raise no social questions other than public acceptance and reasonable cost, this is not the case of other applications which raise the spectre of possible undue influence and a lack of balance in the presentation of issues and in the sampling of public opinion.

While with a limited number of channels reaching all the citizens of the country it seems possible to have at least a degree of balance in the use of the media by politicians and propagandists of ideas because of the clear and large visibility of what happens, the availability of 10 times as many channels will expand this visibility considerably. It will enable those political candidates who are less well off financially to afford to reach an audience; likewise, the political candidate can focus his message on a specific audience for maximum impact and even determine audience reaction.

If the upstream interactive capability is used to get "instantaneous" reactions to ideas and issues presented on the cable system, there is a grave danger that the opportunity for a consideration of balanced viewpoints will not exist. The instantaneous reactions may represent a maximum of emotion and a minimum of logical considered response. Time is necessary to think non-emotionally on sensitive topics. This issue is complex,as it may not be practical to present a subject on television on one day and collect opinions and responses one or two days later. How can we insure that the various sides of a complex question have been well presented before opinions are polled? Illustrative of this high variability of public opinion by polling are the wide swings in popularity ratings of politicians involved in current highly charged issues.

A factor of interest is that at least the hysterical emotional involvement often created in mass meetings is practically avoided by the physical separation of the audience and the distribution of information to home audiences of limited size.

The question is whether there is some useful research to be done in this aspect of telecommunications which could result in beneficial ways of using interactive broadband systems, beneficial in the sense that the impact of imbalanced viewpoints and emotional responses would be lessened.

In this connection, studies might usefully be initiated on the dangers of excessive communications and on the heightening of conflict by over-communicating an issue.

Let us assume that whatever anyone thinks at any one time would be available to his associates. While many misunderstandings could potentially be eliminated, in fact, life could become impossible as there are many thoughts, ideas and plans which have to be filtered, reconsidered, or suppressed, even between persons related by strong love or friendship.

As long as persons use their minds as they are meant by nature to function, there are limits to the amount of information which can be exchanged and absorbed usefully. These limits are impossible to define clearly as they will vary enormously with time and circumstances. However, studies of understanding and misunderstanding in communications, and of the practical limitations on the flow and absorption of information to allow social groups to coexist peacefully may be proper in view of the development of rapid, high capacity and interactive communications.

Another danger involved in interactive communications is its inherent potential for the invasion of the viewer's privacy. The same technology that permits the cable television viewer to interact with the media, could enable the politician to determine which citizens are watching his program and which are watching his rival.

Of course, education, training, telemedicine, information access possibilities, and many other interactive functions are expected to be very beneficial.

The high capacity and responsiveness of this technology will call for the practical education of our citizens to its great potential in enabling them to interact with the media and also to its dangers. Abuses of the technology must be guarded against by an educated, concerned and alert public.

As for the scientific aspect of research in broadband systems, the following items are presented of possible efforts to be pursued or expanded on:

1. The apparently great potential capacity (10^{11} bits/second) and flexibility of optical communications systems which are already under development.

2. Studies of the means of collecting detailed comments on an issue.

3. The present upstream signal systems in which communication with a large number of terminals is effected, is subject to noise, and generalized disturbance. Better solutions are needed based on research in combination with item 2 above.

4. It would seem that as soon as the audience in an interactive cable system passes a hundred, effective audience participation becomes practically impossible; since the audience could reach thousands or even hundreds of thousands of persons, the problem of audience participation is not readily solved. It is possible to conceive of much improved technical solutions to permit the transmission of many comments per person and their correct analysis, without ignoring the importance of the non-response in the assessments.

5. At the moment the U.S. seems to be leading the world in broadband systems, although Japan is moving rapidly in this field. However, the present systems use elementary technologies. This was probably an advantage at the start, but may prove to introduce system limitations later. Relatively little research and development is being done in this field, and while the U.S. is ahead in applications, some advanced work is well justified to keep the lead in technologies for the applications of 10 - 20 years in the future. Possible subjects for research are as follows:

a. Broadband cable network research. The publications in this area have been conceptual or social science-oriented. An investigation needs to be made into whether research in devices and amplifiers has proceeded sufficiently to enable economic implementation of the broadband communications network. An investigative effort is proposed looking at solid state device research in appropriate centers of knowledge and in analyzing amplifier concepts of specific manufacturers.

b. Interactive home terminal research. This intriguing concept is too costly today. An investigative effort is proposed into the principal components (display, keyboard, etc.) to determine whether research should be directed towards achieving elements which could have the potential for achieving lower cost terminals.

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INTERACTIVE CABLE TELEVISION SYSTEMS

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TRAINING AND EDUCATION OF PROFESSIONAL TELECOMMUNICATIONS ENGINEERS

I. Introduction and Problem

The telecommunications industry, along with its supporting science and technology, has grown very rapidly in the past decades. It represents a very substantial part of the US and world economy. It has a vital influence on other industries and businesses that represent even a larger segment of the economy. Furthermore, telecommunications is vital from national security and defense standpoints.

The problem we wish to discuss is the education and training of professional calibre telecommunications engineers to meet present and projected needs of the industry and the country. We would like to know whether in fact there are appropriate curricula and academic courses for specializing in telecommunications engineering, whether these courses and curricula are fully appropriate to the present and future needs, insofar as we can anticipate them.

Relevant to the above is the observation of some of us in the industry, that in spite of the recent apparent abundance of engineering talent available in the electronics industry due to the depressed state of the defense and aerospace industries, competent professional level telecommunications engineers available to assume responsibility are really very scarce. Many professional level jobs are, therefore, filled by marginally qualified people.

II. Questions

The problem can best be highlighted by a series of relevant questions. How has the need for professional manpower been met during its large growth period between World War II and the present? How is professional training provided now? How does industry meet its needs?

A. Related to Schools: From the standpoint of the schools and universities, are there the proper curricula for telecommunications engineers? Is most of the training actually for electrical engineers and electronic specialists, and, if so, is this the optimum way to produce telecommunications engineers of good professional calibre?

Are there enough graduates for the present needs? Are there likely to be enough for future needs? Is there proper training for research engineers whose main professional objective is to advance the state of the art? Is it practical to provide a proper professional level telecommunications training in a four year undergraduate course? Is there not need for a course tailor-made for the telecommunications profession - including suitable graduate curricula for specialties within telecommunications, i.e., common carrier, broadcast, international telecommunications, data networks, computer technology, etc.?

B. Related to Industry: Does the training include appropriate discussion and understanding of the characteristics and problems of the telecommunications industry; how is it organized, managed, regulated? What are the competitive aspects and international factors? How is it affected by the general economy? How is it influenced by the Department of Defense needs, or other government needs, whether federal, state or local?

C. Related to Society: What about the interface between telecommunications and society? What are the significant economic and social aspects like cost and price policy, monopoly versus competition, problems of regulation, privacy, and the fairness doctrine? What is the real and potential impact of telecommunications, and more specifically, CATV and other broadband communications and data networks on education, health services, management of welfare and maintenance of public safety?

Are there suitable curricula or centers of study for mature graduate students, pre and post doctoral, to study, understand and elucidate the really significant issues for the interested public so that it will be possible to evolve sound long range policies, free from undue political and industrial pressures and conflicts?

III. Professional Training - Present and Recent Past

How is professional engineering training in telecommunications provided at the present time, and how has it been provided in the recent past? There have been a number of avenues. The most straightforward has been by formal training as an electrical engineer with an undergraduate degree, followed by on-the-job training in industry or government.

Sometimes the undergraduate work is followed by one or more years of specialized training possibly leading to a master's or doctor's degree. This, in turn, leads to a responsible job in some area of research in telecommunications or electronics.

Sometimes the formal training is in computer sciences, physics, mathematics, or other related areas of science. This then provides an excellent foundation for research in telecommunications.

Sometimes in the past, and particularly during the World War II period, one got a start in telecommunications with little if any professional training, but rather as an amateur radio enthusiast with practical electronic experience. This, coupled with a number of years of significant on-the-job training in industry or in the military services, has led to successful careers in telecommunications. Many of this group are now reaching retirement and need to be replaced.

However, telecommunications has not been established as a bona fide engineering discipline and profession on its own. The courses and curricula have been fine for training students in specialized fields of research vital to telecommunications. Specialists have been trained in amplifiers, detectors, antennas, computers, memories, integrated circuits, electromagnetic theory, information theory, etc. What has been neglected is the training of the well-rounded sound professional engineers who understand the basic technology, and the problems of the industry and the profession, as well as their impact on other industries and society.

The latter capability, if acquired, is through on-the-job training and experience. It has, in fact, been a good way; but is it optimum for our present and future needs?

With some revision and modification of the courses and curricula in the schools and universities a sounder professional training in telecommunications can be provided. This will be advantageous both to the engineering profession and to the telecommunications industry.

Many schools and universities are beginning to appreciate that the courses offered are no longer optimum from the standpoint of meeting the present and projected needs of the telecommunications industry. They are beginning to revise their programs and introduce some innovations in this field. Among these are MIT, University of Illinois, University of Colorado, George Washington University, Brooklyn Polytechnic Institute, and Purdue.

The backing and guidance of the National Science Foundation and the National Academy of Engineering would help this healthy tendency.

IV. Suggested New Elective Courses for the Telecommunications Engineering Curriculum

What are the items of professional training in telecommunications that are generally missing? Following are some examples:

1. Telephony and common carrier industry characteristics and problems.

2. Network and network planning.

3. Transmission systems

4. Switching systems.

5. Traffic engineering, statistics of communications, its measurement and analysis.

6. Electronics technology's impact on common carriers and future telecommunications.

7. Defense communications - special needs and problems, security.

8. Telecommunications system architecture and system engineering.

9. Economics of telecommunications, monopoly, competition, cost, price, etc.

10. Specialized carriers.

11. Data and information systems - need for standards.

12. Computer technology and its impact on telecommunications systems.

13. Radio spectrum - usage and compatibility.

14. Regulation and the legal issues in telecommunications.

15. Broadcasting - television and radio - special issues and problems.

16. CATV.

17. Social impact of telecommunications.

18. Research trends - future outlook.

19. International telecommunications - satellites, undersea cables, international trade.

20. Telecommunications application problems.

Health	Navigation
Law Enforcement	Special state and local issues
Regulation	Surveillance - radar
Education	

The list is obviously not complete, but is representative of the types of studies which professional training must include.

It does not follow that every professional telecommunications engineer must be an expert in each of the above areas. However, a professional calibre engineer with the proper training should at least be aware of most of the fundamentals of these problems and be reasonably expert in a few specific areas.

A good research engineer, who is interested primarily in advancing the state of the art in a specialized area, need not necessarily concern himself with any of the above. But a good telecommunications professional must have the broader concern, because his own welfare, that of his profession and of the industry depend on it.

Thus what is being advocated is not "a drastic change", but a significant reorientation for the telecommunications professional.

It is important to appreciate that society's needs and priorities are changing, as is industry and competition from abroad. The educational system ought to take this into consideration. There is a tendency to be complacent and pat ourselves on the back because we have developed an outstanding technology in the past three decades which was very effective in a war, cold war, and "Sputnik" environment, but without modification is no longer as relevant to our needs as it once was.

V. The Need for Telecommunications Professionals

It is worth discussing briefly the need for this type of professional telecommunications engineer whom we are considering. Following is a listing of significant elements of the telecommunications industry that already need - or will in the near future - need additional professional telecommunications engineering talent.

- Common Carrier: Domestic common carriers like ATT, independent telephone companies, specialized common carriers for data and teleprocessing like Datran, MCI, Western Union, etc. The case of ATT is unique and will be discussed separately below. International common carriers like COMSAT, ITT, RCA, Western Union International, etc.

- Federal Government Departments and Agencies: Defense Communications Systems, including the Army, Navy, Air Force, DCA and a number of special agencies. Federal government departments other than Defense such as Commerce, HEW, DOT, Justice, State, HUD, NASA, etc.

- State and Local Governments: All of the states, and some with special needs, such as Alaska and Hawaii. There will also be special needs for professional analysis and system engineering in many large municipalities with their unique telecommunications problems.

- Manufacturing Industry: This is the area of the greatest need for telecommunications professionals. The firms with such needs include giants such as Western Electric, RCA, ITT, GE, GTE, IBM, Texas Instruments, Raytheon, Motorola and others, as well as the thousands of smaller firms which make up this dynamic industry.

- Broadcasting: This field includes the television networks, the FM and AM radio domestic and international broadcasters, all of whom will continue to need professional telecommunications engineering talent into the near future.

- CATV: The related field of cable television is emerging with a projected growth of 10-25% a year over the next 10 years depending on the regulatory climate. This will call for a large amount of professional engineering talent, if it is to fulfill even a portion of its promise for the industry and society.

In summary, it seems evident that the need and demand for high quality professional engineering talent in telecommunications is, and will remain, very high, as we face our own anticipated domestic growth and the more sophisticated technological challenges from abroad.

VI. Special Case of ATT

ATT represents a very large segment of the telecommunications industry from almost any standpoint - be it planning, system architecture, operations, or research and manufacturing. Its need for properly trained professional personnel is very substantial and vital. But ATT depends on the schools and universities only in part, namely to provide personnel with the right intellectual potential and a good basic scientific education.

The specialized training necessary to match ATT personnel to their careers in ATT is provided in the organization through internal academically oriented training courses. Also, in cooperation with schools and universities, ATT encourages and subsidizes MS, PHD and post doctoral studies. This method insures a good supply of competent and well trained professional personnel.

There is another characteristic of ATT professional personnel which has a profound impact on the whole industry. To a great extent the electronics industry has depended on the mobility of the engineers to spread new technology and techniques. This has been particularly true in the aerospace portion of the industry where it is unusual to find an experienced engineer who has not worked for more than a half dozen organizations. This has been the method of professional advancement - going from job to job and moving upward on the responsibility and salary scale.

As a rule ATT telecommunications engineers and scientists do not move out of ATT very much. Strictly professional turnover in the Bell System is very substantially lower than in any other reasonably comparable telecommunications-electronic organization. The facilities at ATT are unequaled and opportunities for professional advancement are very good. This means that the rest of the telecommunications industry must take care of its own professional training as best it can, depending on internal resources, on graduate professional training in the schools and universities, and on practical on-the-job training or no training at all.

There is one other characteristic of the ATT training in the industry which is very interesting. As a rule elderly electronic engineers are not in demand in industry because, except in management areas, they are considered not up-to-date.

In the case of some ATT retirees however, their technical know-how seems to be in considerable demand, because they have specialized knowledge in telephone networks, switching, traffic studies and related areas where knowledgeable professionals (outside ATT) are very scarce. A number of them have established themselves as consultants in telecommunications to the industry's benefit, as well as to their own.

This is only happening because there are not sufficient numbers of professionals being trained in this area outside of ATT. The more that competition is encouraged in the industry, in the data communications, CATV, specialized carrier, state and local, and international trade areas, the more severe will this problem become and the greater the need for well-trained telecommunications professionals.

VII. Some Tentative Conclusions

The training and education of telecommunications engineers needs to be reexamined, revised and broadened to take into consideration:

- the huge growth of the industry;
- its increasing complexity and sophistication;
- its economic and social importance to the nation.

This training will emphasize, in addition to science and technology, system architecture, system engineering, applications engineering, and the social and economic impact of all aspects of telecommunications.

The new curriculum, including some of the material in Section IV above, would in all likelihood require an additional year or more of professional training. A more detailed study, analysis and further consultation with concerned professionals will be required before a significant recommendation can be made along this line.

Many schools are becoming aware of this problem and are beginning to revise their electrical engineering courses to give a more prominent place to telecommunications. The National Science Foundation (NSF) should help and support this tendency.

One form of such help might be for the NSF to take the lead in establishing a well qualified task force with representation from the universities, industry, professional societies and the major users of telecommunications, including the Department of Defense.

This task force would study in depth the problem of the training and education of telecommunication engineers to meet our national needs.

The task force would end up with a set, or possibly several alternative sets, of specific recommendations for all professional schools and universities for future action on a voluntary basis.

An additional part of the task force work would be to study in some detail the scope of training of telecommunications professionals in other technically advanced countries, such as England, Germany, France, Japan, the USSR, etc., in order to determine whether we can learn something from abroad. Though in most cases the foreign telecommunications industries are very substantially differently organized from ours, they are beginning to face many of the same problems as we are.

VIII Graduate Centers for Telecommunications Policy Studies

All of the above pertains to professional engineering training, including consideration of industrial and social problems as they impact the engineering field. It is not meant to concentrate on the primarily social, societal, economic and legal issues which are important to society.

For the latter, the National Science Foundation effort to establish Centers for Telecommunications Policy Studies in several universities and not-for-profit foundations looks like an important step in a desirable direction. Such centers,when effectively implemented, could do justice to the many policy issues and implications which involve society, the general public and the nation in a very significant way.

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COMPUTER TERMINALS

I. Introduction

The computer terminal provides the interface between a person at one point in a telecommunications network and a computer at another. The many and varied applications of computer systems cannot be satisfied with any one form of interface. Instead, many kinds of terminals are required to suit differing needs. Some terminals must provide a printed record. Others must not print, if only because of the volume of paper which would be consumed if they did. In some situations it is sufficient to reproduce alphanumerical text. Others require images of one sort or another. For some applications it is enough that the text be readable, permitting the characters to be created from a rectangular array of dots. Other uses, such as preparation of masters for photo-offset printing, require high standards of contrast and elegance. There are applications which require a display in color.

The presentation of an electrocardiogram for clinical analysis may require a display having high fidelity for detail. Mechanical design demands a degree of rectilinear fidelity which most applications do not. Some terminals must provide positive identification of one or two users, as when recording a retail sale. There are applications which require simulated speech, while others would be enhanced by the ability to recognize speech.

Taking all of these needs into account, it seems probable that a few terminal types will be produced in large volume for common use. At the same time there will be developed a large number of terminal types to meet more specialized needs.

Possibly the most useful terminal of all would be created if each telephone were equipped with a full alphanumeric touch-tone keyboard. Such a keyboard used with a simulated voice response from the computer would fill a great variety of needs, from making airline reservations to placing off-track bets.

II. Consequences of Large Scale Integration of Electronic Circuitry

The advent of large scale integration of electronic circuitry (LSI) is certain to have a profound effect upon the nature of computer terminals. It has been predicted that it will soon be possible to include on a single chip the entire circuitry of a computer more powerful than those which only recently sold for as much as a million dollars, and that the manufacturing cost of such a chip may be less than that of a typewriter. If these predictions are fulfilled, there will be little need for telecommunications to time-share a computer.

The existence of computing and memory capabilities within the terminal opens up new design possibilities. There are, for example, partially electronic keyboard and printer mechanisms which may be less costly and more reliable than the mechanisms used in present typewriters. Possibly the inclusion of an LSI chip in a typewriter will reduce the cost of its mechanical parts sufficiently to offset the cost of the chip. If so, all typewriters soon may become electronic computers. The inclusion of a chip in a computer terminal radically alters the relative attractiveness of possible components. For example, it tends to diminish or eliminate any advantage which a display device with inherent memory might otherwise have over other devices which do not have this attribute.

III. Electronic Writing Machine

The proposed new terminals with LSI componentry are becoming known as "intelligent terminals," as opposed to the present "idiot" devices. While their advent will have a profound effect on many computer applications, the example of an electronic writing machine will serve to illustrate what lies ahead.

Present-day typewriters are little different in concept from the device into which Samuel Clemmons sank a fortune. The single step of including an LSI chip may alter the character of the device and its use as profoundly as everything which has been done to it up to now.

Providing the electronic writing machine with computing capabilities and a memory large enough to hold a document makes it possible to edit and correct the text of the document until a completely satisfactory version has been achieved. In this way an unskilled typist can produce perfect results. The electronic writing machine becomes a useful tool for a much larger number of people than today can use a typewriter.

Further, it may be possible for a skilled typist to enter text in a personal shorthand like that which radio operators use. An entry such as "u r gog to b talr" might be reproduced in the final copy as "You are going to be taller." For a skilled individual, the ability to use such a shorthand might very significantly increase working efficiency.

In addition, the electronic writing machine might include an acoustical coupler to connect it to the telephone for telecommunications, in this way making it a computer terminal. As an example of the use of the coupler, the writer of a letter might, after completing it, telephone the post office and send the letter to the recipient's "mail box." This would be a data bank where it would remain until the recipient chooses to use his own electronic writing machine to "look in his mail box." Such mail may become the first class mail of the future, with present air mail being relegated to second-class status. As well as being faster, electronic mail of this kind may ultimately be less costly than physically moving printed documents.

IV. Information Sharing

One should not conclude from these remarks that the advent of intelligent terminals will reduce the need for telecommunications. Quite the opposite is true. Our society is increasingly dependent on information-sharing systems - radio, TV, mail, newspapers, schools, libraries, and merchandising serve as examples. By contrast to the vast flow of information, the amount of computing which is done for its own sake is very small. Computers are increasingly being used for information processing, as opposed to computation. Time will prove the computer to have been misnamed. Similarly, telecommunications for time-sharing the computing power of a large computer will be replaced by telecommunications for information-sharing.

Many large data banks will evolve to serve the needs of our increasingly information-dependent society. Because of the cost of maintaining such data banks, and particularly the cost of keeping the information in them up to date, there will tend to be a single bank for each given body of material. The people of the world will share in its use via satellite. Generally speaking, information is blind to geographic and political boundaries. It is increasingly blind to the language differences of the people of the world as English evolves as the common language of communication among all people.

Although many data banks will be available to everyone, there may develop around each of them a faculty specializing in its maintenance and use. As an example of this, we probably are approaching the time when census processing for most developing nations will be accomplished at a central point to insure that the census data from the individual countries can be fitted together for study of worldwide trends. This center probably will be located either in New York City or in Geneva. Around it will develop a pool of individuals who are expert in census taking and census interpretation. The initial choice of location for this data bank may establish where the center of census knowledge will be a century from now.

It has been observed that Lloyds of London did much to offset an otherwise negative trade balance for England for many years. In each case in which the United States takes the leadership in establishing a fundamental data bank useful to the world as a whole, it will be taking a step toward leadership in that field for many years to come. There frequently will be important secondary benefits to derive from the existence of a data bank. If the United States has the pharmaceutical data bank to which the rest of the world looks, the chance that the pharmaceuticals themselves will be purchased in the United States will be greater than would be the case if the data bank were abroad, and in another language.

V. Areas Needing Government-Funded Research

The computer terminal market is and probably will continue to be competitive and profitable. As a consequence, there should be little need for government funds to assist it in evolving. There are, however, aspects of terminal design of great importance which are not likely to get the attention of terminal manufacturers. These relate primarily to the efficient transfer of information between a person and a terminal. The following questions will serve to indicate the range of inquiry which is needed.

1) If tens of millions of students are to spend an hour or more a day before a computer terminal, what can be done to maximize the rate and ease of information transfer?

2) If it is our goal to have as many as possible of the people of the world use our data banks, what can be done to lower the level of English which they must learn to do so?

3) Do computer terminals need both capital and lower case letters? What would be gained and lost if only one form of character were used?

4) Do we need all of the characters in our present alphabet? How about Q? Would we gain or lose from adding characters representing sounds such as ch and th?

5) Would there be less visual ambiguity among the characters of the alphabet if one or more were given new forms?

6) Would learning our language be easier if its orthography and pronunciation were more closely related?

7) Are words like "queue" relics which should be disposed of? Why not spell it Q? The word "eskimos" was spelled "esquimaux" only a few years ago.

8) What color is most suitable for a display? Could we improve the readability of a display by using more than one color, as for example one color for consonants, another for vowels, and a third for punctuation?

We tend to think of anyone interested in the simplification of the English language as being a crackpot, although such people share some good company. Possibly the people who have been concerned with the subject in the past have not been daring enough. Certainly the potential gains increase as more people are obliged to learn English as a second language.

A second area which may deserve government funds is speech synthesis. One's ears are entry ports to the brain which are today little used for the transfer of computer information. As already noted, there would be important uses for synthetic speech, if it were available in a more usable form. The vocabulary should be unlimited, and the speech easily intelligible.

It should be possible to create speech directly from alpha-numerical data in digital form within a computer data bank. This would, as an example, allow a technical journal in a library data bank to be read to a blind person. Such a system would open up to the blind many careers which do not exist for them today.

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FUTURE USE OF COMMUNICATIONS AND TERMINALS IN EDUCATION

I. Introduction

This study speculates on the future uses of communications and computer terminals in education and the demands which these uses will make upon the terminal, the computer, and the communication link between them. The time is the year 1979 and beyond.

Formal education in the United States and in Europe has gone through several decades of growth along relatively consistent and well-defined lines. We now see changes taking place at a much more rapid rate as education struggles to adapt itself to the changing needs of society. It seems probable that the remainder of the century will witness more change in education than has occurred in any comparable period in the past.

Up to the present time, teaching methods have been dictated to a greater degree than we may realize by the lack of the tools necessary for automation. The major tool has been the book, the use of which has been progressively refined over the centuries since the invention of movable type. Today we have new tools which permit changes of great magnitude. Audio tape, film and videotape, television and computer terminals all offer themselves as new dimensions in the educational process. Each of these technologies is in a state of rapid development which promises lower costs, wider availability and new capabilities.

II. Social Environment of Education

Since the changes which are taking place in education are largely in response to changes in society, our consideration of the use of computer terminals and communications will commence with an examination of the social environment of education. All of the things which will be observed here already have been discussed widely in recent publications. They are being restated because they serve as the basis of the conclusions to be reached later on in this study.

A. Cost of Teaching Personnel

The largest single element in the cost of education has always been that of the teaching personnel. Until a few decades ago teachers were poorly paid, which minimized the incentive to improve teacher efficiency. More recently, teachers' wages have been increasing with little offsetting improvement in the number of students whom each teacher can serve. A major challenge for the automation of teaching is to improve the teaching efficiency of our educational institutions, so that higher wages can be paid while at the same time reducing the over-all cost of education.

B. Cost of Space

The second largest cost element in education has been the cost of construction, maintenance, and debt service for the educational plant. The amount of space per student has tended to remain relatively constant, since it has been dictated by teaching methods. Our growing population and the freedom with which migration occurs from one area to another have required a large amount of school construction. This has occurred during a period of rapidly increasing construction costs.

The space used by schools is largely living space, and is correspondingly expensive. It must have its temperature controlled and must be well lighted. There must be reasonable quiet. It must be possible to work in comfort. Schools use their space a relatively short part of the time. For public schools, the school year is usually less than 200 days. During the remaining nearly 50% of the year the space may be completely unused. While colleges and universities sometimes do better than public schools in the use of space during the day, the latter typically occupy their classrooms for not more than six to seven hours. Moreover, by the time a student reaches the junior high school level he should have a study space at home, in addition to the space which he occupies at school. Taken all together, this extravagant use of space for education is possible only in a society which has reasonably well provided housing for its members. Similar provisions can not be made in many developing countries of the world where living space is at a much greater premium than in the United States.

C. Time as a Measure of Learning

At one time it was the practice to apprentice a student to a master for a stated space of time duing which the student was expected to learn what he could from the master. From then until now time has been one of the principal measures of learning. Nearly all educational institutions establish a fixed period, the semester or term, within which each course must fit, regardless of the nature of its material. It is uncommon for a course to take either less or more than this amount of time, except that a course may occupy two or more consecutive terms.

It is obvious that all subjects do not require equal lengths of time to master. It is also obvious that students with differing abilities and backgrounds will require different amounts of time to cover the same body of material.

Clearly, fitting many different kinds of course material into periods of like duration does not serve the needs of either the subject matter or the students. It is designed to fit the limitations of the system.

D. Education as a Life-Long Process

At an earlier time when the rate of social and economic change and the scope and rate of growth of human knowledge were less, it was possible to educate young people with the reasonable probability that the knowledge imparted would be appropriate and sufficient to their use for the remainder of their lives. This is no longer true. We must look upon education as a life-long process for the members of our society who are to remain fully functional as they grow older. Since it is impractical for most adults to interrupt the pattern of their lives for one or more consecutive years to return full time to schools of the present kind, it is going to be necessary to offer them education wherever they are, at whatever times of the day or night they are free, and at a pace in keeping with their abilities and portion of their lives which they can afford to devote to continuing education.

E. Adapting Education to Individual Ability & Background

Courses today are in general designed for students of like background and ability. Any student who is very far outside the norm is poorly served. As the portion of education devoted to adults increases, the range of background and ability found within a "class" will correspondingly widen, emphasizing the need to adapt the scope and pace of the educational process to individual needs.

F. Requirement of a High School or College Degree

Our society is placing increasing emphasis on high school and college degrees as requirements for employment and promotion. It has been observed that Thomas Edison did not have the education to meet the minimum requirements for employment as an IBM engineer. Mr. Thomas Watson, Sr. lacked the college degree demanded today of an IBM sales trainee. The Wright brothers, Henry Ford and Charles Kettering all lacked the sort of education which we would consider today to be necessary for the kinds of work they did so well.

It is also clear that organizations very often make a certain level of education a requirement for employment, even though the requirement has little or no relevance to the needs of the job. It is sufficiently evident that this works against an equal sharing of opportunity so that we are seeing pressure to remove the requirement of a high school or college diploma as a condition for employment where it has no direct bearing on the work to be done. We are also seeing greater use of equivalency certificates as an alternate to diplomas.

G. Ancillary Services - Busing, Lunch, Sports

In order to provide more uniform and broader educational programs, our educational institutions have tended to grow in size and reduce in number. Bringing students together in large numbers in this way has forced schools to enlarge the scope of the services which they provide to include services unrelated to education. There are public school districts within New York State which operate over one hundred buses, many times the number of buses available to serve the general population in the same area. In general, these transportation systems tend to lock the school system into a rigid schedule which is difficult to change. The coming and going of his bus is a major determinant of what each student can accomplish during a day.

Similarly, schools usually manage large lunch programs, sometimes serving more people than the public restaurant facilities available within the school district. The provision of transportation and lunch for students places a considerable strain on the system. Management attention must be devoted to supervision of these services and space must be provided, all of which dilutes the attention to education.

For many districts the burden of school taxes is so great as to leave little money to provide for transportation, library service, sports facilities and auditorium space for general public use. At the same time, the use of the facilities provided to the schools is proscribed to exclude the adult taxpayers who support the facilities. The school buses are not available for them to ride, they are not free to stop at the school lunch room for a meal, they may not borrow books from the school library, the gymnasium is closed to them, and they do not have free access to the school as a public meeting place. Unless the district is wealthy enough to duplicate these facilities, the adult taxpayer is deprived of what he has bought.

H. The Information Explosion

The range and scope of human knowledge are growing at a rapid rate. There are many important fields in which it is impossible for any human being to keep himself well informed. Instead, each of us is forced to be increasingly selective in what we learn.

At the same time, everyone is exposed to a wider range of information than ever before. Even those who are functionally illiterate are learning a great deal about the world and its people through such media as radio, TV and travel. For those who can and do read, the range of subject matter available in books and periodicals has never before been so great.

I. The World as School

The physical world and the society in which each person lives serves as a school which will teach him most of what he ever learns. No amount of time in class would have taught Darwin what he learned from his trip on the Beagle. It seems unlikely that Picasso's work would be improved by art courses, or that Abraham Lincoln's speaking style would have been enhanced by a course in rhetoric. There are boundaries beyond which only the real world and society at large can serve as teachers.

In general schools are surrogates for real life, institutions which make learning easier by bringing together in convenient proximity people and materials conducive to learning and provide an environment free of distractions. While it is obvious that schools serve these purposes very well under favorable conditions, life teaches us that there is no substitute for contact with the real world and that for many kinds of subject matter school is second best to real life. The student who must learn from life may be privileged, and not under-privileged.

As an example, all of us learn a language at an early age. Most of us learn it more easily and better than we ever learn another language using the methods employed in school.

III. What the Future Holds

If one is willing to accept the preceding observations as reasonably representing the environment in which education finds itself today, it is possible to proceed to certain speculations as to the changes which may occur.

A. Teaching How to Learn, to Work and to Communicate

There is no way in which in the time available our young people can be given a comprehensive grasp of the factual information represented by such disciplines as history, physical and political geography, mathematics, science, language and anthropology. Consequently, one of the goals of our educational system must be to teach them how to learn, how to be effective, and how to communicate with others. They must be taught as early as possible to read, to write, to speak lucidly, to think logically, and to perform arithmetic and other essential mathematical processes. They must be taught how to obtain needed information, how to organize their work, how to work with others, both as leader and as subordinate, and to observe the world and society around them. They must learn how the local and larger communities operate, and what these communities offer and expect of them.

By the time the student has reached the secondary school level, schools in their present form serve these needs poorly. Much of what the student needs to learn can be mastered better through closer contact with the community than in the classroom. It is reasonable to expect that in the future more of education at the secondary and college level will be accomplished through institutions in the community, or through student projects organized and executed by one or several young people. In this way the community and the students themselves will assume more of the responsibility for their education.

We can expect to see students deeply involved in work with local institutions, including the judiciary, welfare, community development and the communications media - newspapers, radio and TV. More young people will do creative work at an early age in such fields as art, mathematics, science and anthropology. Much of their time may be spent in these activities, and less than today spent in the present kind of classroom instruction.

A single example will serve to illustrate how this may come about. Cablevision services are required by the FCC to set aside a channel for educational purposes. It may turn out that the management of this channel will fall into the hands of the students in a community, with students in each of the secondary and higher institutions providing materials for viewing by the community at large. Such channels might provide a refreshing contrast to what one sees today on commercial TV.

The time required for activities of this sort will become available in several ways. In part, it may be obtained by using new teaching techniques such as Computer-Assisted Instruction to improve learning efficiency. Replacement of the present rigidly scheduled school day with a more flexible program in which each student's schedule is more nearly fitted to his own needs can also give him more time for his own use. Finally, it is to be expected that schools will abandon any attempt to teach large bodies of factual materials, such as "world history," and substitute more manageable courses designed to interest the student in a subject area and to teach him how to make it a part of his life.

B. Education in the Home

To a much greater extent than is true today, education may take place within the home. At the primary school level, students may continue to spend about as much time in school as they do today because of the extent to which primary schools are relied upon for social conditioning and as daytime foster parents for our children. However, as children grow older and become more responsible for themselves they may spend less and less learning time in school and more such time studying at home, at neighborhood learning centers, or elsewhere in the community. It is possible that at the college level much more learning will take place off campus with a reduction in classroom activities and with greater dependence on conferences between instructor and student and occasional group meetings to maintain personal contact.

C. Videophone Classroom

It may be that in the future an instructor and his class will meet through videophone or its equivalent, with the students and possibly the instructor as well remaining in their own homes. This would have the virtue of eliminating commuting time for all involved, and would allow a "class" to reside over a much wider area than is possible today. This in turn would permit an institution to offer a wider choice of courses, and to offer them at a greater choice of times to meet the differing needs of an increasingly adult student body.

A videophone classroom could operate in the following way: Each student might have a TV viewer which would connect by a "telephone" line to the school. When time for the course arrives, the student would dial the school and the course. A "telephone" exchange at school would connect together the TV viewers for all members of the class. They would be able to see one another on a split-image screen, but would hear only the instructor. By pressing a button, a student could cause his image to flash on the instructor's screen and so signal that he wishes to be heard. More simply, he might hold up his hand or otherwise signal by physical means. The instructor's viewer alone might have the ability to determine which member of the class, if any, is to be heard.

A system of this kind is simple in concept, and should not be expensive in relation to its utility. The saving in expense and time of travel alone for students might be sufficient to justify its cost.

D. Certificates of Mastery

The present use of course credits as a record of scholastic accomplishment may diminish in favor of certification that an individual has reached a certain level of mastery of a specific body of material without regard to the manner in which the knowledge was acquired. A student may not need to have attended an institution to obtain certification from it in one or more areas. For a person who has grown up in another country, certification of proficiency in the language of that country might be very easy to obtain.

The ability to make certifications in this manner would depend upon there being a detailed definition of the subject matter for which certification is being given. This could be done much more readily in some subject areas such as mathematics or pharmacy than in others, such as creative writing.

Similarly, the ability to certify competency in this way depends upon being able to test exhaustively an individual's mastery of a subject. Computer terminals can be of great assistance in this, since they make it possible to test much more thoroughly and accurately than is possible using present manual testing methods. When a student fails a certification test, he might be provided with an analysis of his strengths and weaknesses and with a prescription for the measures which he might take to improve him sufficiently to qualify. If he passes the test, he might be told what to do to qualify for the next higher proficiency level in the same subject area.

The student might be able to take the certification test, or selected parts of it, again and again during his studies. In this way, the testing might give direction to his work. Each retest could pick up where the previous one left off, and so cover only those areas which remain in doubt. In this way the testing could be exhaustive and accurate, and at the same time unrepetitive and rewarding to the student.

E. Computer-Assisted Instruction

Computer-assisted instruction (CAI) is basically a dialog between a student and a computer, with the computer side of the dialog having been programmed by a teacher. Since the computer responses have been created by the teacher, the quality of the dialog depends upon the teacher's ability to anticipate the student's actions and program responses appropriate to them. CAI promises to be of great value as a way of individualizing instruction without the need for human instructors.

Depending on the nature of the material being taught, the control over the direction which the dialog takes may in one case rest primarily with the student and in another rest primarily with the computer acting under the direction of the author of the CAI course.

For the computer to guide the course of the dialog, it must have some past history of the student's level of performance on the CAI course material, or it may be the results of prior testing. To this extent, testing and CAI can be made to augment one another. Completion of a CAI course may carry with it certification of mastery of the subject.

F. Television and Cablevision

The use of film and of guest lecturers for teaching is rapidly increasing, but usually in a rather haphazard way. Attending such an event is often inconvenient to the student because of the time at which it is scheduled and because of the need to commute to it. It is reasonable to expect that in time cablevision channels committed to education will provide a rich fare of films and lectures which the student can view in his home. Videotape is becoming more reliable and less costly to use, and it is predictable that a guest lecturer in a community may have his lecture taped and repeated several times for the viewing convenience of students.

Teachers may choose to videotape their lectures. This would allow them to polish their presentations, and would free them of the need to cover the same material again and again. The lecture could be shown more than once over a period of several days to ensure that everyone including employed adults has an opportunity to view it. The tape could be made at the time most convenient to the teacher, thereby allowing him to be free of the institution a greater part of the time.

Videotape (and film to a lesser degree because of its higher cost and the greater technical difficulty of producing it) should be recognized as important new media of expression for students as well as faculty. It is reasonable to expect that students will use videotape as a medium for presentation of thesis materials, and that in general much of the videotape programming presented by an institution will have been prepared by students.

G. Remote Reference to a Library Catalog

It may be possible for a student to interrogate a library catalog from a computer terminal in his home. Where there are several libraries in a community, their contents may be listed in a single combined catalog. The catalog may indicate whether the document is in the stacks or on loan, and in the latter case when it is due to be returned. It also may be possible for a student to reserve documents, and to have them delivered to a place from which he can conveniently pick them up. This might be the neighborhood learning center nearest his home.

H. Remote Reference to Documents

It may be possible for an instructor to arrange to have selected reference documents made available by videophone, by display, or printing computer terminal for use by students. In this way, a single copy of a document might serve many students without the need for them to visit a library for the purpose. While one would like to accomplish this by direct video viewing of the original document, an intermediate step in this direction would be to enter the contents of a document into the computer as data which the student might view or retrieve at will.

In the course of time much of the contents of our libraries may be stored in digital form, and so be available at all times to every student.

I. Computer Document Editing

A computer terminal can be a very useful tool in the preparation of texts, reports, student essays and documents of many kinds. The original of this document was prepared using a computer terminal in this way without the assistance of a typist. The value of the computer lies in the ease with which changes can be made in a document as one proceeds from the first rough draft to its finished form. One can freely make changes, additions and deletions in the text and then ask the computer to produce a new clean copy incorporating them. Repeated manual retyping is avoided, and a level of perfection can be achieved that is difficult to attain if each change, no matter how small, requires retyping to obtain a clean copy.

The assumption is made that all serious students from the junior high school level up will be able to type. The ease with which typing errors can be corrected makes it possible for a typist with limited skill to produce good results.

J. Computation and Data Processing

The computer terminal is, of course, ideal for computation and data processing. Using a high-level language such as APL, students from possibly the fifth grade up will have full access to the computer for computation and data processing studies. This will permit them to undertake studies requiring larger amounts of computation and data processing than it is possible to accomplish by hand.

Data banks will be available for student use. These might, for example, contain census data which the student could use for independent data processing studies. In this way, high school and college students may be able to undertake studies of a significance which in the past has been expected only of graduate students.

K. Multi-Media Teaching

As new media for teaching become available they may tend to augment rather than replace earlier media as teaching tools. A typical course may employ several media appropriate to its goals. In addition to lectures and books, on which many courses place exclusive reliance today, a course may employ videophone classes, films, videotapes or lectures on cablevision, computer-assisted instruction, video reference to information in the library, and use of computer terminals for computation, data retrieval and document preparation.

L. Passive as Opposed to Dynamic Teaching Methods

In general, films, videotape and audiotape have been less effective as teaching devices than at first was expected of them. To a degree, the limited effectiveness of these media is because they fail to involve the student as directly as classroom and computer-assisted instruction are able to do. If the student's interest flags, it is easier for him to let his thoughts drift or to go asleep over a book or in front of TV than would be the case in a well-run classroom. During computer-assisted instruction the process immediately comes to a halt when the student stops responding.

It is foreseen that future teaching methods will aim to involve the student directly and continuously, and whereever possible to put the direction of the teaching process in his hands.

There are many subjects for which the order in which the individual elements are learned is of little importance. For them it may be quite satisfactory for the student to guide himself as long as subsequent testing insures that sooner or later he grasps all of the essentials of the subject. Foreign languages are excellent examples of such subject matter.

IV. The Future Form and Function of Educational Institutions

The new teaching media may bring about major changes in the form and function of colleges and universities and somewhat less change in primary and secondary schools. Instead of living at school or commuting to it, the student may satisfy a larger part of his needs through communication. The institution may become a communication center and a resource repository which its faculty and students visit less frequently than today. Much less physical plant may be required and what there is may be dispersed throughout the community. The drawing radius of an institution may be many times what it is today, where the influence of an educational institution tends to be limited by the distance over which its students can commute.

As in so many aspects of present-day society, bigness will be a virtue. The larger the institution, the greater the scope of the subject matter it can offer and the larger the resources it can support. The investment in library facilities, computers, video equipment, etc., will be great, with the result that the cost per student for these facilities can be kept at a reasonable level only by having the institution very large. Small institutions will be forced to share facilities with one another.

Bigness may not be the disadvantage it is today if the student is free to work on his own much of the time. While the greater physical distance separating the instructor and his students may to some degree reduce the feeling of personal contact, the skillful use of the videophone may do much to mitigate this and may, in fact, make personal contact more readily possible than it is in reality today for most students.

Subject matter may tend to be offered in smaller units and repeated more frequently. Those subjects which can be accommodated by computer-assisted instruction may be continuously available.

Graduation from an institution may have less meaning than it has today. Depending on the nature of his studies, a student may complete his program at any time during the year. There may be an inherent assumption that the student will at some time in the future resume his studies at the same or a different institution. Graduation would carry with it certification of a certain level of mastery of a list of subject areas. Through continued study after graduation the student might add to this list year by year throughout his lifetime.

V. Large Scale Integration of Computer Circuitry (LSI)

We are rapidly reaching a point where very large amounts of computer circuitry occupy very little space and cost very little to produce. Moreover, such circuitry performs very reliably. This brings us to the threshhold of a major technological revolution which in time will affect a great many of the electrical and mechanical devices and appliances which we are accustomed to using. We already have seen electronic hand calculators replace their mechanical predecessors. The new electronic calculators are easier to use, less costly, more versatile and more reliable. They are better in every way.

Polaroid has employed LSI in its latest camera. LSI is about to dramatically reduce the cost of computers and at the same time increase their power. It promises to revolutionize telephone systems, and communications systems in general. The sections which follow presuppose the rapid application of LSI in many fields.

VI. Electronic Typewriter

It seems probable that the typewriter will be one of the next devices to which LSI electronics will be applied. Doing so will have several far reaching consequences. First of all, the use of electronics will permit a less complicated printing mechanism to be used. Simplifying the mechanical structure will at the same time reduce weight and cost, and improve reliability and maintainability. The reduction in the cost of mechanical parts alone may be sufficient to cover the cost of the LSI electronics. The new printing mechanisms will be able to operate at several times the speed of present typewriters. While this will not influence the speed with which manual typing can be done, it will permit the typewriter to be more effective as an automatic typing machine.

Once electronics has been introduced into the typewriter, it will cost very little more to add memory, the ability to compute and execute computer programs, and the facilities to communicate over telephone lines with other computers and data banks. The typewriter is about to become a computer in its own right able to perform extensive and complex computations. It will be able to do data processing on limited amounts of data.

The existence of memory and data processing facilities within the typewriter will allow it to be used for document editing. As a document is typed, the data will be stored in the memory of the typewriter. After completion of entry it will be possible to make corrections and revisions at will without retyping the complete text to do so. When the text is complete and satisfactory, it will be possible to print it at several times the speed of present typewriters.

The ability to communicate over the telephone will make the typewriter a computer terminal. It may be in this way that we see computer terminals entering the home and becoming as ubiquitous as typewriters are today. Since the typewriter will have computing ability within itself, it will not be necessary to time-share the computational facilities of a large computer for tasks of ordinary dimensions. The communications facilities will be used primarily for information gathering and information sharing. The computer to which the connection is made usually will be a data bank of one kind or another.

VII. Learning Center Equipment

We will now examine the electronic equipment requirements for a future learning center. This center may be in a home, it may be a neighborhood center serving many students, or it may be on the campus of an educational institution. When off campus, it would serve secondary and college level students and adults continuing their education.

The learning center would have one or more television sets. These would provide access to educational channels on cablevision. In addition, they should be capable of being connected to the video classroom facilities of a number of educational institutions to permit students to participate in a wide selection of courses of this kind.

The learning center would provide one or more computer terminals. Some of these might be the electronic typewriters already described. Others might provide, in addition, a display screen to permit graphic data to be presented. This would also allow data in character representation to be presented at a much more rapid rate than any mechanical printer can do, and would be particularly useful for scanning purposes, such as searching library reference files. When the day comes that the computer can speak with a large vocabulary we will wish the terminal to have audio communication capabilities. This would be extremely useful for foreign language instruction.

Learning centers will make some use of film and audio and video tape. However, the technical problems involved in distributing these media are such that much of the material available in these forms may be offered on a scheduled basis, or on request over cable TV and cable radio circuits. Audio tape will continue to be used in the manner it now is for language laboratories. We probably will see much more common use of audio tapes for the kinds of instruction which do not require the full attention of the student. A good example is language tapes designed to sharpen the student's auditory perception of a foreign language. These can be used rather casually in a learning center, at home, or while driving a car.

It is often suggested that television will be married to the electronic typewriter as a way of producing a device with keyboard and display capabilities. While this may come about, few educational uses have a direct need for the unique feature of TV, which is its ability to present motion. Motion implies a much wider bandwidth for the communication link to the terminal. This probably will dictate that the display device normally present a static image. This does not preclude the rather rapid scanning of data, but avoids such a flow of data from being a continuous requirement of the terminal.

VIII. Electronic Libraries

Computers and electronic typewriters soon will be almost universally used for the preparation of text for publication. The old method using linotype and galley proofs already is obsolete because of the time and cost of making changes and corrections. As a consequence, nearly all printed material will be available in electronic digital form suitable for storage in data banks.

It is evident that no one educational institution can accommodate in its libraries physical copies of the flood of publications of interest to its constituency. Instead, there may be a reliance on large data banks as libraries, with the entire contents always immediately available to everyone. The libraries of educational institutions may be used primarily as repositories for old books and for publications in common demand.

In order to make an electronic library practical, it will be necessary to have a means for storing data at very low cost which at the same time permits rapid automatic retrieval. Such a means of storage is the remaining missing link which precludes the rapid development of vast data banks for many purposes, of which the electronic library is only one.

At the present time, the annual cost of operating a library usually exceeds that of the publications purchased. By automating the handling of the publications, the electronic library may reduce very substantially the cost of libraries.

The information provided by an electronic library would be available to the user on a display device, or might be printed if the amount of data is not too great. For many uses, this method of obtaining access to published information will not be as convenient as the books, magazines and journals we use today. The electronic library may be most useful for research and reference purposes. It may do little to stem the flow of printed matter of the kind we now use.

IX. Nature of the Computer Data Bank

Since computer terminals will provide substantial computing capability, it seems probable that in the field of education large computers will be used primarily to manage data banks and communication. Data banks will grow enormously in size as we draw into them much information now stored in printed form or on microfilm. Some of the stored information may be on rotating magnetic disks or similar devices for rapid access. Much more will be stored passively on tape or similar media, but with the ability to be recalled automatically on short notice.

The passive storage will probably be digital rather than a photographic image to facilitate data management and transmission. Storage density will be very high, on the order of that of microfilm. Consequently, vast amounts of information will be stored economically and at the same time will be available quickly.

While certain data banks will be maintained by educational institutions, many will be managed by consortia, and others will be national or international in nature. As an example, a single data bank might serve to store vast amounts of information relating to a class of plants or animals.

X. Communications

Three levels of communication seem to be required between the learning center and an educational institution. One of these would be for educational broadcasts, and should be amply served by one or more educational channels on cablevision wherever it exists.

A second requirement is for data communication between terminals and computers. This is comfortably within the bandwidth of present local voice telephone circuits, and it is probable that such facilities will be used to meet near-term needs. A single telephone voice circuit between a neighborhood learning center and a school may have sufficient data carrying capacity to serve many student terminals. When a terminal in one central office area must communicate with a computer in another central office area, it seems probable that the communication between central offices will be taken care of by specialized circuitry modified for the efficient handling of digital data. This should allow many terminals to share simultaneously the equivalent of a single voice circuit and so make long distance digital data communication very much less costly than corresponding voice communication.

The video classroom introduces a third and more severe communication requirement. It corresponds to that of the videophone system which the telephone industry is preparing to provide. The educational application for videophone may, in fact, provide the greatest single incentive for making such service available in the near future. Because of its cost, video classroom service is not likely to be commonly available in home learning centers for some time. The cost per user diminishes considerably for neighborhood learning centers, since a number of users presumably could share a single circuit to an educational institution.

It appears that each educational institution will have communications links at all three of these levels to other institutions in order to share cablevision and video classroom offerings, computers and data banks.

XI. Telephone Equipment

A number of electronic telephone central offices have been installed. None of these have as yet taken advantage of the current revolution in LSI circuitry. As this occurs, there should follow the same dramatic improvement in performance and reduction in cost that are expected in the computer industry. In view of the vast amount of telephone central office equipment in existence, it is not reasonable to expect that this will occur very quickly.

Except for meeting the increasing voice, data and video demand with microwave and satellite communication links, there may be little change in the character of the communications system between central offices. Similarly, the present system of twisted pair circuits which serves to connect telephones and terminals to the central office in an area may for some time remain as they are. The use of pulse code modulation together with digital error-correcting repeaters is capable of greatly increasing the information carrying capability of twisted-pair telephone lines. This could significantly raise the level of local data service which can be provided without replacement of the present wire system with coaxial cable.

Possibly at some future time there will be a single broad-band circuit into each home to serve all of its communications needs. The implementation of any such system presupposes the discarding of the present system of local circuits and central exchanges. Whether it will take place in a given area as a single giant step, through the development of competing systems serving the same area, or through a separate parallel system which gradually supplants the present one is hard to predict.

XII. The Human Element

Anyone contemplating for the first time the future uses of electronic equipment in education discussed here may wonder if it will not have a dehumanizing effect. This need not necessarily be the case. In certain respects the mail, radio, television, film, publications and the telephone all diminish human contact. In other respects they increase the possibilities for rewarding contact and allow us to lead more satisfactory lives.

If we go about restructuring our educational system in a sensible way, it should be possible to remove many impediments to education and to free the student and the teacher to make better use of their time and of the contacts between them. Reduction in the amount of travel needed to study, elimination of the need to sit through class discussions of material that one already understands, access to vast libraries of information, the ability to share in videoclass discussion with people scattered over a wide geographical area, access to data banks and large computers can all serve to provide a better education and at the same time allow the student to do more on his own.

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THE PROSPECT FOR U.S. TERRESTRIAL COMMUNICATIONS IN THE 1980's

Telephone traffic has been increasing for the past decade at a rate of about 5% per year. Long-haul toll calls have been growing more rapidly; all toll at a rate of 7.8% per year and interstate calls at 10% per year. These trends are expected to continue for the next 10 to 20 years (Figure 1).

This projection leads to no absurdities, or even greatly different patterns and habits in telephone use. In 1970, calling rates in the United States were 779 per capita for all calls and 49 per capita for toll calls. In 1990, the rate for all calls is projected to be about twice the present rate and for toll, about four times the present rate. This would be a calling rate for toll which is still only one-quarter the present total rate (Figure 2).

Long-haul facility growth has paralleled traffic growth. The growth in calling rate along with a trend to longer holding times and greater average distance on calls has required a growth in facility capacity, measured in voice circuit miles, of over 15% per year (Figure 3). Projection at this rate indicates a required growth in long-haul facility capacity by a factor of 5 to 10 in the 1980's(Figure 4). Radio has been the workhorse of the last two decades, but spectrum and system capacity limitations indicate a trend to guided systems (Figure 5). A "superhighway" approach to the interstate national network will accelerate this trend and, by concentrating traffic in fewer high cross-section links, will favor high capacity low unit cost systems such as waveguide. The capacity of these systems is such that even the enormous circuit mile requirements of continued 15% per year growth will not overtax our ability to design and build facilities to meet the needs through 1990 (Figure 6).

The toll facilities plant, following the trend already well established by T-Carrier in the exchange and short-haul (> 50 mile) plant, will become predominantly digital. Digital multiplexing with access at appropriate bit rates for all existing services already exists in part. Remaining levels and codecs for a complete hierarchy are under final development and will be available well before 1980 (Figure 7). A series of digital

TRAFFIC
10^9 CALLS

	1960	1970	1980	1990
TOTAL	94.0	159.6	—	—
TOLL	3.43	7.24	17.7	39.9
INTERSTATE	1.04	2.71	7.3	17.9

Figure 1

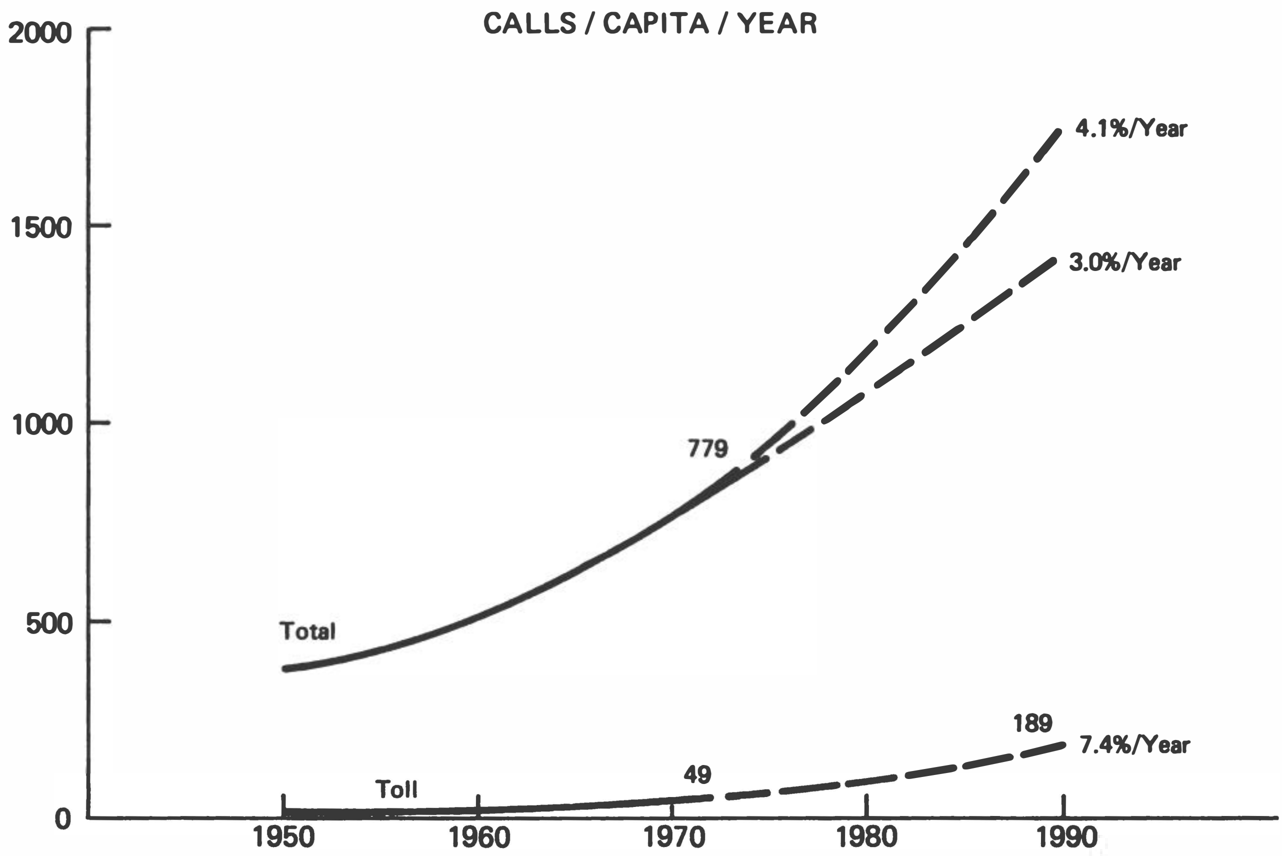
CALLS / CAPITA / YEAR
2000
1500
1000
500
0
4.1%/Year
3.0%/Year
779
Total
189
7.4%/Year
49
Toll
1950
1960
1970
1980
1990

Figure 2

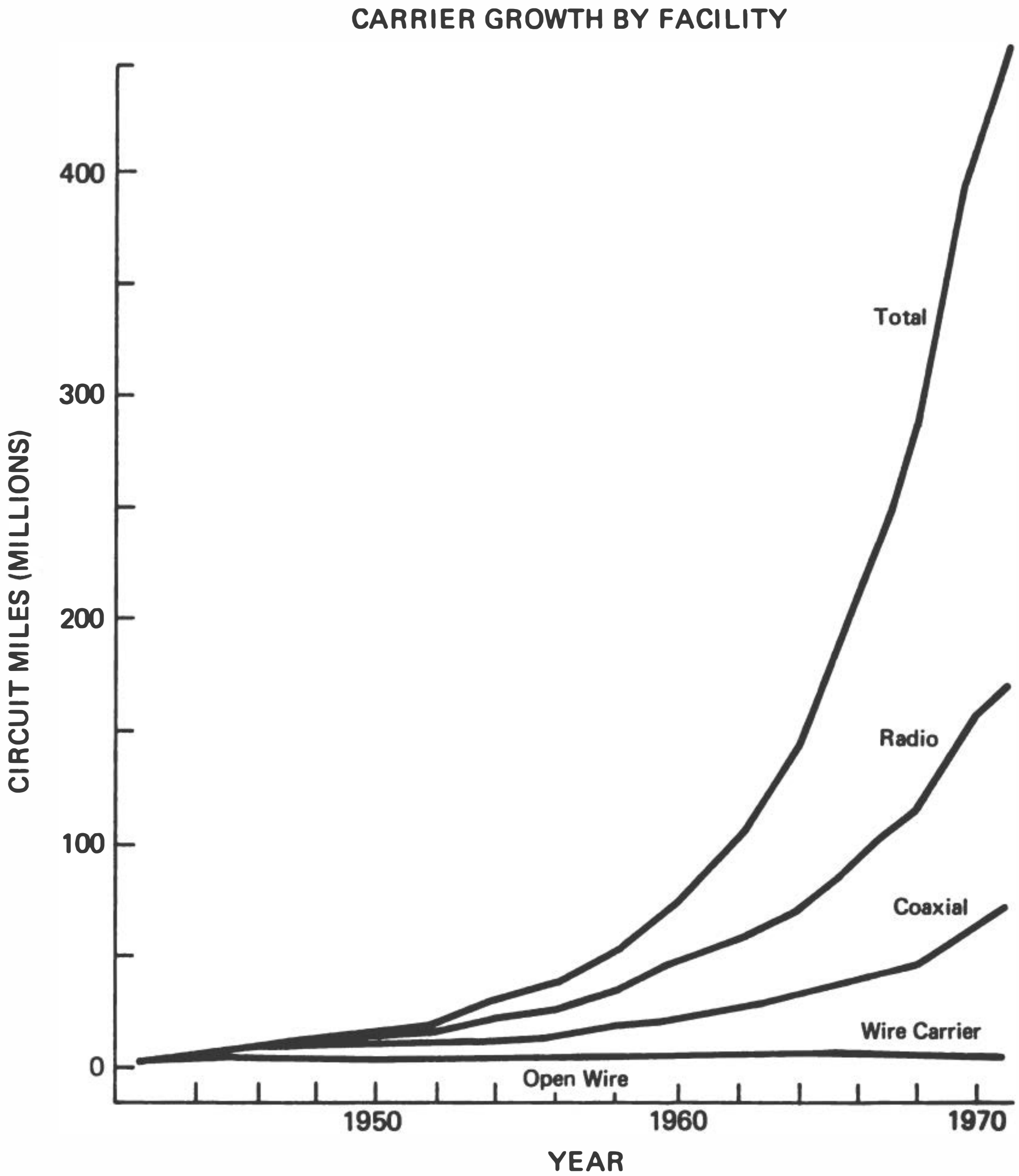
CARRIER GROWTH BY FACILITY
CIRCUIT MILES (MILLIONS)
400
300
200
100
0
Total
Radio
Coaxial
Wire Carrier
Open Wire
1950
1960
1970
YEAR

Figure 3

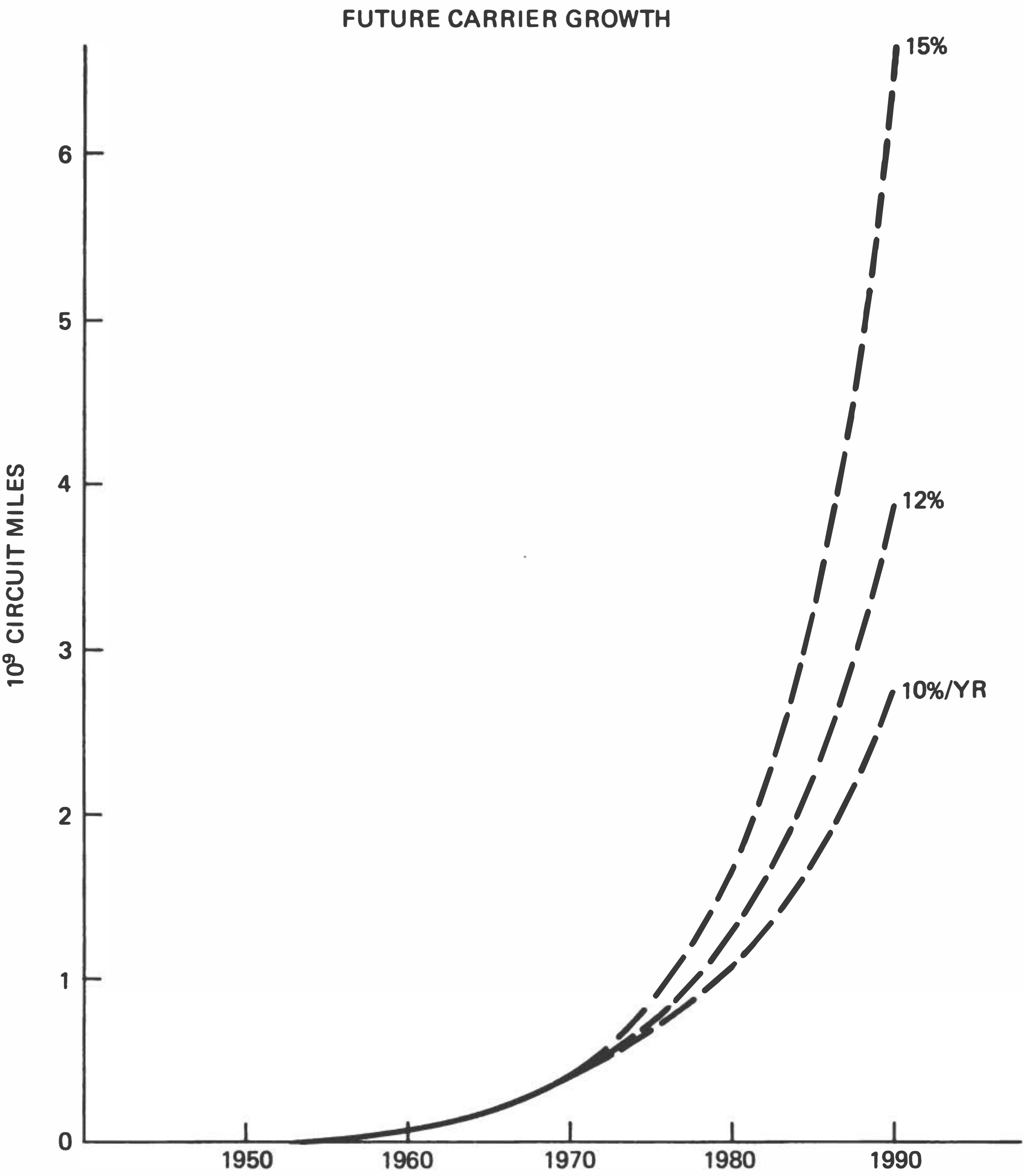
FUTURE CARRIER GROWTH
10^9 CIRCUIT MILES
0
1
2
3
4
5
6
1950
1960
1970
1980
1990
15%
12%
10%/YR

Figure 4

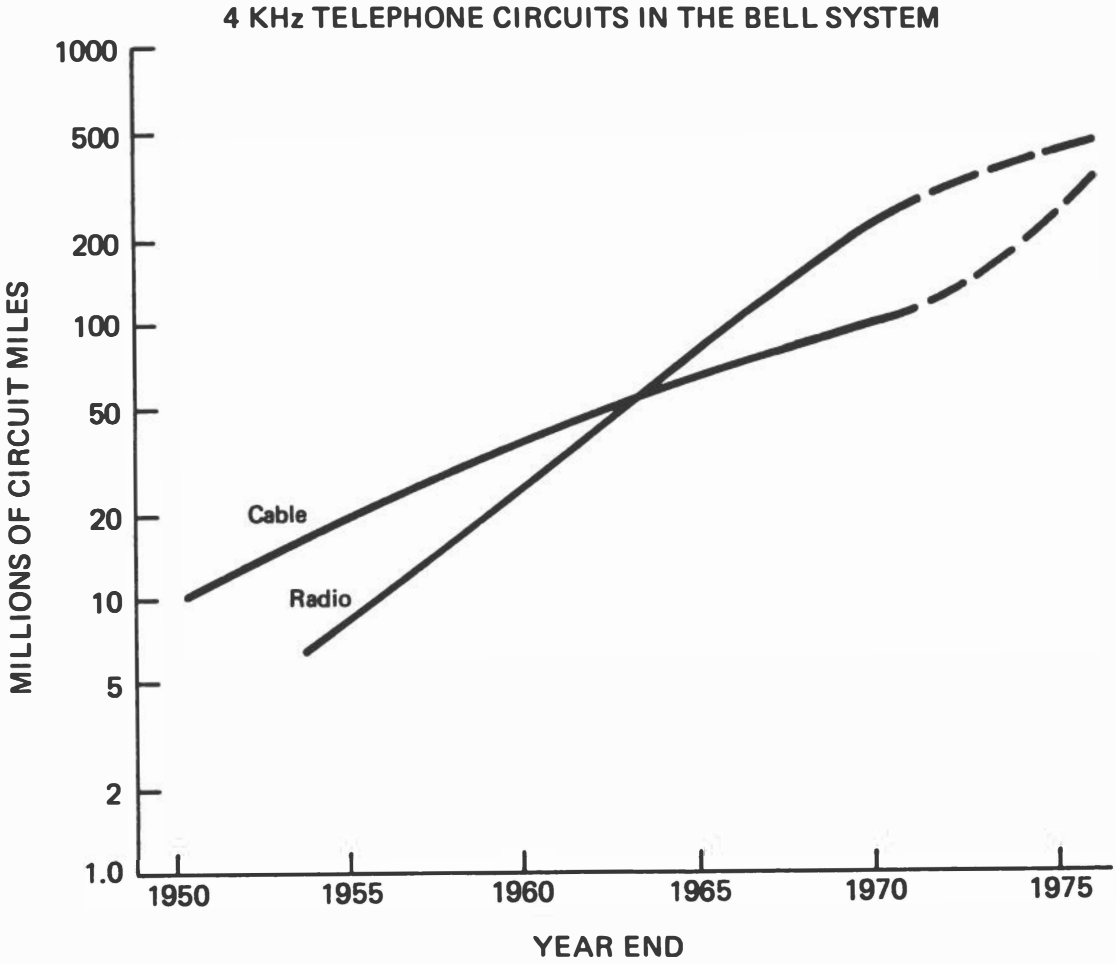
4 KHz TELEPHONE CIRCUITS IN THE BELL SYSTEM
MILLIONS OF CIRCUIT MILES
1000
500
200
100
50
20
10
5
2
1.0
Cable
Radio
1950
1955
1960
1965
1970
1975
YEAR END

Figure 5

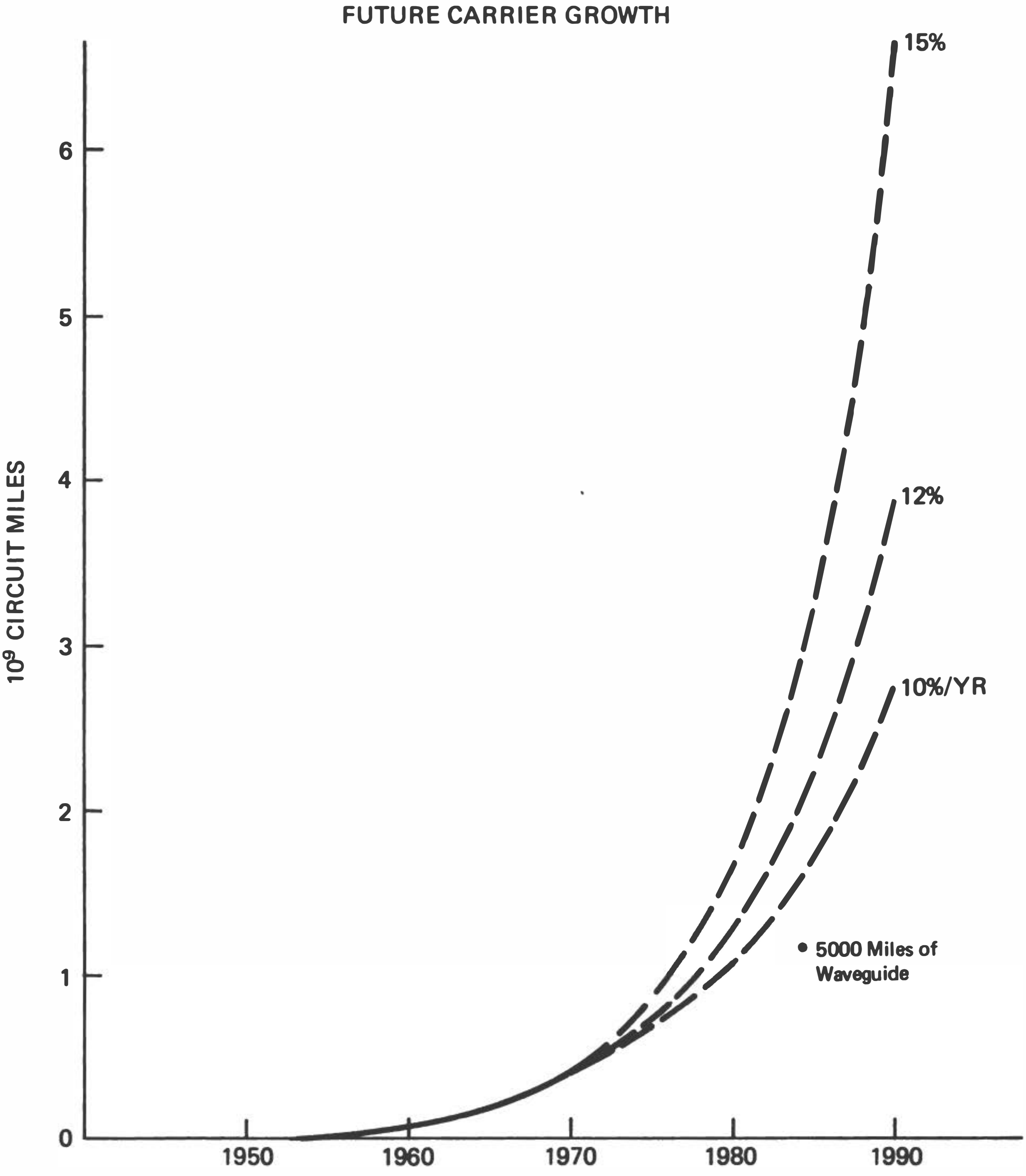
FUTURE CARRIER GROWTH
15%
12%
10%/YR
5000 Miles of Waveguide
10⁹ CIRCUIT MILES
0
1
2
3
4
5
6
1950
1960
1970
1980
1990

Figure 6

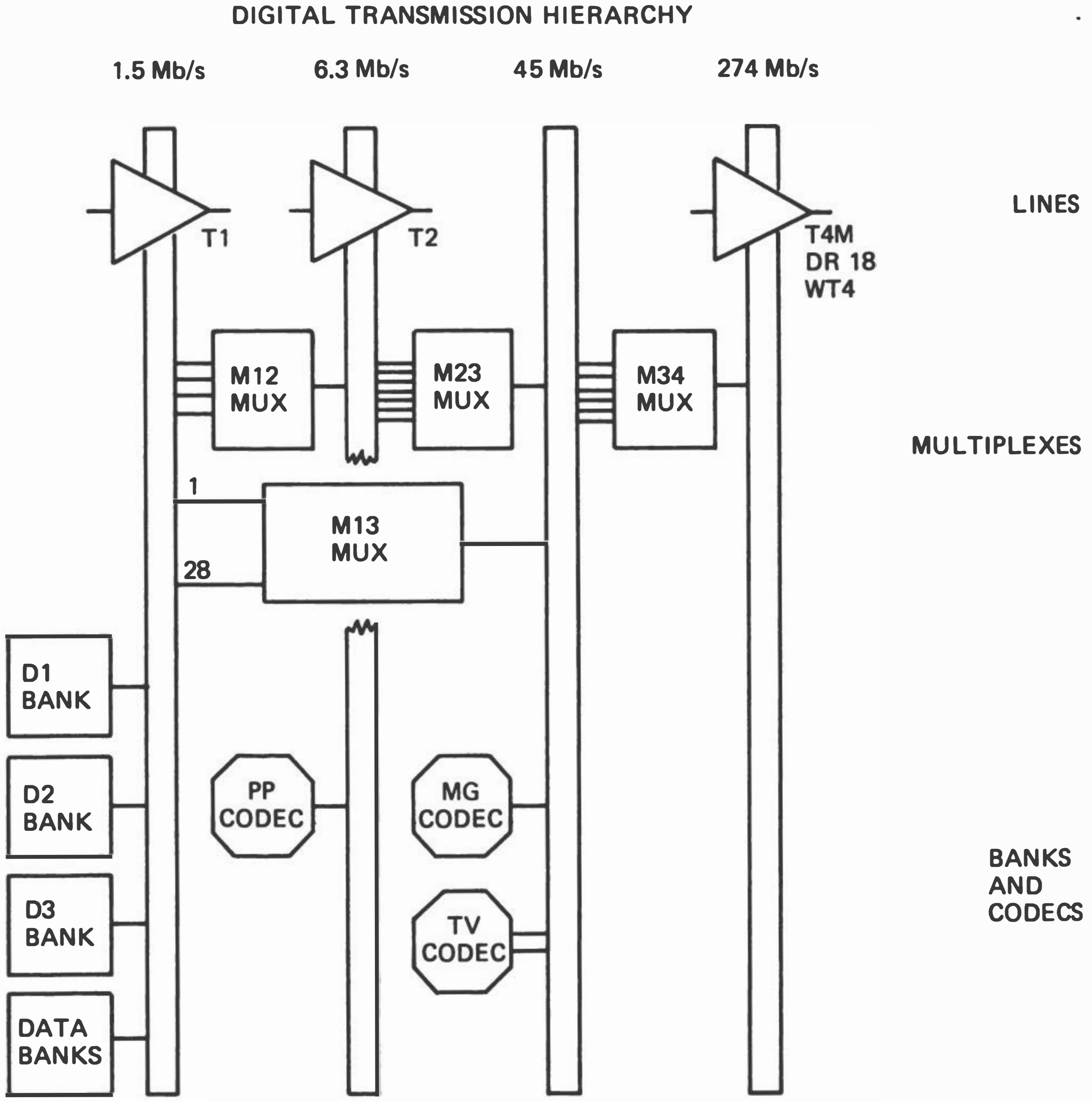
DIGITAL TRANSMISSION HIERARCHY
1.5 Mb/s
6.3 Mb/s
45 Mb/s
274 Mb/s
T1
T2
T4M
DR 18
WT4
LINES
M12
MUX
M23
MUX
M34
MUX
MULTIPLEXES
1
M13
MUX
28
D1
BANK
D2
BANK
D3
BANK
DATA
BANKS
PP
CODEC
MG
CODEC
TV
CODEC
BANKS
AND
CODECS

Figure 7

transmission systems on pairs, coaxial, waveguide, and probably domestic satellites, will become available before 1980. They will capture a large share of long-haul growth and constitute a significant fraction of the long-haul plant by the mid-1980's. Continued growth, mostly by digital facilities, will make the plant predominantly digital by 1990. The introduction of time division toll switching (No. 4 ESS) in the late 1970's and its widespread use in the 1980's will be a strong factor in favor of digital transmission facilities, but both the transmission facilities and digital switch will compete economically in an otherwise analog plant.

Exploitation of existing analog plant, as well as the large amount that will be added before digital facilities become a significant long-haul resource, will continue. Significant capacity for digital transmission can be realized by multilevel modulation in portions of the available spectrum on both radio and coaxial media. Economical mining of large numbers of additional analog circuits may be possible by single sideband on microwave radio and follow-on systems to L5 on coaxial. The extent of this may be such as to alter the timing on the spread of new purely digital long-haul plant by two to four years, but not the conclusion that the plant will be predominantly digital by 1990. The advantages of digital plant and the ultimate limitations of the analog media point to this. The nature of new media, such as optical fibers, which may be important by the late 1980's also favor the conclusion that digital transmission will prevail.

An inescapable consequence is that we will have a hybrid plant, predominantly analog in the early years and predominantly digital by 1990, but a mix for the entire decade of the 1980's and beyond. Interfacing in the local plant will continue to be at voice frequency. In the long-haul plant, a key item will be the mastergroup codec which encodes a 2.5 MHz 600-channel analog mastergroup into a 45 mb (T3) digital signal and reconstructs the analog mastergroup signal from the T3 bit stream as required (Figures 8 and 9). Encoding smaller blocks of the analog hierarchy is obviously possible, but little need for doing so is expected. The MG codec will be especially important in the early stages when a small amount of digital plant is imbedded in a largely analog plant.

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Holmdel, New Jersey

ANALOG DIGITAL INTERFACING

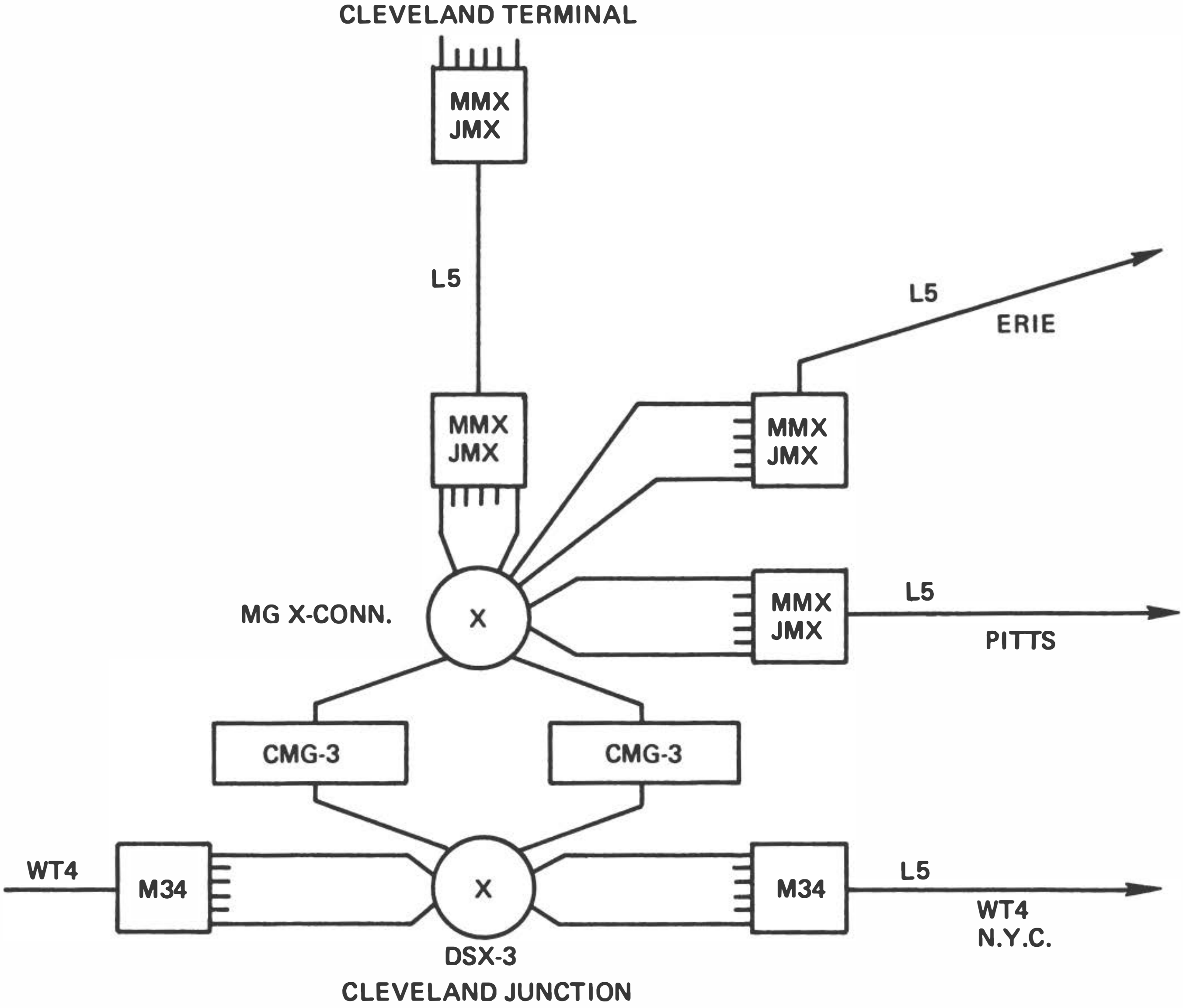
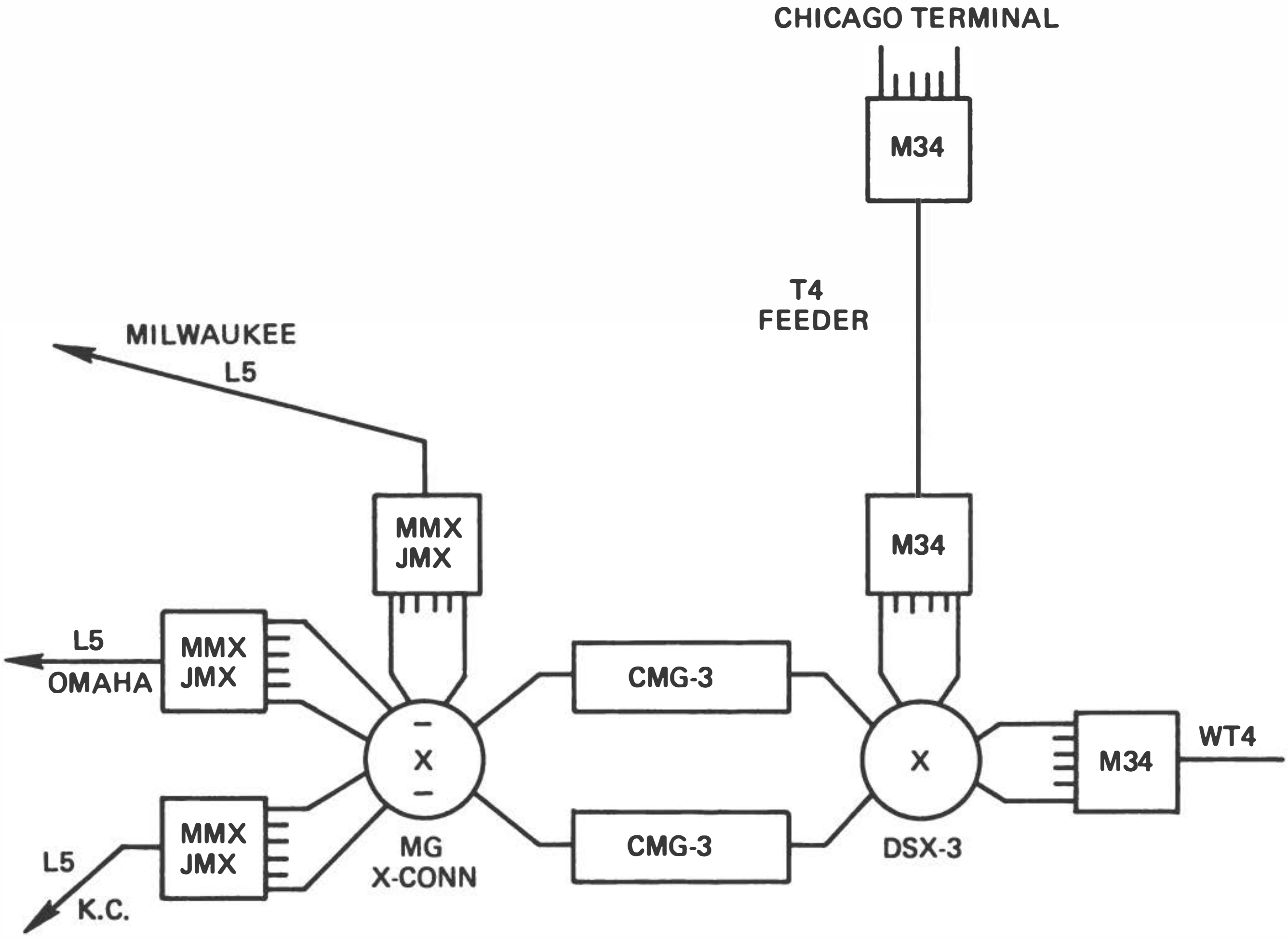


Figure 8

ANALOG DIGITAL INTERFACING



CHICAGO JUNCTION

Figure 9

OPTICAL COMMUNICATIONS

I. Introduction

The idea of using light for the transmission of information is an old one. Almost a century ago Alexander Graham Bell[1] showed that speech could be transmitted over a beam of light. He called his invention the "Photophone". However, he (wisely, it turns out) decided to stick it out with an electric current on a metal wire.

While optical communications received consideration on and off since then, the real impetus occurred a little over a decade ago with the invention of the laser - the source of coherent light. Today, research aimed at making optical communications a practical reality is being pursued vigorously in all industrialized countries. The reasons are simple and obvious: the promise of truly enormous bandwidths; possible economic advantages (sand is cheaper than copper); and small size. An examination of the progress made during the past decade toward the goal of making optical communications a practical reality[2] shows: a) that the progress has been sufficiently rapid that we are today on the threshold of potential applications; and b) that a lion's share of this progress has been achieved through research carried out in the United States. Let us examine the veracity of this statement in greater detail by examining the progress made on the various components or parts of a possible communication system.

II. Sources

In any communication system there is a source of the carrier over which information is transmitted. In an optical communications system the source will be either a laser (a source of coherent light), or a light emitting diode (LED). Over the past decade, literally dozens of various lasers have been invented and developed to various stages of sophistication. It is striking that almost every laser of possible use in optical communications had its birth and was subsequently developed in the United States. The very long list starts with the pulsed ruby laser (at Hughes Research Labs); through the first cw gaseous He-Ne

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1) A. G. Bell, "Selenium and the Photophone", The Electrician 5, 214 (1880).

2) By "practical reality" is meant a system or systems of interest and use to telecommunications utilities that can compete successfully with present methods of communications. In some important sense "optical communications" *is* a reality even today. For example, the lunar laser ranging experiment accomplished by the Apollo mission represents an optical communications system.

laser (Bell Labs); the ion lasers (Hughes); the Nd doped glass and YAG lasers (Bell Labs); the CO_2 laser (Bell Labs); the semiconductor injection laser (IBM, GE, Lincoln Labs); the parametric oscillator (Stanford U.); the heterojunction GaAs-AlGaAs laser (Bell Labs); the dye laser (IBM). Others have made their contributions, to be sure. For example, the TE excitation of CO_2 lasers came from Canada, electron beam excitation received greatest attention in the USSR and very high power pulsed lasers (not really of much direct use in communications) in France and the USSR. But obviously the lion's share of the progress occurred in the United States. The U.S. industry today dominates the commercial laser market. It is also striking how broadly based this expertise in laser technology is in the United States. It is not limited to any one, or even half a dozen laboratories. The same is true of the LEDs.

For reasons to be stated later, the most promising candidates for use as sources in a practical communication system are: 1) the heterostructure GaAs-AlGaAs injection laser; 2) the Nd-YAG laser and a miniature LED. All of these emit adequate power (one would like more) at adequate efficiency (one would like more). Reliability, life, and cost remain a problem and must be improved.

III. Transmission Medium

Fog, rain and snow and other vagaries of the weather affect the transmission of optical waves through the atmosphere and, except for special application (transmission in space where there is no weather or for very short distances) the use of atmosphere as the transmission medium is not likely to prove practical. The use of lenses - either discrete or distributed (gas) - in shielded ducts remains a possibility. Such systems have shown to be technically feasible again through research carried out in the United States (primarily at BTL). Economically they might be viable only if and when very large capacities are needed (hundreds of thousands of voice circuits). Such needs are well in the future.

For more immediate application the optical fiber is thought today to offer the best promise as the transmission medium. It was Lord Rayleigh who first pointed out that dielectric waveguides will guide light. But the more modern impetus came from the research sponsored by the British Post Office at STL in England. The modern fiber consists of a central core and a dielectric cladding whose index of refraction is lower than that of the core. The developers of this medium first faced the seemingly unsurmountable problem of reducing horrendous optical absorption losses. No more than five years ago the best optical fibers showed losses of hundreds of decibels per kilometer. But here, too, progress has been phenomenal. Liquid-filled optical fibers (developed at BTL and Australia) exhibit losses of less than 15 db/km and the best glass fiber most recently announced by the Corning Glass Co. shows a loss of only 4 db/km near 0.8 μm and 1.05 μm region of the spectrum (where the GaAs, the Nd-YAG and the LEDs operate).

Such low-loss fibers are already adequate for a variety of applications. But a myriad of problems remain to be solved. To mention just a few, we must learn how to control dispersion (here the Japanese Self Foc fiber is noteworthy), how to make sturdy cables out of the fragile fibers, how to splice such cables, and how to connect sources and other optical devices to such fibers.

IV. Modulators, Detectors, etc. and Optical Repeaters

The simplest optical communication system must have, in addition to the source and the transmission medium, a modulator of some sort and a detector. In more complex systems, optical repeaters will be required. The basic physical principles on which the operation of all these devices rests is, of course, well known. But in order to optimize the various devices, a body of knowledge has had to be developed on how light interacts with matter, and new materials have had to be invented which enhance the useful aspects of this interaction. An excellent example of the interaction of the quest for basic knowledge, the invention of new materials and construction of useful devices is the work leading to efficient electrooptic modulators. First there was quite extensive research on the physical nature of the electrooptic effect; new and/or exotic materials were examined and studied (for example $LiNbO_3$, or the "bananas"). As a result, the improvement in modulator efficiency has been dramatic. It is now almost, but not quite as good as that in the microwave range of the spectrum.

The accumulation of the body of knowledge on how light interacts with matter is now well on its way, again primarily through research in the United States. Here universities, industrial research laboratories, as well as government laboratories all have made important contributions. While the quest for this knowledge is far from complete, modulators and detectors can be built today which would be adequate for a communication system. Undoubtedly they will improve with time. An important contribution to this improvement will come from the new concept of integrated optics - a technology originated in the United States within the past few years.

In summary, in the field of research and development leading to practical optical communications, as in almost any other area of telecommunication R&D, the United States has no equal. Its R&D enterprise is broadly based in universities, industry, and government labs. Although it has not been possible to generate dollar figures, judging by the results, the enterprise has been adequately supported from a variety of sources. This enterprise has performed well in the past, and if not tinkered with, is likely to perform equally well in the future.

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Holmdel, N. J.

OPTICAL COMMUNICATIONS - IN THE 70'S AND BEYOND

I. Summary

Recent forecasts by the Stanford Research Institute (SRI)[1] and others have indicated growth or trends for telecommunications traffic over the switched network as more than doubling during the remainder of this decade. Although much of this expanding traffic can be accommodated by multiplexing and digital techniques over existing networks, the rapid growth of wide band services, principally video, cannot be readily accommodated on existing transmission systems without loss of quality of pictures, or degradation of information due to cross talk, bandwidth limitations, etc.

To compound the transmission difficulties, proposals are being made for additional services, mainly wide band video and other wide band transmission services which will some day be introduced as part of the "wired city concepts" for distribution through the "local loop" plant. (See references to articles by E. B. Carne, P. Goldmark, J. R. Pierce, etc.)[2,3,4] and the excellent report by the NAE Committee on Telecommunications, "Communications Technology for Urban Improvement."[5]

Alternative wide band communication transmission systems are discussed in this memorandum, namely, "optical transmission" applying coherent or incoherent light sources, optical planar dielectric waveguide technology (integrated optical subsystem) and fiber optics, as the basic components for wide band information transmission as compared to the circular low loss millimeter waveguide system being developed by the Bell Laboratories.

II. Traffic Forecasts

An SRI report, "A Study of Trends in the Demand for Information Transfer," February, 1970, by R. W. Hough, C. Fratessa and others, was prepared for the National Aeronautical and Space Administration, under Contract NAS2-5369 and SRI Project MU-7866. In tabular and graphic form reproduced from this report, is given the projected information transfer over the switched network for 1980 and 1990 as compared to 1970 (see pages 119 and 120). The expression chosen for this common denominator is bits (binary digits) per year. The method of conversion entailed first an assumption about the information transfer mode most likely to be used for the service - voice, video, alphanumeric coding, standard facsimile, high quality facsimile (newspaper and photo), etc. Next, a standard conversion method was assumed for each mode of operation, such as 30,000 bits per page for alpha coded text, 64,000 bits

Table 1

PROJECTED INFORMATION TRANSFER VOLUME, 1970-1990

(Bits per Year)

	1970		1980		1990	
	Total	Long Distance	Total	Long Distance	Total	Long Distance
Voice (x 10^{17})	20	1.0	50	37	100	10
Video (x 10^{16})	0.56	0.33	9.0	1.5	230	25
Record, data, and private wire (x 10^{15})	0.38	0.34	3.5	3.1	30	27
Written (x 10^{15})	15	10	20	14	30	21

Table 2

CLASSIFICATIONS USED TO SUMMARIZE RESULTS OF THE STUDY

Voice Telecommunications

- Telephone
- Mobile Radiotelephone
- Radio Program Transmission

Video Telecommunications

- Videotelephone
- Closed Circuit and Other Special Television Services
- Television Program Transmission

Record, Data, and Private Wire Communications

- Public Message Telegraph
- Teletype service (TWX and TELEX)
- Data Transmission
- Private Wire Systems

Written

- Books and Magazines
- Newspapers
- Mail

PROJECTED INFORMATION TRANSFER VOLUME, 1970-1990

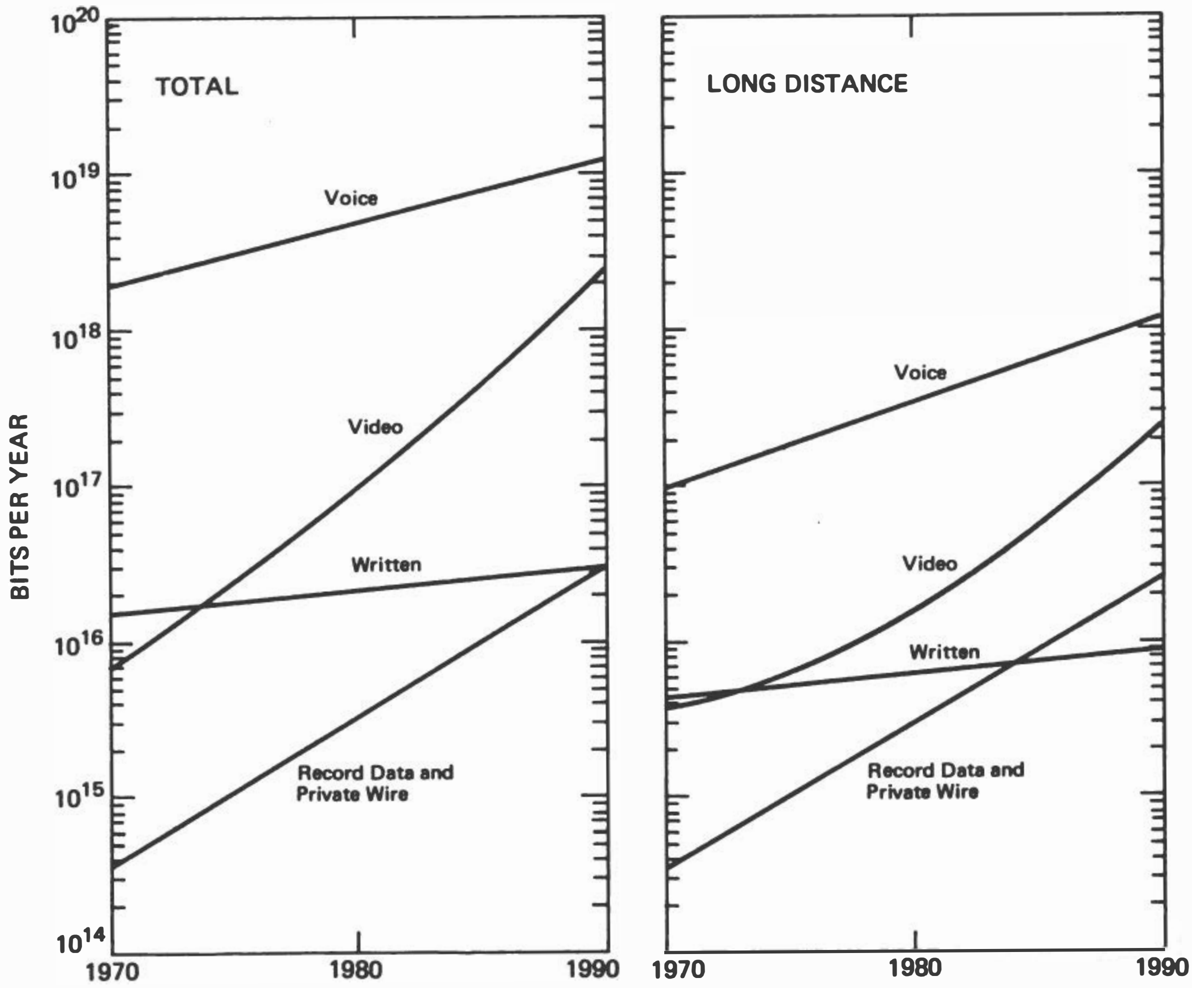

Figure 1

per second for voice (assuming conventional PCM coding), and 130 megabits per page for high quality newspaper facsimile. Finally, those factors were applied to the volume of transactions that had been projected for the various services. The result, then, was a statement of potential information transfer volume expressed in all cases in bits per year.

It may be noted from the data presented in the tables, that the volume of voice transmission is presently greater by two orders of magnitude than all other information traffic combined which is being transmitted in 1972. However, voice transmission appears to be following demographic trends while video is growing at 35% per year and data at approximately 25% per year. Data does not yet appear to be a factor in clogging up the transmission medium, except for the problems it presents in the form or kinds of modulation required and the problems of multiplexing. Video is another matter entirely when one recognizes that a single 6 MHz television channel will require 100 megabits/sec., or at least 50 MHz in channel bandwidth[6] and a 1 MHz video phone channel would use up 6 megabits/sec. or approximately 3 MHz of bandwidth of an existing transmission medium. These are very large bandwidth bites out of the existing radio transmission links.

According to E. Bryan Carne[2], by mid-1980 "a wide range of services could be made available for the business community," such as videotelephones, interactive TV electronic mail, data services, etc., if cost and transmission become feasible. With the additional requirement on bandwidth, how much further will the present transmission networks be taxed, particularly if to this new "wired city" one adds additional network traffic such as the following:

- community affairs traffic (newspaper-like)
- educational traffic
- medical traffic
- community management traffic
- transportation information traffic

Where will this transmission capacity come from, or how will the introduction of the above-mentioned new wide band services be affected by insufficient transmission capacity? How will such services be switched through the network? These are among the hard questions of great concern to the telecommunications industry and the people it serves, namely, all of us. In the following section we will look at some alternate projected transmission technologies that may soon be put into practice, or that can be "made to happen" if sufficient stress is applied by the research arms of the telecommunications industry and by proper assists from the various government agencies.

III. New Developments in Transmission Technology

As discussed earlier it now appears from the "trend tables," compiled by various investigations that continued growth of traditional voice and data services at present rates will demand this doubling of present transmission capacity in less than ten years. Much of this increase can be accommodated by multiplexing the existing plant, mostly by digital techniques. On the other hand, high quality local video service presents technical and economic problems that need to be solved by long-range research. The latent demand for video transmission appears to be very large. If the price can be made reasonable and the quality improved substantially, there should be a considerable market for these services.

The present loop plant has very limited capability of carrying video signals without developing excessive cross talk between the video and audio channels.

A. Projected Technologies

A number of new communications techniques for higher bandwidth are in various stages of development in laboratories throughout the world.

The major ones are:

- Optical Fibers
- Laser Links
- Circular Millimeter Wave Guides
- Light Pipes
- Digital Microwave
- Improved Satellite Links

B. Millimeter-Waves and Optical Transmission

Communications engineers know that as the carrier frequency goes up, the amount of information that can be carried out on the carrier also increases. Since the frequency of light (10^{14} - 10^{15} cycles/sec.) is several orders of magnitude greater than that of microwaves (10^9 - 10^{10} cycles/sec.), then the potential for information capacity can be enormous. Earlier efforts to about 1964 or 1965 demonstrated optical communications experiments with modulation, detection, and simple transmission through the atmosphere, and the ability to carry one or even several TV signals over a laser beam.

This capability, however, had some drawbacks. Laser light was, after all, "light." A laser beam is readily scattered by the atmosphere in conditions other than absolutely clear such as clouds, rain, or smoggy weather. The conclusion with regard to the mode of transmission was that the laser beam would necessarily have to travel through a pipe, or other friendly medium, and lenses and mirrors would be required to keep the beam directed along its chosen path, a costly and technologically difficult procedure. Also, the optical components which were developed to provide modulation or detection themselves placed restrictions on the bandwidth that might be usefully employed in communications systems. At Bell Laboratories (in 1966), where much work had been going on to take advantage of the coherent and narrow spectral distribution of laser beams, priorities for communications appeared to shift to the circular wave guides as the wide band transmission carrier, in spite of the recognized technological problems and inherent high cost of such systems.

An excellent presentation of the Bell Laboratory efforts in optical communications technology is the paper by R. Kompfner, Optics at Bell Laboratories - Optical Communications. In his article Dr. Kompfner outlines the history of R&D in optical communications at the Bell Laboratories from pre-laser days to the present. He also speculates on when optical communications systems will pass beyond the stage of engineering feasibility into the realm of practical applications.

Circular waveguides are now emerging from the laboratories into field trials. They are exclusively long-haul, very wide bandwidth systems (240,000 voice or 180 TV channels). Cost per channel will not be competitive until about 50% of the capacity is used. The minimum bending radius of the waveguide is 200 feet, making it useless in congested areas. Incidentally, hollow light pipes would have the same kind of problems as circular wave guides with respect to bending radius. They do not appear at present to represent a serious approach.

C. State-of-the Art of Optical Communications

Optical fibers represent a very promising approach to the wide band transmission system.

- In local distribution networks fibers will permit wideband video transmission with very small demands for duct space. (Bends can be as sharp as a few centimeters in radius.)

- On interexchange trunk routes fibers can carry large amounts of voice, video and data, again with small duct space requirements.

- If\optical multiplexing techniques can be developed, fibers will prove useful on toll routes for carrying medium or heavy loads. The potential bandwidth available in an optical system surpasses the circular waveguide capacity.

D. Optical Fibers for Information Transmission

Although optical fibers have been in use for several years, their high attenuation (1000 db/km) had limited their use to special applications requiring only a few meters of transmission. The discovery[7] by Corning Glass Company less than two years ago that fibers could be made exhibiting losses less than 20 db/km has spurred work on fiber research in many laboratories throughout the world. In addition, the virtual certainty that low loss fibers will eventually become commercially available has triggered work on the many other components necessary for an optical communications system.

Optical fibers can propagate either a single light mode (if their diameter is small enough) or many modes. A typical single mode fiber may have a core of only two microns diameter surrounded by a cladding of much larger (several mils) diameter and very slightly lower refractive index. The small diameter makes coupling of light into the fiber difficult, and only coherent laser sources can be efficiently coupled. However, the inherent bandwidth is limited only by the dispersion of light velocity in the fiber medium over the wavelengths contained in the message. Limiting bandwidths of 10 GHz have been predicted. Corning has developed single mode fibers in 600-foot lengths with extrapolated attenuations of less than 10 db/km.

Multimode fibers have core diameters in the order of 100 microns. This allows efficient coupling to less expensive light sources such as LED's. However, the different modes propagate with slightly different velocities, resulting in considerable dispersion of the signal and limitations of bandwidth. BTL studies of certain multimode fibers indicate a limiting bandwidth of 30 MHz for 1 km length. This limitation may be significantly reduced by a structure[8] produced by Nippon Sheet Glass Company in which the refractive index decreases radially from the fiber center. This has the effect of self-focusing the light (hence the name SELFOC) and equalizing the path lengths, thereby reducing the dispersion. This fiber is available commercially in 200 meter lengths with attenuation less than 100 db/km. Laboratory samples of 40 db/km have been made.

The lowest attenuations reported have been for fibers with liquid cores (BTL 13.5 db/km, and University of Southhampton, England 10 db/km, Australian Government 5-7 db/km). These fibers are relatively easy to make with low attenuation, but their practicability in a system is unknown. Most recently Corning has reported a loss of only 4 db/km for a glass core fiber.

Laboratory techniques have been evolved[9] at BTL and at Corning for splicing fibers with high optical throughput (97%). However, this requires sub-micron tolerances. Field splicing of fibers will clearly demand sophisticated techniques.

At the Electro-Optics Conference, September 1972, in New York City, several of the participants expressed strong confidence in adequate solutions to losses in single and multi-mode fibers, ability to provide low loss couplers, approaching the simplicity of UHF connectors, and the ability to achieve wave guide bundles for spatial distribution, etc. It was Corning's belief, backed by a sizable expenditure on fiber optics technology, that the day will come when the fiber bundle will replace coaxial cable economically for a large number of video and other wide band applications.

To provide the light beam, light emitting diodes (LED) appear to represent the best sources for multimode fibers. Burrus[10] had developed a high radiance (small emitting area) LED and coupled it into a multimode fiber with an over-all conversion efficiency of 0.6%. This particular LED is presently limited in conversion efficiency, power output (2 mwatt), and life (3000 hours).

For single mode fibers, lasers are necessary and no clear choice can be made. Double heterojunction diode lasers[11] perhaps have the most promise, if their very short lifetime (less than 100 hours) can be overcome. Other types under consideration include thin film lasers pumped by LED's and miniature gas lasers. The problems in all of these are somewhat formidable at the present time.

Assuming that lasers will be developed which are economic in price and have reasonable conversion efficiency and power, a modulator will be required in order to impress the information onto the light (LED's and diode lasers can be modulated directly by varying the current). While bulk modulators have long been known[12, 13], they are unsuitable both physically and economically for a practical system. A useful optical communications system will require optical signal processing and detection components which are rugged, efficient, and which can perform identical functions to that of their electrical counterparts.

Thin film integrated optics consist of a deposition of thin optical film onto a substrate. The films may be amorphous or single crystal, and in some cases semiconductors. Thicknesses are of the order of the wavelength of light, approximately

1 micron. The uniformity and optical behavior of such film make possible wave guiding of light, coupling, and frequency mixing. The technology is just in its earlier stages, having begun in 1969-1970. Success with integrated optical devices will provide many of the principal components which can serve as building blocks for a fully multiplexed PCM system at data rates impossible to transmit along coaxial lines.

E. Optical Detectors

Silicon avalanche detectors are commercially available with gain-bandwidth products of one hundred GHz and with quantum efficiencies of 50% or better. The detector, therefore, does not represent a present technical bottleneck, although substantial cost reductions are necessary before an optical communications system could be economically viable. Recent developments of an extremely fast photomultiplier called the dynamic crossed-field photomultiplier (DCFP) makes possible direct optical detection to 1.2 GHz.[14]

IV. Program Considerations

Programs to consider for monitoring and support to meet the needs for wide band services include:

A. Fiber Technology

- Develop and evaluate fibers for attenuation and dispersion.

- Perform coupling and splicing experiments.

- Investigate fiber handling techniques, including sheathing of fibers.

- Perform theoretical studies on fiber bandwidth and attenuation.

B. Light Sources

- Develop high radiance LED's which may be directly modulated.

- Study possibilities for film lasers and recommend most likely candidates for development (such a laser would be complementary to thin film modulation techniques).

- Develop diode injection laser specifically for communications purposes. Power, life, and spectral output would be tailored to wide bandwidth requirements.

C. Modulation

- Develop thin film modulator.

- Develop coupling techniques.

- Theoretical work to optimize modulator and coupling designs.

D. Multiplexers

- Development of optical multiplexers and demultiplexers.

E. Electronic Subsystems

- Development of drivers for PCM modulators.

- Development of signal processors for high bit rates, 100 Mb/sec.

F. Demonstrations of Wide Band Systems

- Suggest and implement vehicles to demonstrate optical transmission and multiplexing.

V. Concluding Remarks

It is becoming increasingly evident by many studies of trends in the usage of the electromagnetic spectrum for telecommunications that bandwidth requirements are rapidly expanding and may soon become self-limiting due to overcrowding of the available information transmission channels. Exploitation of higher and higher frequencies into the millimeter waves is well under way, but will entail expensive hardware and installation costs demanding almost from the beginning a high utilization or fill factor to be economical. For other practical reasons such wide band services provided by circular millimeter wave guide cannot readily be installed in built-up areas, areas which may be the early heavy users of video and high data rate services.

The emerging technologies of low-loss fiber optic transmission lines, small efficient lasers or LED's, integrated optical components for modulating and detecting, may provide the answer to almost unlimited bandwidth and signal handling, as well as high degree of flexibility, gigahertz bit rate per second, and economic telecommunications systems for the urban communities.

Many laboratories throughout the world are considering in piecemeal fashion the various components. Corning, Schott, Bell Labs, Bendix, American Optical, and others are doing glass fiber development for low-loss optical transmission. Processors and modulators, and other integrated optical circuits are being studied in the laboratories at GTE, Bell, Hughes, Zenith, North American Rockwell, and many others. And, similarly, developments in fast optical detectors capable of stripping off hundreds of megabit/second signals from a carrier are being worked on at still other laboratories. A few large laboratories, like Bell or GTE, whose prime concern is to upgrade their telecommunications services, are examining the communications system in its entirety, as well as the components needed.

From the numbers of documents made regarding optical communications by the various members of the Telecommunications Research Panel, it would be desirable that the interested parties constitute themselves a Task Force on Optical Communications to review and recommend to the full Panel:

1. Whether optical links are a viable approach to wide band services.

2. Who is doing what.

3. Where are the gaps in technology or systems approaches.

4. And if they are worthwhile, what incentive or support could be offered to implement these needs.

The key to success will be the intensive research on materials and phenomena, with the same intensity as was required to make the integrated circuit field successful.

To provide impetus and incentive, the Panel on Telecommunications Research may find it useful to recommend certain of these programs for NSF support, and better yet, to set goals to tax the existing state of art on "telecommunications systems needs" where crowding of bandwidths, crowding of space, flexibility and social needs set the requirements for the extension of the radio frequency spectrum for telecommunications into the optical spectrum.

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R&D TRENDS FOR COMMUNICATIONS SATELLITES: COMPARISON OF U. S. AND OTHER PROGRAMS

This paper will cover a) major goals of communications satellite design; b) the approaches to be taken toward meeting these goals (in the process of spelling these out the R&D work needed will be apparent); c) status with respect to other countries in the field, and d) conclusions.

I. Goals

These can be stated quite simply as the desire to get more and more channels per satellite and to produce these at lower cost per channel.

II. Approaches

The general approaches can be estimated by looking at the trends from the first satellite through the present and extrapolating these. Early Bird started using a toroidal antenna pattern in which most of the energy was radiated away from the earth. Also, its bandwidth was only about 10% of that then allocated to communications satellites. Since that time the trend has been to satellites which fully utilize the allocated 500 MHz bandwidth and have directional antenna beams which illuminate the earth only, as well as narrower beams covering one sixteenth of the visible earth.

The point of diminishing returns has already been reached as far as obtaining more channels by means of satellite radiated power. For example, in Intelsat IV, by going from a global beam to a spot beam a 16-fold increase in radiated power is obtained, but only a doubling in channel capacity results because of the limited bandwidth. In the future the trend will be to increase effectively the allocated bandwidth by using multiple antenna beams so designed that their overlap is sufficiently low so as to permit reuse of the spectrum in each beam. Thus, the use of four beams would yield a 4-fold increase in capacity per satellite.

Sufficient work has been done to show the practicability of simultaneously using two polarizations in transmissions to and from the satellite. This provides another doubling of capacity for a given bandwidth.

Work is underway on time division modulation methods to achieve greater numbers of channels per repeater and also to permit interconnection of the various beams.

Beyond this, the 1971 World Administrative Radio Conference allocated bandwidths at 11 and 14 gc; and at 20 and 30 gc to the fixed satellite service. The first pair of bands total 1000 MHz, the same as the presently allocated 4 and 6 gc bands, while the bandwidth of the latter pair is five times as great. This should permit a 6-fold increase in channel capacity. Work is needed to develop suitable satellites and earth station RF components for these new bands; and also to improve our knowledge of propagation at these frequencies.

Considering the above, a satellite including a number of beams could have a total two-way telephone capacity in the order of 1/4 million circuits. In addition to working on the communication aspects mentioned above, work will proceed on the spacecraft aspects of trying to get more power from a given weight-size satellite. This, coupled with development leading to light-weight components, should ultimately permit a given capacity to be obtained in a smaller satellite, thus further decreasing the cost per channel.

Improvement in reducing earth station antenna sidelobes would be useful in permitting closer satellite spacing along the geostationary orbit. Similar work on satellite antennas should permit closer spacing of illuminated areas on the ground.

III. Foreign Communication Satellite Activities

A. Canada

Canada started in the communications satellite area by designing and building the communications repeaters for the Relay satellite in 1961, and also the Alouette scientific satellite in the same period. Some subsystems for the Intelsat IV satellite were built in Canada. More recently, in November 1972 the Canadians launched a satellite for their domestic use. This satellite was built by Hughes and was launched by NASA for Canada. Several dozen earth stations have been built, ranging in size from 25 foot to 97 foot diameter antennas, with the majority of them being of the smaller size. A substantial number of these stations are of Canadian manufacture, but for the most part the Canadian manufacturers are subsidiaries of, or affiliated with, American companies. The system will be used for transmission of TV and two-way telephony.

The Canadians and NASA are jointly working on an experimental "Communications Technology Satellite." Canada is to build the entire satellite, except for the 200 watt 12 gc power amplifier. NASA is to supply the Delta rocket and the 200 watt amplifier. The satellite, to be launched in late 1975, will be used for the experimental transmission of TV to small stations. ESRO (European Space Research Organization) is supplying a 20 watt traveling wave amplifier and flexible solar cell arrays to the Canadians for use on this satellite.

B. France/Germany

In order to provide a background in satellite technology for French and German industrial concerns, the Symphonie satellite project was started in 1967. Two flight models were to be built for launch in 1972 in connection with the satellite and rocket (Europa II). This rocket, the first model of which was launched early in 1972, failed and several major subsystems have to be redesigned. Because of this, it has not yet been decided whether to continue with this rocket or to use an American Delta rocket to launch the satellite. The schedule has slipped from 1972 to late 1973, or possibly early 1974. The cost for development and construction of two satellites and two rockets had risen from the original $65,000,000 to about $150,000,000 by early 1972. By comparison, the cost of developing, building and launching eight simpler Intelsat III satellites each of about three quarters the weight, including the cost of eight rockets, was about $100,000,000.

The Symphonie satellite itself will weigh about 450 pounds, which is well under the 600-700 pound capacity of the Delta rocket. It will have two repeaters of 90 megacycle bandwidth and two elliptical beams, one covering most of Europe and Africa and the other covering most of South America and the eastern part of North America. The satellite will be stabilized with a momentum wheel, an approach which has been used in the American ITOS series. Both French and German manufacturers have built subsystems for the Intelsat IV satellites.

C. Italy

In 1967 Italy initiated the SIRIO program which called for the development, construction, and launching of a geostationary satellite for space research on physics of the magnetosphere and propagation experiments in the 11/18 gc region (which was being considered for communication satellites at the time). This program has been delayed so that the original launch date of the last quarter of 1971 is now scheduled for the first half of 1974. The satellite itself is technically somewhat similar to the Intelsat III, but would operate at millimeter wavelengths, and use a narrower beam antenna. Italy has participated in Intelsat IV subcontracting work.

D. Japan

Japan has plans for a communications satellite to be launched in the 1977 period. A contract for system engineering and preparation of specifications for this satellite has been awarded to Philco-Ford, but it is likely that the satellite would be designed and built in Japan. A Japanese manufacturer has also built subsystems for the Intelsat IV satellite.

E. United Kingdom

The award of a 6-month project definition phase contract for the U.K. Geostationary Technology Satellite (GTS)* has been announced. The project definition phase is for approximately £0.5 million and is expected to lead to a development and construction contract in the amount of £15-20 million for a 1976 launch using a Delta rocket.

The satellite will be 3-axis stabilized and will utilize the same 5.5 foot diameter antenna for 12/14 GHz coverage of the British Isles and offset L-band feeds for elliptical coverage of part of the North Atlantic for maritime communications experiments. The TV broadcast experiments will involve primarily propagation investigations as well as the utilization of various ground antenna sizes for community and direct-to-home TV receptions. Several British manufacturers have built subsystems for Intelsat IV satellites.

F. U.S.S.R.

The U.S.S.R. launched its first communications satellite, Molniya I, in 1965 and since then has launched at least 20 of

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*Previously named the U.K. Applications Technology Satellite.

this series. Based on the available information, this satellite is primarily used for TV transmission to several dozen earth stations inside the U.S.S.R., but it also has the capability for limited telephony transmission. The orbit is elliptical, with approximately a 12-hour period, and an inclination of 64° North, resulting in an apogee of about 24,000 miles which focuses the satellite on the Northern Hemisphere and provides coverage over all Northern latitudes. Transmission is in the 900 MHz region.

Reports have been received of the launch of a more advanced communications satellite, Molniya II, with a similar orbit, but higher capacity repeaters in the 3400 to 3900 MHz band. In 1968 the U.S.S.R. filed with the International Frequency Registration Bureau for allocations in this band for a geostationary satellite, "Statsionar" to be launched by the end of 1970, but none have yet been reported in orbit.

Both the Molniya II and Statsionar use 20 repeaters for telephony each with 10 MHz bandwidth and 7 watt transmitter power, working into an antenna beam covering the visible earth plus a higher power, wider band repeater for TV. Using available characteristics of their earth stations and the above satellite data yields a repeater capacity of 120 one-way telephony channels, and a total capacity of 1200 two-way telephone circuits, in addition to one TV channel. It is estimated that the solar array for these repeaters must produce at least three times the power output of an Intelsat IV, and that the satellite's 21 repeaters probably weigh about twice or more than Intelsat IV's 12 repeaters of 36 MHz bandwidth. However, using the U.S.S.R. earth stations in both cases, an Intelsat IV should have twice the capacity of the Statsionar because of its greater bandwidth, and with Intelsat's earth stations, four times the capacity.

IV. Comparison with U.S. Systems

Communications satellite technology in the U.S. is well advanced over that of other countries because:

-- the need existed, and

-- spacecraft technology and launch vehicles from NASA and Department of Defense satellite programs could be applied to communications satellite design.

Other countries of the world outside the U.S.S.R. have a need in that most of them are members of Intelsat and therefore eligible to participate in the design and construction of its satellites. Their lack is an extensive space technology background. The U.S.S.R. has the space experience, but apparently has relatively limited need, judging by its communications satellite objectives.

While the Franco-German Symphonie project has experienced difficulties, there is little doubt that these countries will eventually launch a communications satellite. While Symphonie won't be economically viable, future designs may well be economic, based on the Symphonie experience and also on their participation in Intelsat R&D programs (approximately 28%* of the Intelsat IV satellite program was subcontracted outside of the U.S.). Their problems have been due to their relatively limited number of space projects, aggravated by politics. The U.K., Canada and Japan should be better off in this respect.

Because U.S. communications needs are much greater domestically than internationally, the introduction of a domestic satellite system will undoubtedly provide the stimulus for development of the 11/14 gc, 20/30 gc bands, and also the greater exploitation of the 4/6 gc bands.

Meanwhile, Japan and Western Europe are also developing microwave components for 11/14 gc and 20/30 gc for use in terrestrial relay systems as well as for satellite use. They have a good background acquired in developing and building substantial numbers of similar components for 2, 4 and 6 gc relay systems and must be considered serious competitors in this field.

Their disadvantage vis-a-vis the U.S. is mainly in the spacecraft and launch vehicle area. Because of their relatively limited needs and experience, their space programs thus far have moved at a slower pace and have become obsolete more quickly. It was pointed out that the Europa II rocket to be used for the Symphone satellite may be scrapped. This rocket is a follow-on to the Europa I series. Together, they represent 11 launch attempts without a single successful orbiting of a satellite and an expenditure of over 2/3 of a billion dollars spread over most of a decade.

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*Corresponding to foreign subcontracts of $29.7 million out of a $106 million total. This figure covers the development and the construction of eight satellites.

By comparison, the rapid U.S. growth is epitomized by the U.S. Delta program, with its synchronous orbit payload capability increasing as follows: 85 pounds - 1965; 190 pounds - 1966; 300 pounds - 1968; and 700 pounds - 1973. All of these increases were due to improvements in the various stages which originated in programs other than communications satellites. Actually, of a total of over 80 Delta and Atlas/Centaur rockets launched since the launch of Early Bird (the first commercial communications satellite in 1965), only about 20% have been for commercial communications satellites.

Thus, the growth of the commercial program has been due in large part to the broad space technology base provided by NASA and Department of Defense satellite and rocket programs. These programs have maintained a number of highly skilled spacecraft and rocket engineering teams around the country, together with subsystem and component manufacturers. Their expertise grows as new programs pose problems of increasing sophistication. The recent NASA and Department of Defense cutbacks have already slowed down this growth. While no country outside the U.S. and U.S.S.R has yet built a commercial communications satellite, there is little doubt that toward the end of the 1970's Canada, Italy, France/Germany, Japan and the United Kingdom will have the capacity to do so.

V. Aerosat and Maritime Satellites

Serious consideration of the use of satellites for communications between planes and land based stations started in about 1964. In early 1973 there is still no firm plan to proceed.

Initially, with the limited payloads available from rockets which could be considered for such a project, the basic question was economic viability. Other questions were debated, e.g.,-the channel capacity needed; the power required per channel; the choice of frequency (VHF or UHF); and an important nontechnical question of who was to own and operate the system. These tended to be secondary issues at the time.

As the payload capability of the Delta increased year by year, and as tests on the Applications Technology Satellites (ATS) yielded useful experimental data, the relative importance of the various questions changed and that of choice of frequency became paramount.

Finally, in the last two years the U.S. Government has endorsed the use of UHF, and the Delta payload capacity has reached the point of assuring useful capacity, so that the major question remaining has been that of ownership and operation of the system. For the past year the program has remained stalled at dead center pending a resolution of this problem. Technically, an aeronautical communications satellite can be designed with today's technology; what is needed is a resolution of the non-technical problems. Recently ESRO has been selected by the West European countries to manage their share of this program, in conjunction with a U.S. partner yet to be chosen.

While the application of satellite communications to maritime use is easier than to aeronautical, since a physically larger shipboard antenna can be used, substantial interest of the maritime community has arisen only in the last couple of years. The 1971 World Administrative Radio Conference allocated frequencies for such use adjacent to the aeronautical satellite service in the 1600 mc region, both exclusive and for sharing with aeronautical satellites.

Since the frequencies are adjacent, and the applications similar, it would appear technically and economically desirable to build one type of satellite for both services simultaneously. However, there are some groups in each of the two camps who feel that some "sovereignty" will be lost by such joint use. The cost comparison of a joint system versus separate systems may resolve this issue. A more important problem, similar to that which has arisen in the Aerosat program, is the decision on how the maritime system is to be established and operated. Here, too, no clear solution is yet in sight.

VI. New Applications of Communications Satellites

The 1960's have seen the growth of the international communications satellite system from its first experiments to one with 80 operational antennas. The 1970's will see the application of communications satellites to domestic and regional use, and to special applications. As regards domestic service, Canada will have its system in operation by early 1973; and the U.S. has a number of specific proposals pending. The special applications area is somewhat nebulous. Various uses of satellites for communication via stations with relatively small antennas, 7 to

18 ft. in diameter have been proposed for remote areas whose only communication means has been H.F. radio. While there is no question as to the technical feasibility of such systems,* their economic feasibility is still open to question. It is difficult, if at all possible, to predict the extent of future use of such new systems. The approach will likely be one of adapting existing systems to demonstrate and test new applications, in addition to testing more advanced satellite concepts with NASA's ATS series of satellites. The NASA ATS-F satellite, to be launched in 1974, will also test the feasibility of TV broadcast to small stations.

VII. Conclusions

The U.S. lead thus far is based on satellites and rocket technology from NASA and Department of Defense programs.

Until now no other country, except the U.S.S.R., has had available our broad range of rockets for launching satellites. However, the U.S. has recently agreed to launch satellites for all countries subject to rather nominal restrictions. Therefore, all countries are now on an essentially equal basis as far as availability of launch vehicles is concerned.

During the last decade other countries have begun to develop their own satellite technology. While by far the major portion of this work has been funded by the countries themselves, their participation in Intelsat R&D programs and in actual development and production of Intelsat III and IV satellites (totalling over $25 million) has given them a close coupling to U.S. technology programs.

The future application of communications satellites for special purposes - domestic, regional, aeronautical, maritime and broadcast - will result in a need for development and construction of new satellites. Even with these new uses the relatively few satellites needed make it uneconomical for most countries to build up a capability in this field. Furthermore,

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*Since the beginning of 1972 Intelsat has provided 24 hours per day communications via its Pacific satellite between an 8 ft. antenna station in the Antarctic and the U.S. earth station at Jamesburg, California, at 800 bps with an error rate of approximately $1/10^6$.

all of these services will operate with synchronous satellites so that it will be technically and economically desirable to use a given spacecraft design for several different services by suitable modification of the communications package, thus further decreasing the potential market. Regardless, other countries are continuing development in this field based on considerations of national posture rather than economics. This incentive, coupled with the availability of rockets and the recent growth of satellite know-how as mentioned above, will provide the means for other countries to enter this field. From the U.S. viewpoint, this should provide a market for rockets, but there will be a loss in satellite markets.

Offsetting this is the fact that the use of satellites for U.S. domestic purposes should open up a market for satellites with one and even two orders of magnitude greater capacity than for international use at least for a number of years. The development and production of such satellites should provide the stimulus to keep a leading U.S. position. This assumes that non-technical considerations which stalled this program from 1966 to 1972 and resulted in a Canadian domestic satellite (built in the U.S.) before ours, are resolved expeditiously in the future as they arise.

The U.S. leadership in satellite design is based on the existence of a number of highly experienced engineering and manufacturing teams built up over the past 10-15 years for the development of NASA and Department of Defense satellites. The techniques and know-how which they developed on these government programs have formed the basis of the Intelsat family of satellites. In the case of the Hughes Aircraft Co., which developed and built 3 of the 4 types of Intelsat satellites, one can trace their evolution from Syncom (NASA) via Intelsat I, Intelsat II, ATS-1 through 5 (NASA), TACSAT (Defense), and finally to Intelsat IV. Each satellite design was nourished by its predecessors and in turn contributed new information (sometimes in the form of what not to do) to successor designs. These evolutionary changes had their troubles, but judged in comparison with other satellite programs, even greater troubles can be expected when initiating more radical changes from previous designs.

The government is the only organization financially able to support development of radically new satellite designs and techniques. For example, the ATS-F program includes satellites which will, in orbit, extend members supporting the solar arrays to form a structure over 50 feet long, and also deploy a parabolic antenna 30 feet in diameter. Included experiments cover ion engines, precision pointing to better than 0.1^{o}, TV broadcast, navigation, millimeter wave propagation, and radiation detectors of various types. The program involves an expenditure of over $200 million, or over twice Intelsat's gross annual revenues. From such programs will come the basis for future commercial satellite designs, as well as for new military and scientific satellites.

Other governments are proceeding with their own communications satellite programs. Japan and Germany are looking into the development of high powered satellites for broadcast use. The U.K. and the CEPT are planning experimental communications satellites for the 1976 period. Japan is proceeding on a similar schedule, and an Italian experimental satellite is now scheduled for 1974 launch. Canada is building an experimental satellite to test operation of a relatively high powered transmitter at 12 gc (involving light weight deployable solar arrays of over 1 kw output) which could be the forerunner of a broadcast TV system. This complete satellite will be built in Canada, except for the high power amplifier and the Delta rocket, which will be supplied by NASA for a 1975 launch. Thus, at a time when all major countries are engaged in breaking new ground in this field in order to insure a place for the future, the U.S., already in the lead, has cancelled the ATS-G, H and I. The effects of this cancellation should appear in the second half of the 1970's because of the anticipated need for advanced aeronautical, maritime, domestic, regional, and international satellites.

Commercial satellite ventures must, because of the high costs of satellites and rockets, take a conservative design approach. Radically new approaches involving expenditures of many tens of million dollars, can't be funded by today's satellite business. For example, Intelsat's 1972 gross revenues were just under $90 million.

Several other countries are developing entire satellites, including communications packages. I recommend that the detailed design of satellites for operational commercial purposes (communications, broadcast, aeronautical, and maritime) be funded by non-government entities; but the U.S. Government should continue to sponsor the advanced satellite techniques and components useful to all satellites*, government and non-government, in addition to its sponsorship of new satellites for specific non-commercial purposes, i.e., government, military, and scientific applications, and demonstrations of satellite technology for systems having no early commercial potential.

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*This includes new designs of attitude control, structures, thermal systems, power sources, mechanisms, and RF systems, including in-orbit tests and demonstrations.

EARTH STATIONS

This paper will briefly review the 10-year history of communication satellite earth stations with emphasis on the trends in design during this period.

I. Antennas and General Station Considerations

The first commercial earth station antenna, built by AT&T at Andover, Maine, was a 60-foot aperture horn which was scaled from the 20-foot aperture horn used in terrestrial radio relay stations designed for the Echo satellite experiment. This design was chosen to maximize the gain and to minimize the noise temperature for a given size aperture. Although the antenna was designed to withstand 100 mile per hour winds, a radome was added in order to simplify the operational problems during the heavy snowfalls of a Maine winter. This antenna worked well for the experiments for which it was intended; however, it was not satisfactory as a model for future production because of its high cost and because of the radome loss which could be as much as 6 to 9 dB from rain or wet snow. Later models used parabolic reflectors and Cassegrain feeds in order to eliminate the waveguide loss which would occur in a lower cost front-fed antenna. Initially, 85-foot diameter reflectors were used from available NASA and Department of Defense designs. The development sequence has gone as follows:

-- Learning how to get the desired gain and noise temperature over the 500 MHz bandwidth (centered at 4000 MHz) and the transmitting gain over an equal band centered at 6000 MHz.

-- Having achieved the electrical performance, the next step was to modify the mechanical design so that an operator working on equipment behind the feed cone could stand on a horizontal floor regardless of the elevation angle of the antenna.

-- The next step was to achieve the above, but at lower cost.

-- About the time the above items were accomplished, communication satellites had matured to the point where performance and reliability compared favorably with terrestrial systems and the emphasis was then placed on decreasing the number of men needed to operate a station.

-- This trend has led to the design now being built by most manufacturers. This consists of a circular concrete structure about 50 feet in diameter and one story high on the top of which the 97-foot antenna is mounted on a wheel-and-track arrangement. The low noise paramps are in an upper room behind the feed and all other equipment usually in the room below the antenna.

-- Recently some new antennas incorporate multiple reflectors so that the terminals of the feed are at ground level, avoiding the need for an upper equipment room.

-- Development is underway for feeds capable of operating with two orthogonal polarizations simultaneously, and providing adequate isolation between these to permit reuse of the frequency spectrum.

-- With approval of new frequency bands by the World Administrative Radio Conference in 1971, new equipment will be needed at 11/14 gc, and also at 20/30 gc.

-- The antennas in general use shaped reflectors and achieve aperture efficiencies of 70% and noise temperatures as low as 50°K at 5° elevation. It is doubtful that much more can be accomplished in these areas. Each of the major industrial countries design and build their own feeds and antennas.

Equipment is now fairly standardized and sufficiently reliable so that in most of the smaller stations it is technically feasible to employ one man per shift for two of the three shifts per day.

The costs of earth stations having 97-foot diameter antennas have dropped from the range of $6 - $12 million in 1965 to $4 - $8 million in 1969, and to $3 - $6 million at the present time. Costs vary widely depending on the number of countries with which it is desired to communicate cost of land, and the austerity of the design. For most countries of the world the earth stations represent their entry into the space age and facilities are therefore provided for visitors. Funds are also allocated for an architectural design of which the country can be proud.

In the U.S. the cost of land for ground stations has varied from several tens of thousands of dollars (West Virginia) to several hundreds of thousands of dollars (Hawaii).

II. Electronic Equipment

A. Power Amplifiers

At the present time, of the 80 antennas and related electronics in the Intelsat system, the traffic per station varies from 4 to 1200 circuits and the number of countries with which a given country communicates varies from 1 to 28. The amplifier output can accordingly range from several watts to several kW. Until now the highest power amplifier has been an 8 kW TWT 500 MHz wide, but recently 12 kW tubes have been developed. Life has been very satisfactory, ranging from 1-1/2 years to 3 years. For smaller stations 3kW klystrons and TWT's are used and air-cooled versions of these are now available, thus simplifying maintenance. For still smaller stations, 300 W air-cooled TWT's are typically used. The tubes for these amplifiers are manufactured in the U.S., Japan and Europe. In future satellites, when the narrower antenna beams will be used for the satellite receiver, earth station transmitter power will decrease.

B. Paramps

While the 25 MHz bandwidth masers were used in the early stations, the need for more bandwidth resulted (1966) in 150 MHz masers. With the desire for still more bandwidth, the trend shifted to paramps of 500 MHz useful band, since masers could not realistically be designed for such wide bands. The paramps resulted in an increase in noise which was compensated by going from 85-foot diameter antennas to approximately 97-foot, which is the size now used in practically all earth stations. While such paramps are built mainly in the U.S., but also in Japan and Italy, and to a lesser extent in France and Germany (both of whom have only built for their own use), the cryogenics are supplied only by Arthur D. Little Company (Boston, Mass). Extensive work is underway on uncooled paramps mainly for proposed domestic satellite systems. The leading companies in this field are in the U.S. and their expertise in both cooled and uncooled versions can be traced back to government requirements for similar equipment. During the last two years the performance of such amplifiers has improved from 200°

to 100° and is now down to 50 to 60°K. Recently some international stations located in southerly latitudes have gone to uncooled paramps, which, in conjunction with 105-foot diameter antennas, results in the required antenna gain-to-system-noise temperature.

C. Low Level Electronics Equipment

The accepted method of modulation in the Intelsat system today is FDM/FM. Therefore the multiplex equipment, IF amplifiers, modulators, demodulators, and up and down converters are all similar to those used in terrestrial radio relay systems and are built in most of the heavily industrialized countries of the world. The major difference in earth station equipment as compared to radio relay systems, is that greater flexibility is needed in the former as compared to the latter. This has resulted in the design of dual conversion up and down converters permitting rapid change of frequency with little or no retuning of amplifiers.

D. New Multiplex Systems

Because of the wide range of traffic carried by the different stations, work has been underway on developing multiplex and modulation methods which can be most efficiently adapted to the differing traffic requirements. In particular, initial installations are now underway for the so-called SPADE system which has been designed for countries having relatively few channels to relatively many other countries. In this system a time division orderwire is shared by up to 50 countries on an automatic basis. A voice channel is then automatically assigned any unused carrier frequency, transmitted by PCM/PSK, which may be on a different frequency for each new call. Each station has a computer which keeps track of the status of the various assignments. This system decreases the cost of the earth station and increases the number of channels per satellite repeater as compared to the conventional FDM/FM system. At the present time this equipment is being built in Japan and in the U.S.

E. TDM (Time Division Multiplex)

While the SPADE system is more efficient in the case of a few channels and FDM/FM is most efficient in the case of a large number of channels directed at one country, it appears that for intermediate numbers of channels, TDM may be advantageous. Experiments are underway on a 50 megabit system which will provide about 800 channels shared among several countries. Development on such systems has been undertaken in Japan, Germany and the U.S. Extensions of this system to permit switching of channels on a TDM basis among various beams of a satellite are also under study. In addition, digital speech interpolation, a more sophisticated form of TASI, is being developed in Italy, Germany, Japan and the U.S., which should provide a doubling in channel capacity for the same power and bandwidth.

III. Summary

Satellite earth stations have generally reached a fair degree of maturity. As an example, the eight U.S. stations for the past year and a half have achieved circuit continuity of 99.99% (ratio of circuit hours on the air to circuit hours possible during a year). While the U.S. has been the major supplier of such stations throughout the world,* the choice has not always been made on the basis of technical quality or price, but also on national considerations of mutual trade and long-term loans. In this respect the U.S. has been at a disadvantage as compared to other countries where there exist closer ties between the government and its manufacturers.

For future domestic, regional, special purpose, and broadcast services (the latter funded thus far by NASA), small stations with antennas ranging from 32 feet down to 7 feet in diameter may be more economical considering

*The U.S. has supplied approximately 43%; Japan 20%; U.K. 13%; France 9%; Canada 8%; Italy 5%; and Germany 3%.

the number of stations and the number of channels in the system. Several U.S. companies are taking the lead in developing such stations for the anticipated future market; however, for export the problem mentioned above will exist here also.

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COMSAT
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ATS ALASKA TELEMEDICINE EXPERIMENT

I. ATS-1 Project Description

The objective of the ATS-1 Alaska telemedicine communications experiment is to demonstrate and evaluate the use of communications satellite technology to provide reliable, voice-grade, intrastate communications to isolated communities using small, inexpensive ground stations. These villages are isolated by geography, weather conditions, unreliable radio communications, and a lack of telephone service. Village medical aides and their patients depend on infrequent contacts with doctors in larger towns and cities for consultation, diagnosis and treatment. The inadequate communications services in Alaska have forced the State to examine alternate technologies which can provide communications facilities to all areas of the State. This ATS-1 experiment provides the Alaskan health care community, and the Department of Health, Education and Welfare with information necessary for planning and implementing future systems. Continuing experiments are planned for the follow-on ATS-F satellite.

Twenty-eight villages and towns in Alaska have been outfitted with inexpensive (about $2,000) VHF, voice-bandwidth, transceiver ground stations.* Access to the VHF transponder on the ATS-1 satellite has been made available to the experimenters. Communications takes place among the villages and with the larger stations in Fairbanks and Anchorage.

The health care experiments were started in March 1971 with two villages (Allakaket and Venetie) communicating with the hospital in Fairbanks via the VHF voice channel on ATS-1. The objective of the scheduled one-hour per day "Doctor Call" was to determine the value of the reliable, but time-limited voice channel to provide health care services, and to provide some experience for the village medical aides operating with a small low-cost satellite terminal. The experiment was expanded in August 1971, to include 18 other villages in the Tanana River region northwest of Fairbanks, and eight larger towns and cities equipped with Public Health Field Service Hospitals. This expanded experiment provides medical education programming, remote health care diagnosis and treatment to each of the villages.

The satellite receiving terminal equipment is located in the village medical aide work area. In the 20 villages in the Tanana region, the equipment is time-shared with the school teacher who has a remote line from the terminal. One of the

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*See page 151 for their characteristics

joint educational/medical experiments includes the evaluation of specially designed listening equipment for the native Alaskan children, who generally have a severe hearing disability. A second,but equally important aspect of the health care experiment is being conducted by the National Library of Medicine's Lister Hill National Center for Biomedical Communications. It uses satellite channels to transfer medical records, diagnosis data and research materials among the Field Service Hospitals.

The National Institutes of Health, in cooperation with the University of Washington, Stanford University, and University of Wisconsin, conducts a program of consultation to sub-professional health personnel in the villages as part of the "Doctor Call" experiment. This is a potentially important new health care service for remote, sparsely populated regions.

II. ATS-1 Findings

The availability of a reliable and regular form of communication to the remote areas has resulted in an improvement in the medical care available to the residents of these remote villages. Some lives have been saved and considerable alleviation of patient distress has been achieved through the ability to secure prompt attention by medical personnel.

The growing effectiveness of medical communications between the Service Unit Hospitals and the remote villages is demonstrated by the striking growth in utilization of satellite channels as compared to HF channels as shown by the following table:

	"Satellite Village"	"HF" Village
Average number of days Tanana Doctor contacted:		
10/1/70 to 7/31/71 (via HF)	49.6	39.5
10/1/71 to 7/31/72	230.7	20.0 (via HF)
Average number of cases treated:		
10/1/70 to 7/31/71 (via HF)	43.6	22.0
10/1/71 to 7/31/72	152.9	14.8 (via HF)

Service Unit Hospitals that serve only villages without satellite ground stations do not tend to use the satellite channels to other hospitals or major centers. This is because alternate telephone or TTY circuits are available and are apparently preferred. In cases where a village has reliable

HF service as well as a satellite ground station, the HF circuits are preferred because their use is not limited by the ATS-1 schedule.

III. ATS-F Project Description

A somewhat more extensive telemedicine communications experiment is being planned in Alaska using the 2.5 GHz transmitter on ATS-F, which will be launched in the spring of 1974. The three federal organizations cooperating with the State of Alaska are the National Library of Medicine, the Bureau of Health Manpower Education, and the Health Services and Mental Health Administration. This experiment will be under the direction of the Federation of Rocky Mountain States, with the University of Washington as coordinator. The use of the 2.5 GHz, 15 watt transmitter and high gain antenna on the ATS-F satellite provides a much higher flux density at the ground receivers, and thus video signals as well as voice signals can be transmitted to the remote village sites. In addition to the extension of communications capacity to include television, schedule flexibility with ATS-F may permit appreciably more time to be devoted to Alaskan experiments, at least on occasion, than has been possible with ATS-1.

The criteria of approval for each experiment proposal are that they must be part of an ongoing program with an existing data base, they must have measurable objectives, and they must not unduly raise the expectations of the people in the experiment.

For operations in Alaska, an operations center is planned for Fairbanks. Somewhere between 20 and 40 receive-only terminals are planned, with five transmit stations, consisting of fixed terminals in Anchorage, Fairbanks, Bethel, and Juneau, and one transportable station. Figure 1 shows the ATS-F footprint (-3db and -10 db) over Alaska as well as the location of the various medical centers, hospitals, and villages participating in the ATS-1 experiment. (See page 150.)

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Donald P. Rogers

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ALASKA EXPERIMENTAL SATELLITE COMMUNICATIONS PROJECT
ATS-F FOOTPRINT (SATELLITE AT 94°W LONG.)

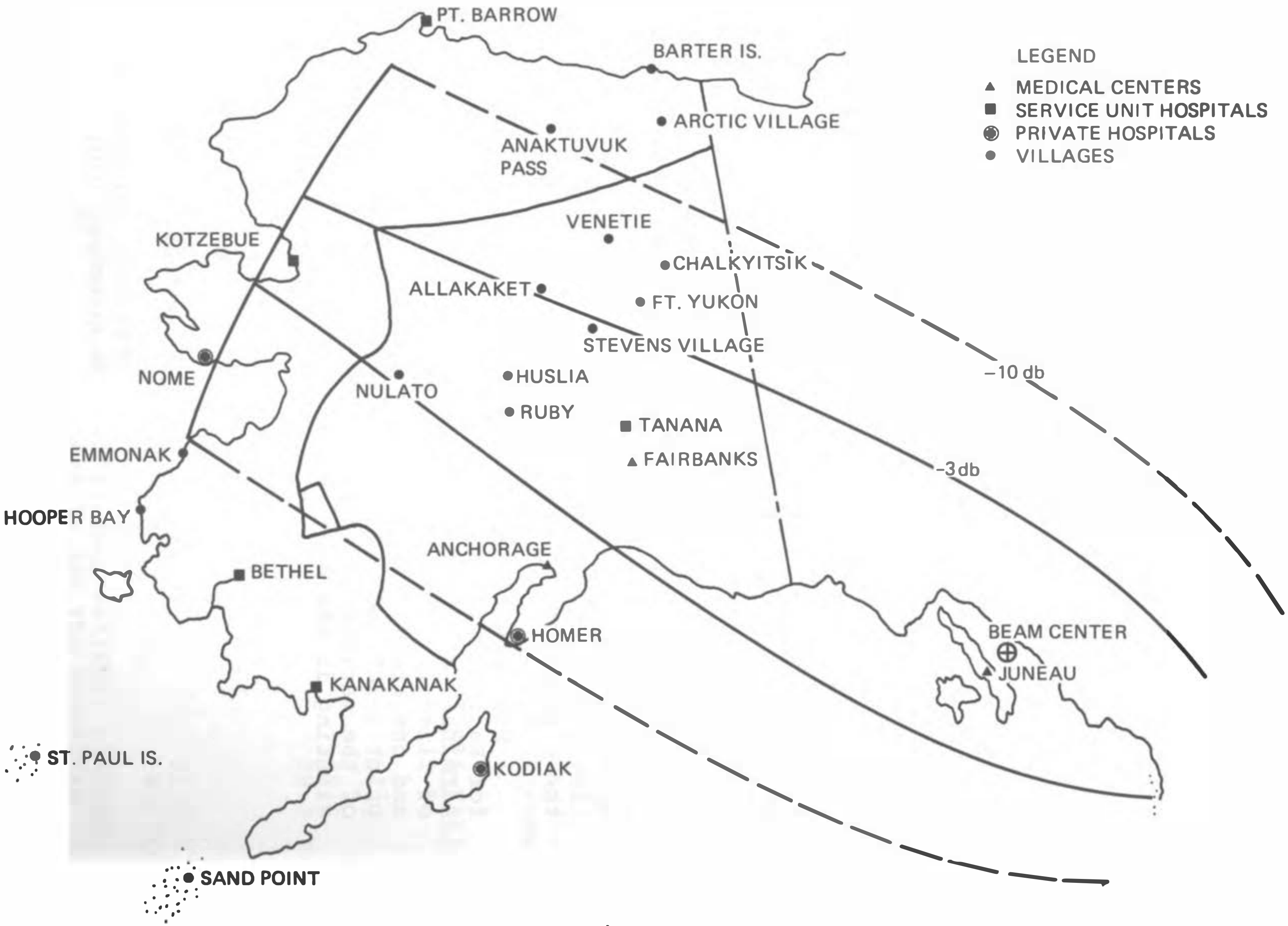

Figure 1

Description of Terminal Equipment

1. Low Power Stations - ERP + 61.4 dBm

   A. Transceiver - Motorola Micor T73 RTN Series

   1. Receiver frequency - 135.60 MHz
   2. Transmitter frequency - 149.22 MHz
   3. Frequency deviation - $\pm$ 5 KHz
   4. Rated transmitter output power - 110 watts

   B. Antenna - 8 turn helical

   1. Antenna gain - 14 db

With a 3 dB transmission line loss, the ERP of the low power station is 61.4 dBm.

2. High Power Stations - ERP + 66.7 dBm

   A. Transmitter-Receiver - Motorola Base Station Model B93MPIB-1000B

   1. Receiver frequency - 135.60 MHz
   2. Transmitter frequency - 149.22 MHz
   3. Frequency deviation - $\pm$ 5 KHz
   4. Rated transmitter output power - 375 watts

   B. Antenna - 8 turn helical

   1. Gain - 14 dB

With a 3dB transmission line loss, the ERP of the high power stations is 66.7 dBm.

COMPUTER COMMUNICATIONS NETWORKS

I. Introduction

The need for direct communication among computers is the most recent manifestation of society's demand for flexible communications services. In providing for this need, and in performing R&D that will lead to systems adequate for the future, the United States substantially leads the rest of the world.

Electrical data telecommunication began with the demonstration of the electrical telegraph by Wheatstone and Cooke in 1837. Nationwide telegraph networks grew rapidly, and the first successful trans-Atlantic telegraph cable was completed in 1866. Bell's invention of the telephone in 1876 led, by early in the twentieth century, to a public voice telephone network that surpassed the telegraph network in size and use. In 1931 AT&T began service on a TWX (teletypewriter exchange) network specifically for low speed (about 10 characters/second) data communications. Data communication by teletypewriter continues to play a significant role in business and, to some extent, personal communication.

A revolutionary change in data communication requirements occurred in the late 1950's due to improved electronic digital computer technology. With data processing systems able to generate and process vastly increased volumes of data, improvements were necessary in both the rate at which data could be transmitted and in the convenience with which this data could be gotten into and out of computers. Ubiquitous telephone networks were attractive resources for providing data communications services throughout the United States and the rest of the world.

The voice network, however, was designed for the transmission of continuously changing "analog" waveforms spanning a frequency range from about 200 to 3000 hz. Data, with its binary nature, had to be transformed by "modems" (modulator-demodulators) from the digital form required by the data terminal and computer equipment to the analog form required for transmission on the telephone network. By the late 1950's the Bell System's DATAPHONE service allowed terminals and computers to communicate through the switched telephone network or private lines at modest bit rates. During the 1960's the variety of modems supplied by the telephone companies grew substantially, and independent suppliers entered the market. By 1972 the number of modems in service was about 300,000, with about one-third of these provided by non-Bell System suppliers.

In the early 1960's much of the interest in computer-computer communication was for load sharing-purposes. This communication was usually off-line and involved tape-to-tape transmission. Increased volumes of data required higher transmission rates, and data sets for "broadband" transmission at 40.8 Kb/s (later 50 Kb/s) became available.

Another form of computer access also became popular. Taking advantage of the great speed of digital computers, systems were designed that allowed the computer to switch rapidly from serving one user to another, giving each the impression that he was being served continuously. Remote access to these "time-sharing" systems through teletypewriter and display terminals grew dramatically and commercial bureaus were established to sell such services. Primary access to these systems was made through the switched telephone network.

Specialized data processing services were also established along industry lines, for example, airline reservations, hotel reservations, stock quotations, credit card checking, bank operations, and many others. These all make use of the public telephone network to link thousands of terminals to central computerized data bases which can be examined and updated appropriately for each transaction.

Several vendors of commercial time-sharing services have established networks employing leased lines to link their computers. CDC's Cybernet, Tymnet, and the G.E. time-sharing network are examples. Efforts aimed at reducing communications costs (i.e., line charges, data set charges, and interface costs) have led to extensive use of minicomputers as programmable communications "front ends" to larger machines, and as communications concentrators which obtain economies by multiplexing intermittent low-speed data from many terminals onto a smaller number of higher speed channels. Some of this work is indeed R&D currently in progress.

Although there is much effort in this important and rapidly developing field that cannot be included here for lack of space and time, the next two sections will outline a few of the U.S. and foreign projects that relate to computer netting.

II. Computer Communications R&D

It should be noted immediately that the United States leads the world significantly in R&D on computer communications, and in applications of computer communications techniques. This is hardly surprising in view of our commanding position in the areas of computer and communications systems manufacture and use. Relevant R&D is taking place in many places in the United States, including government agencies, universities, the communications carriers, the computer manufacturers, and computer users.

The largest effort directed specifically at computer communications research is the ARPA network. R&D effort for it is being carried out at many university and industrial laboratories supported by ARPA funds. It is an example of what Clay T. Whitehead, Director of the Office of Telecommunications Policy, has called a "value-added network", i.e., a network that utilizes common carrier transmission facilities, but adds its own switching, error control and other special service features. 50 Kb/s private lines leased from AT&T are used to link about twenty large computer installations in all parts of the United States. The ARPA network is making a pioneering attempt to interconnect diverse computer systems, despite the difficult problems caused by vastly different software conventions found in various computer operating systems. In addition, the ARPA network has developed a distributed store-and-forward message switching system to implement the necessary routing and switching functions between computers. Analysis and simulation techniques have been developed to optimize network topology and to model the performance of the system. The network design is conservative in that it uses available technology in its hardware implementation (e.g., standard Bell System 50 Kb/s transmission links and Honeywell 516 minicomputers for the store and forward switches).

IBM also does extensive R&D on computer communications. Several laboratories are involved, including the Yorktown Heights and Zurich research laboratories. Analytical network optimization studies are conducted, as are experiments with switched digital transmission loops.

The Bell System is supporting substantial R&D with the objectives of improving performance and lowering costs of data communications services. A significant commercial step was taken in November 1972 with the filing of tariffs for a digital data service, an all-digital private line data network that is expected to serve 96 major cities by 1976. Substantial economic advantages result both from the elimination of modems and from improved utilization of digital trunks that will be used in the system. Digital transmission employing regenerative repeators will also lead to greater reliability for data communications. Continuing R&D on digital switching and transmission techniques will enhance performance and provide economic savings for both voice and data traffic during the next decade.

Several research experiments in computer communications are being conducted at Bell Laboratories. In-house digital systems are being constructed to experiment with minicomputer networks. Both distributed control "Pierce loop" and common control switched systems are being investigated. These systems use packet rather than line switching techniques and are capable of carrying data at rates exceeding 1 megabit/second. Experiments aimed at developing techniques for effective resource sharing are in progress. Because of the rapid switching and high data communications rates that are possible, new forms of computer sharing and usage will emerge.

III. Foreign Efforts

Just as foreign countries are behind the U.S. in computer and communications technology, their efforts in computer-computer communications also lag the U.S. by several years. For example, one measure of the use of data communications is the number of data sets in service. At the end of 1971, there were some 300,000 data sets in use in the U.S., compared to about 40,000 in all of Europe. However, in specific cases, good work is being done that overlaps some of the work being done in the U.S.

England has the most highly developed computer and communications capability outside the U.S. The British Post Office has supported studies of a possible separate digital network for data communications. An experimental service of this type may be operational in a few years. Both industry and national laboratories have been involved. A group at the National Physical Laboratory under D. W. Davies has an in-house experimental packet switching network in operation. They have long been strong advocates of packet switching and digital transmission for data applications.

In Canada a limited data network is already in operation. Calgary, Ottawa and Toronto have been linked with a 56 Kb/s transmission facility specifically intended for data. Experiments with digital communications loops are also being conducted at the University of Toronto.

In France a cooperative experiment including IBM and several French universities is being undertaken to develop a software system capable of solving some of the difficult problems that arise in computer networks. Even though the network will only link IBM/360 computers, substantial problems must be overcome.

IV. Summary

The United States, with its substantial lead (3 to 5 years) in both computer and communications technology, also leads the world in efforts on computer communications R&D. However, the field is in its infancy, and great progress must be made to realize the potential of effective computer-computer communications. Problems introduced by a lack of standards in computer operating system software, in communications conventions, in character sets and usage conventions, and other areas lead to enormous operational difficulties.

The large data networks that currently exist usually involve man-computer communication. Examples include time-sharing systems, credit card validation, and airline reservations systems. Having a man in the loop means that relatively small data transfers are required and low data rates (< 300 b.p.s.) are adequate. In addition, the moderately long time (10-25 seconds) needed to establish a connection through the voice telephone network is frequently acceptable.

Having computers at both ends of the communications loop changes the requirements dramatically. High data rates become desirable. Short-call set-up times (milliseconds) would be useful. Delay in getting messages between machines must be very small, if high performance processors are to be kept busy. End-to-end digital transmission becomes desirable to reduce error rates, to obtain rapid switching and to make full use of available transmission bandwidths. Demand multiplexing and packet switching must be thoroughly evaluated as alternatives to present techniques involving line switching and synchronous time division multiplexing.

Major benefits to be realized from computer networks arise from the advantages of "sharing". Various forms of sharing can be expected to develop. Load sharing will permit a heavily loaded machine to get some of its work done by a more lightly loaded member of the network. Data base sharing will allow a single data base to be accessed by many machines, providing storage economies by reducing the need for duplication of files. However, many difficult problems concerning privacy and controlled access to files must be solved before large scale data base sharing will be socially acceptable. Specialized processor sharing will allow a unique processing capability, for example high-speed display image processing, to be accessed by all members of the network rather than only by local customers. Program sharing will permit processes in one machine to utilize programs that run in other machines without the need for physically moving the program. Reprogramming algorithms to make them run in several environments will not be necessary.

Another important benefit, although possibly further from realization, will result from new hardware and software architectures that will emerge when machines can communicate effectively at high data rates. Simplification of software in each machine may result if a given computer is responsible for providing only one type of service for the whole network. We may see a range of network service nodes developed, each with a single or small number of functions. To increase network processing capabilities, nodes will be replicated or replaced by faster technology. Reliability requirements will dictate the amount of redundancy designed into networks to maintain service. Specialized processors of great power and efficiency will be designed to perform specific functions.

Special attention must be paid to standards at all levels. New national data networks should be mutually compatible. The growing number of private networks will one day need to be interconnected. Standards for error control, synchronization and end-to-end coordination are required. Differences in word size, character set, and communication protocol currently hinder useful communication between programs in computers that are already connected electrically, and these and other problems are magnified in networks. In many of these cases it is not simply a matter of legislation. R&D is needed before the options are properly understood.

In the near future we can probably expect that new developments will continue to unearth more questions than answers in this rapidly changing and technology-dependent field. With persistent effort we may expect that new and more effective uses of computers will develop as an understanding of network technology is achieved.

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RESEARCH DIRECTIONS IN NETWORKS OF COMPUTERS

Most of the research in the area of computer networks in the past have been on the question of interconnecting large numbers of computers in remote locations. The research effort has tended to concentrate on the question of sending bits from one location to another. There are now many solutions to this problem, most of which appear to me to be satisfactory. As such I no longer find this problem interesting.

I personally believe that the most important question in this area is to get a good understanding of what the end users want. Most computer networks have found that their traffic level is substantially below that which was predicted before the network was built. I believe this is due to two things. First, there was insufficient thought given as to what people would really be doing with the network. Second, although the network provided good facilities at the bit level, it was very difficult for the users to actually make use of remote facilities.

I think the most interesting question is that of distributed data base. The requirements for this can best be shown by an example. Today IBM does payroll processing in many locations, and, if an employee transfers from one location to another it often takes a period of several weeks before the payroll records are actually moved to the new locations. If we had a network of computers, we can see this taking place automatically. In a primitive version one would just enter a move statement. For instance if Phil Dauber was transferred from San Jose to Yorktown Heights, a move statement would cause the appropriate payroll records to be copied from the San Jose file to the Yorktown Heights file. In an automatic system, even the move statement might not be necessary. All that would be necessary would be for San Jose to stop accessing the Phil Dauber record and the Yorktown Heights system to start accessing it. The algorithm would then deduce that the most appropriate location for the Phil Dauber records would be in Yorktown Heights and hence would copy the record from one place to another.

Another question of interest is load levelling. In some hypothetical load level system, jobs would be moved automatically from one computer system to another in a network in order to balance the loads at all these locations. Due to the difficulty of moving large online files, I do not believe load levelling makes sense in most commercial applications. However, if it were true that in some scientific job shops a significant percentage of the computer time was spent on jobs which consist of only a small number of cards, then load balancing would make sense. I believe a small study making measurements of typical environments and doing analysis could determine which are the environments in which load levelling made sense. If there were a sufficient number of these environments, then it might be worthwhile developing more sophisticated load levelling technology.

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ARPA NETWORK RATIONALE: A 5-YEAR REEVALUATION

I. Introduction

Since its conception in 1968 the ARPA Network has progressed rapidly from a totally undefined hope to a major national computer resource sharing service interconnecting over 34 computer centers. Besides serving as the vehicle for the development and exploitation of multi-computer resource sharing, it has demonstrated the effectiveness and economy of an important new form of communications technology, packet-switched communications. Within the next five years, the extension of packet communication concepts into the areas of radio and satellite communication should revolutionize as well the effectiveness and economy of both local and international data communications.

The current ARPANET was not designed for these extremes and is most efficient for interconnecting moderate to large computers or user complexes scattered at a fair density over a nationwide geographical area. Since the future will bring vastly improved techniques for both tying isolated small users to the network and interconnecting networks together worldwide, this evaluation will confine itself to delineating the domain within which the ARPANET is used and for which its design makes it most economic.

II. Historical Development

The first four ARPANET modes were installed in late 1969 after a year and a half of study and development. It was in the initial period (1968) that most of the global design decisions were made; i.e., to use packet switching, interconnecting small Interface Message Processors (IMPs) with 50KB lines, accepting messages of up to 8000 bits from capable host computers, and breaking these messages into packets of 1000 bits or less for store and forward transmission. The initial analysis of network performance and cost, made in late 1968 just prior to contracting for the development of the IMPs, has proven to be very accurate and the same numbers are still quoted for parameters like the end-to-end packet delay (.1 sec).

The second year (1969) was spent developing the IMPs and installing a four node test network. Since the initial network worked essentially as predicted and it was recognized that at least 15 nodes would be necessary to achieve adequate resource diversity and usefulness, the network was immediately expanded to include the 15 ARPA computer research centers most likely to contribute to the development of resource sharing software. The communication network tying these nodes together was complete by February 1971; however, the development of an agreed upon standard for host-to-host intercommunication and the related host software for all the computers was not complete until August 1971.

III. Development of Network Usage

Although very limited usage of the network existed throughout its early development, it was not until all 15 nodes were compatibly interconnected in mid-1971 that true user activity could usefully begin. Shortly after this point, in September 1971, another phase of network growth was begun: the addition of user nodes without their own major host computer through the use of a new device, the Terminal Interface Processor (TIP) -- essentially a small IMP connected to its own minicomputer terminal processor.

The TIP permitted a whole new class of network use, i.e., a group or centers on the network could now look to the network for all its computation requirements instead of operating a local computer service. This strategy for obtaining the optimum mix and balance of computer capability from large, cost-effective computer centers without the many problems associated with running a local center has been so successful that about half the network nodes are now of this type. Also, during the past year several additional host computer service centers have been added to the network as the user requirements for quality computer service expanded. The entire expansion of the network beyond the original 15 research nodes has been in response to requirements (and full reimbursement) from non-network research projects, both in ARPA and other government agencies.

Usage of the network has mainly been of three types: remote access to time-shared systems, subroutine-like use of large numerical machines, and file transfer. The remote access use is similar to the use of commercial time-sharing networks; users access the net through a TIP and use one of the many time-shared host computers on the net. For reliability they usually keep their files at several compatible host sites and use whichever host is available. The software and file transfer protocol has now developed to the point that, if one is operating on one computer with files stored at another, it is both convenient and fast (seconds) to access the files.

The second major usage of the net is to run large numerical processes on large, fast remote batch hosts while using a time-sharing computer for the interactive portions of the tasks (program editing, data input, output processing and display). For many applications, interactive manipulation of the data is essential, but the central task of numerical computation can be run far faster and far cheaper on a large number cruncher host. The cost and time savings are often both more than a factor of ten.

The third major network activity is file transfer. Files must be interchanged between host computers quite frequently for the previous two applications. But, in addition, there has been considerable use of the network for the bulk movement of large data and program files in preference to mailing tapes since the network is more reliable, less error-prone, usually cheaper, far faster and eliminates human handling.

A six-month Air Force test of the network for the pure movement of data traffic showed that throughput rates of 20-30KB could be maintained. (Forthcoming changes to the routing technique should more than double this.) The test results also showed a lower monthly cost, while providing at least ten times the throughput and responsiveness of the alternatives available. So it has turned out that this type of network usage (pure data movement) is both economical and attractive, even though the original design goals of the network were aimed at interactive computing. Such data traffic is useful for the network since it provides a large low-priority background load which expands the instantaneous capacity available and helps maintain efficient line utilization, thus reducing the cost to everyone.

IV. Network Traffic

Figure 1 shows the internode network traffic over the first 14 months of user access. Usage has increased exponentially at the phenomenal rate of 26% per month throughout this period,

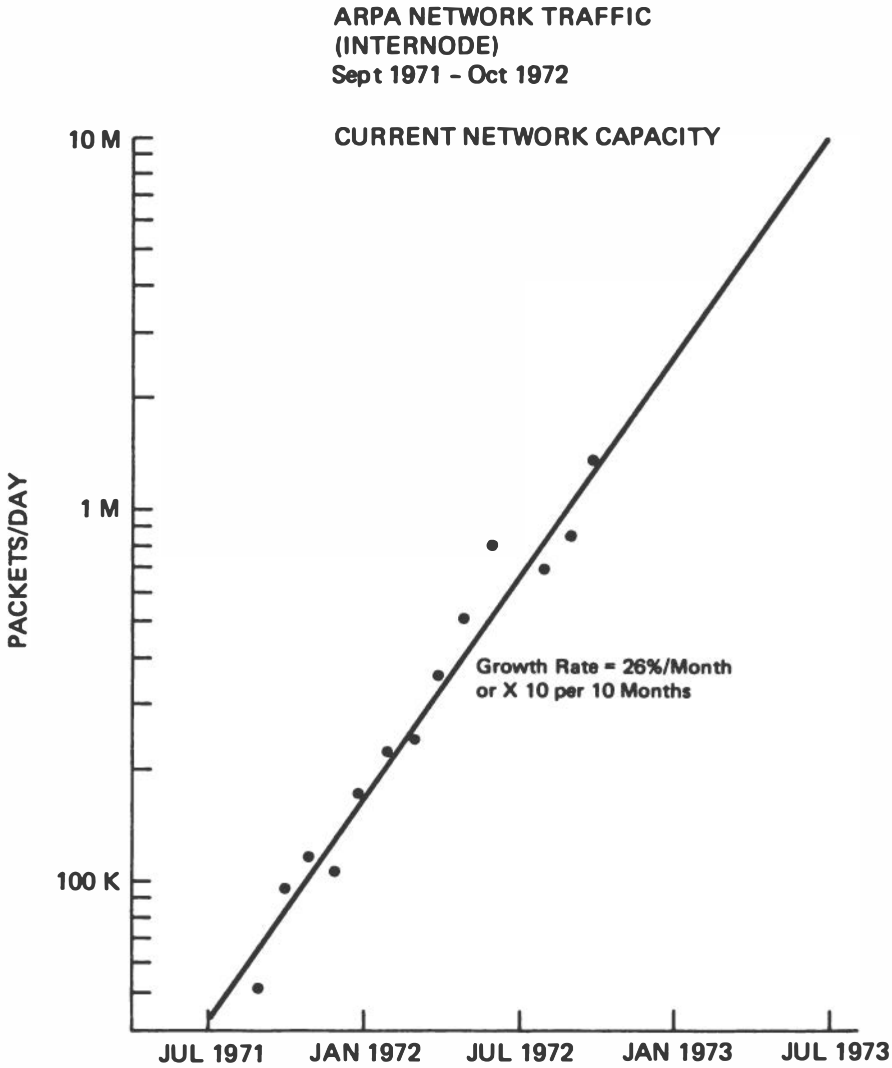
ARPA NETWORK TRAFFIC
(INTERNODE)
Sept 1971 - Oct 1972
CURRENT NETWORK CAPACITY
10 M
1 M
100 K
PACKETS/DAY
Growth Rate = 26%/Month
or X 10 per 10 Months
JUL 1971
JAN 1972
JUL 1972
JAN 1973
JUL 1973

Figure 1

while network size has only increased linearly by one node per month. Internode traffic in October 1972 was 1.36 million packets per day which corresponds to 9% of the computer power in the network being used remotely. In addition to this, the network also handled .45 million packets per day of local traffic, which means that 12% of the total computing power of the network's 22 serving host computers was distributed via the network. On an annual basis the value of this computer time would be $2.1 million or slightly more than the network cost. However, at the current growth rate the network should be fully loaded by July 1973, in nine months. Since the cost saving incurred by selecting the proper network computer for each problem is usually 100 to 300%, the network is already cost-effective. When it is fully loaded, the network costs only amount to 10-15% of the computer costs.

V. Cost-Effectiveness

In order to fully support computer resource sharing reliably and responsively on a nationwide basis, the communications network must be approximately the size and cost of the current ARPANET (34 nodes and $2 million/yr). Based on recent measurements the network traffic generated by a fully loaded, moderate sized, time-shared computer is 720,000 packets per day. A minimal network such as the current ARPANET has a basic capacity of 10 million packets per day. Therefore, in order to fully utilize the basic capacity of the ARPANET would require 14 moderate size computers to be fully accessed through the network. Additional capacity can easily be added beyond this point, but with no great economy of scale. Figure 2 shows this effect for generalized national networks of ARPANET technology.

By utilizing the above measurement of network traffic produced by a host and estimating its rental at $720,000 per year, total network traffic can be related to the total computer resource value accessed via the network (each computer dollar produces 365 packets of traffic). Thus, the relative cost of network communication can be related overall to the annual computer value used. Since there are some fixed costs associated with adding each additional node, the cost-effectiveness depends partially on the number of nodes, but the main effect is produced by the dollar volume of usage. This means that at least 10-20 million dollars of computer time usage must be expected before a nationwide network becomes optimally cost-effective. Once this activity level is reached, the main benefit from increased usage is improved reliability and increased peak throughput capability.

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ARPA, Arlington, Va.

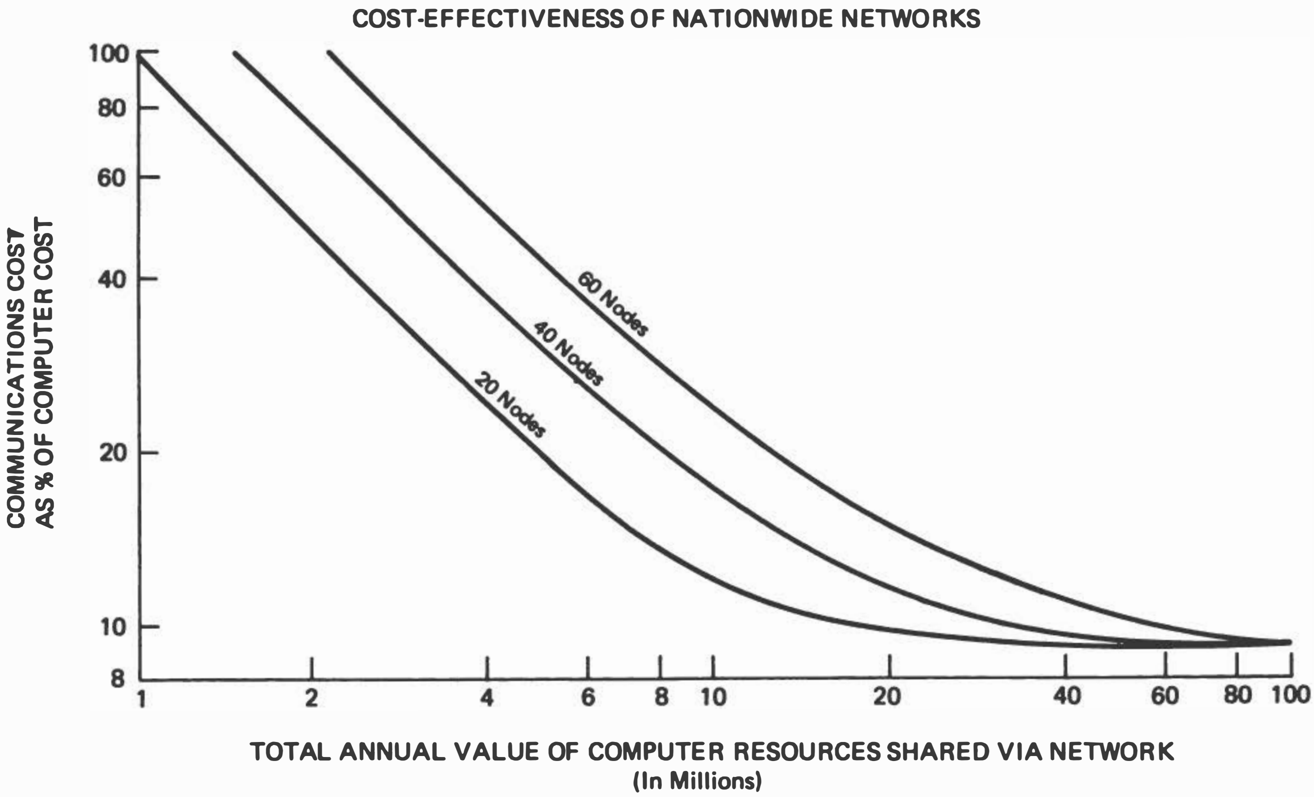
COST-EFFECTIVENESS OF NATIONWIDE NETWORKS
COMMUNICATIONS COST AS % OF COMPUTER COST
100
80
60
40
20
10
8
60 Nodes
40 Nodes
20 Nodes
1
2
4
6
8
10
20
40
60
80
100
TOTAL ANNUAL VALUE OF COMPUTER RESOURCES SHARED VIA NETWORK
(In Millions)

Figure 2

RESEARCH IN TELECOMMUNICATIONS SWITCHING

I. Introduction

Within the time allotted a review was made of research work undertaken both in the United States and overseas in the field of telecommunications switching. This review included contacts with overseas associates, and reviews of overseas publications, the minutes of the United States Independent Telephone Association Manufacturers Sub-Committee, and papers presented at the International Switching Symposium in Boston and the International Conference on Communications in Philadelphia, both in June 1972.

In summarizing the results of this review, the remainder of this document will provide suggestions for further research, review the funding of research in telecommunications and switching overseas and in the United States, and review the relative positions overseas and in this country in five main sectors: public telephone switching; private telephone switching (common carrier and interconnect); message switching; telex switching; and data switching.

II. Suggestions for Further Research

Arising from this study are indications that further research would be desirable in the following areas:

Electrical Interfaces

Research is needed into miniature electrical interface devices so as to eliminate bulky items such as transformers and other electro-mechanical devices used mainly for isolation in line and trunk circuits.

Man-Machine Interfaces

Research is needed into application of electronic logic in simplification and functionalization of man-machine interfaces for operator/attendants' work stations, so as to reduce their decision-making to its most functional form.

Electronic Crosspoints

Continued research is needed into electronic crosspoints for both space and time division organization of switches to supplant presently used techniques with electronic devices having lower working impedances, logic operating levels compatible with those used in control logic, and lower power consumption.

Telecommunications Traffic

Additional research would be desirable in stochastic processes viewed from randomness in time of arrival (as appropriate to switching systems), rather than randomness in level which has traditionally been studied for supporting transmission systems. Specific areas where additional research would appear productive include development and improvement of analytical formulas for dimensioning of common control equipment for switching systems; traffic overload analysis and simulation; and traffic of a wide variation of data rates vying for access to common facilities in packet switches.

III. Overseas Research Funding

The principal finding of this study has been that overseas switching research is significantly funded by Government departments. This is in effect a natural outcome of the organization of telecommunications overseas where Government departments, or corporations with total or partial Government ownership operate the telecommunications services. Research leading to products covering all principal sectors of the telecommunications switching market are included in these countries' programs.

As few of these Government departments own their own switching factories, there is a tendency for this research to be made freely available to national industries. These national industries also conduct substantial research in this field with their own funding. It is quite clear that the intent of this Government funding and free interchange with industry has as its underlying motive the support of industry in export markets. For example, in France (2) in speaking about the reason for placing into production Time Division Electronic Switching, the motive was given as follows: "The principal advantage of a decision of this nature will be in the industrial sector; it will permit French industry to prepare its production and maintenance organizations and to look for foreign markets".

In France, the CNET (National Center For Telecommunications Studies) has a budget for externally conducted studies in electronic switching of $89,000,000 over the 5 year period 1971 through 1975 (1). This amount is listed as 33% of the total of such external study contracts. This is not only the largest single identified element in the CNET External Studies Program, but electronic switching research is listed as the first of four principal programs in the text of the CNET submission for the French Government's 6th (five year) Plan (2). It is also very evident that the French Government is trying to promote the system developed by CNET by assisting the French company CIT in their sales activities abroad. An example is Poland where CIT was assisted by its Government in obtaining a recent order for time division PCM switching.

In the United Kingdom, for the year ending March 31, 1971, direct research in switching and signalling is listed at $6,500,000. In addition, a major share of the $2.1 million on data and related sub-systems covers work on Data Switching (3). These two items combined represent 28% of the British Post Office's (BPO) research funding. A large portion of this work is done in association with industry which provides complementary research funding. An example of the close collaboration between the BPO and industry may be found in reference 6.

In Japan, the Telephone Administration, the Nippon Telephone and Telegraph Public Corporation (NTT) has conducted a development which has involved all major Japanese manufacturers (5). By keeping the Japanese market closed to foreign suppliers and paying very high prices on switching equipment, Nippon Telephone and Telegraph is subsidizing Japanese manufacturers on the export market. NTT seems also to influence the Japanese marketing strategy, and has on occasion provided NTT engineers to assist Japanese manufacturers on turnkey export installations.

While less comprehensive information was obtained, reference to joint Government-industry cooperation on Electronic Switching programs was identified in Germany (data switching only), Switzerland (4), Sweden, Norway and Denmark.

There is also a tendency of a few administrations in different parts of the world to try to control not only the development, but also the manufacturing of switching equipment. The Swedish Administration has had its own factories producing switching equipment since the automation of the network began. In Italy, the Telephone Administration (SIP) now belongs to the same group STET as the manufacturing company, Siemens Italiana (SIT), which was formerly part of the West German Siemens company. STET belongs to the large Government-owned holding company IRI. In Spain, the Telephone Administration CTNE will control its own switching manufacturing company in ten years, having at present a 49% interest in that company.

IV. U. S. Switching Research Funding

Switching research in this country is significantly funded by the Bell Telephone System for public and private telephone switching and for data switching. By practice in accordance with judicial decisions this research serves only as a basis for products of the Western Electric Company and is available to that company's licensees only incorporated in products subsequent to initial manufacture by the Western Electric Company.

The Department of Defense funds significant amounts on voice and message switching for military purposes. Significant impact has fallen out of programs such as AUTOVON and AUTODIN into the commercial products of the manufacturers who have been awarded those specific military contracts. The military program for the Tri-Tac Switch should provide similarly for future impact on product development in the commercial sector by the successful contractors for the studies leading to development of that switch. It would appear that the most significant impact of Department of Defense (DoD) supported research work in the past has been in enhancing the competitiveness of U.S. computer manufacturers in the message switching area. The Advanced Research Project Agency (ARPA) network (24) continues to provide leadership in this field.

A review was made of the support by the National Science Foundation (NSF) in the areas of Information Sciences and Systems, and Network Theory and Circuits. None of the projects for the 1971-72 fiscal years (as derived from their titles) appear directly aimed at the support of circuit switching, and only a few on packet switching. While there will be some fallout from the substantial work in support of the computer area, which will have an application in communications switching, by and large, these NSF programs are unlikely to have more than limited effect on communications switching.

In the industrial sector, funding by the computer manufacturers of work on message switching is a natural adjunct of the primary computer business and seems likely to maintain a leading U.S. position in that field. Limited additional switching research is funded in the United States by General Telephone & Electronics, United (North Electric), Stromberg-Carlson, and ITT. For competitive reasons the exact values of research funding in the industrial area other than the Bell Telephone Laboratories (BTL) are not readily available. What is clear, however, is that the share of the switching market to which these manufacturers have access is so much smaller than that of the Bell System that their combined efforts are at least an order of magnitude smaller than those of BTL.

Ideally, R&D should not come from Government, but from the anticipation of profits in a competitive free enterprise system. In view, however, of the substantial levels of subsidy available to overseas manufacturers, it would appear attractive to have some form of U.S. Government support of R&D activities, such as tax rebates to industry. Support of research in telecommunications switching at universities or non-profit institutions would result in greater public awareness and an increased pool of the technical manpower needed by American industry to produce and use the telecommunications switching systems of the future.

However, support for telecommunications research may not, by itself, be sufficient to make a substantial contribution to export competitiveness of switching products.

The real problem of export-import trade imbalance on switching equipment in the United States is that of competitive pricing rather than technical superiority. Trade incentives, such as Japanese Government support and the Spanish Government export tax rebates, widen the gap of competitiveness much more than any superior technology achieved through Governmental research participation in such countries. A specific case in point is that of Fujitsu PBX's imported from Japan and sold by United Business Communications in preference to their own North Electric PBX. The reasons for this action appears to be price and quality, not superior technology, particularly as the Fujitsu PBX has required modification for the U.S. PBX market. R&D incentives alone, therefore, are insufficient to offset the cost-price differences resulting from the higher U.S. labor and overhead costs versus the broader support and incentives granted by foreign countries. They could, however, be a useful step in the right direction, particularly when coupled with other appropriate steps on the trade and monetary fronts.

V. Public Telephone Switching

The BTL representative on the Panel has expressed the view that the research at BTL on public telephone switching is not surpassed anywhere overseas. A review of programs underway overseas tends to support this view. While the Japanese and many European Administrations have such programs, no single country was noted with a more advanced program for local public telephone switching than that of A.T.&T. as exemplified by Electronic Switching Systems #1 and #2. In Sweden and in the Netherlands public toll telephone exchanges of the semi-electronic type, and in France local telephone exchanges of the PCM type have been commissioned in advance of similar switches in the United States. Some ten other countries will get such exchanges within the next three years. However, the research work of BTL leading to the Electronic Switching System #4 appears to be substantially ahead of any published information on analogous Time Division Switching Systems in Japan, United Kingdom, France (8), Switzerland (4),or Italy.

In the independent telephone market, United (North Electric) has introduced in the United States the above referred to Swedish designed toll switching with substantial local adaptation(7). ITT has announced the introduction of a proprietary French design of a local public telephone switch. In both cases, the design had benefited through Government (PTT) funded trial exchanges in the originating countries (Tumba, Sweden and Roissy, France). In addition to the substantial research and development by these manufacturers leading to these systems, North has developed the NX-IE and Stromberg-Carlson its "Cross Reed" System in the United States. G.T.&E. also have a similar advanced switching program for the EAX, TSPS, Crosspoint Tandem (a small 4-wire tandem switch), and the CI-EAX. Part of the latter has benefited from work in a Canadian affiliate. Northern Electric of Canada (through their U.S. marketing subsidiary Northern Telecom) have recently introduced their second generation stored program control electronic switching system (SP-1) to the U.S. independent, i.e., non-Bell market (21). This work has been mainly done by Bell-Northern Research and is essentially funded out of telephone operating revenues from Canadian subscribers.

The Canadian Government does, however, have two programs for sharing research and development costs in industry called PAIT (Program for Advancement of Industrial Technology) (22), and IRDIA (industrial Research and Development Incentives Act) (23). The PAIT program normally allows a 50% reimbursement of research leading to advances of the nature stated to be incorporated in this switch. In addition, the IRDIA program provides for tax free cash grants, or credits against federal income tax liabilities, equal to 25% of all capital expenditures during a fiscal year for scientific research and development in Canada, and 25% of the increase in current expenditures for scientific research and development in Canada during a fiscal year over the average of such expenditures in the preceding 5 years. A company which has received assistance under PAIT may include in applying for an IRDIA grant that portion of qualifying expenditures incurred, but not reimbursed under PAIT. Time did not allow investigation to determine whether these programs were a significant factor in funding research leading to this project.

In general a calibration of the relative competitiveness of products resulting from research overseas can be determined from the acceptance in the export markets of products resulting from such research. The structure of the industry in the United States, and a consequent lack of meaningful export activities in communications switching does not permit a similar comparison to be made in this manner.

In summary, therefore, BTL is taking care of its own research in this sector of the switching field. The Bell System appears satisfied with its in-house efforts. For the remainder of the domestic manufacturers supporting the independent telephone industry, it is doubted that any program short of support on the scale being given in individual countries overseas would make it worth while for these manufacturers to design systems of this type wholly within the United States, except in specific cases where they see a realistic market potential. This is principally a result of the size of market accessible to them as compared with their overseas counterparts, or Western Electric, rather than a lack of technological capability to design comparable products in this country.

VI. Private Telephone Switching For The Common Carrier and Interconnect Market

In the electro-mechanical switching area, the high cost of tooling piece parts has tended to make private telephone switches (PABX) reconfigured derivatives of the public telephone exchanges designed for the same manufacture. This was generally true both in the United States and overseas. A strong trend has developed recently towards the use of electronics in exchanges designed for private telephone use. As tooling is not so important a factor in the use of electronics, a divergence from this former trend is appearing. While some electronic PABX designs are appearing as derivatives from public exchange designs (e.g., France), some completely new designs for PABX use are appearing. Reference 12 gives an example of a Government (PTT) funded joint effort with industry in Japan. Quite a number of company-funded programs have also created commercial fully electronic PABX's such as the ITT TE 400A in the United States (9), two products in Germany (10,11) and the IBM 2750 in France (13). The area of electronic PABX's appears to be one where the United States has a potentially exploitable technological base in active electronic components which could lead to the development of a strong U.S. industry capable of exporting products and technology (14).

In addition, the character of the private telephone switching market is in the process of change as a consequence of the decision of the FCC to open this field to competition through allowing interconnection of customer owned or leased equipment to the public telephone network under certain conditions. This so called "interconnect" market comprises both private telephone switches (PABX), but also a large array of terminal apparatus for voice and data communications. The former is of primary interest for this section of the report.

The immediate consequence of opening the "interconnect" market to full competition brought on conditions analogous to that of the automobile industry with many imported products appearing on the U.S. market. The few U.S. PABX equipment manufacturers who had been serving the independent telephone common carriers stepped up their efforts, as was anticipated. On the other hand, the record of the "interconnect" market to date has been one of substantial imports of technology. Of the 49 PABX types recently surveyed (15) covering products available to the "interconnect" market (excluding those of the Western Electric Company), 17 PABX's came from the United States, 11 from Japan (2 assembled here), 4 from Canada, 4 each from the Netherlands (part U.S. adaptation), Sweden (part U.S. adaptation) and Germany, 3 from France, and one from Spain. As a consequence, the United States in 1971, for the first time, had an unfavorable trade balance in the customs category of telephone and telegraph equipment.

VII. Message Switching

The term message switching tends to have two different meanings according to whether it is applied to services such as reservations, message telegraph, etc., or to data switching. For the purposes of this review the term "message switching" is applied to the former services and the term "packet switching" to the latter in accordance with present usage by ARPA and the CCITT. The term "message switching" is often also called store and forward switching.

The principal finding of this review has been that American companies are dominant in this field because of efforts by the principal computer manufacturers and reflecting the early support given this class of service by the Department of Defense, particularly such programs as AUTODIN.

Even overseas where the principal PTT's have required such services for message telegraph and telex retransmission, American computer manufacturers have won in international competitions. Specific examples of this are in Australia (Common User Data Network), Switzerland (ATECO), Sweden (ATESTO) and Spain (CTNE Interim Data Network). Because of this indication of American dominance many PTT's are deferring programs for message switching to dates when integrated data switching can be available from national manufacturers. This subject is covered in a subsequent section on data switching.

In the commercial sector, predominant usage has been reservation systems and concentration of computer communications. The U.S. computer manufacturers have obtained an overwhelming majority of contracts in this area. It has been noted that even where overseas manufacturers have won message switching competitions there has been a strong tendency to use processors, and memories and/or peripherals of U.S. companies.

The conclusion of this review has been that there is no element in message switching which has not already been covered by research supporting the computer industry. Therefore no special additional treatment needs to be taken for research in support of message switching per se. Further comments are made in a subsequent section on the data switching market.

VIII. Telex Switching

The review covered both direct circuit switching for telex use, and packet switching. Included in this market are successor switches meeting that portion of the market now covered by 45.5 and 110 baud TWX, as well as 50 and 200 baud national and international telex.

France, Germany, Italy and Belgium have inaugurated 200 baud telex services and a commitment is noted by the balance of the Common Market countries to follow suit mostly in the period between now and 1975. It can be anticipated that this speed of service will spread to the North American markets as a minimum to service requirements of international companies.

Traditionally telex switching has been a direct circuit type of switching and has been derived from public telephone exchange designs for the reasons discussed above under Private Telephone Switching. In the international electro-mechanical telex switching market, Siemens A.G. has been the dominant worldwide manufacturer in the past. Some years ago when it became apparent that semi-electronic telex switches would become practical, an early lead in this class of exchange developed in the United States. Major factors in this lead were the system installed in the mid-1950's for the General Services Administration, and switches from two U.S. manufacturers for Western Union (domestic). This same class of system was also installed in Canada by Canadian National/Canadian Pacific Telecommunications. However, for want of continuing large scale market requirements and because of changing economics this lead was dissipated.

Large semi-electronic direct circuit switching systems have been installed overseas recently in Denmark (16) and in the Netherlands. More modest computer-controlled switches have been installed in Italy, Hong Kong, Portugal and Panama. These modern designs appear more economical than the earlier U.S. designs and will presumably be the principal factors in the intermediate term export market. Only the small Portugal and Panama switches are products of a U.S. manufacturer (Fredericks).

The development of packet switching discussed below has resulted in modern forms of semi-electronic direct switching being economical only in smaller sized telex exchanges and at higher speeds. This latter point results from the cost of direct circuit switching being affected in only a minor way by an increase in transmission speed, whereas cost of the packet switch's processor and memory increase in direct proportion to bit rate.

Packet switching is a natural derivative of message switching in that the equivalent of circuit switching is obtained by providing sufficient throughput capacity achieved by fast links and short message units (packets) to reduce the queueing time to a transition, bit, or character (typically about 10 ms).

Here again in the United States an early lead was obtained as a derivative of defense research and turned into successful products by three U.S. manufacturers (Control Data, Astrodata and Data Trends) who provided switches under contract to the three international record carriers (the Control Data Switch was, however, limited to outbound calls only). Overseas Siemens A.G. and N.V. Phillips have developed comparable and larger machines with indirect German Government support going into the Siemens development which also serves as the base for the German Post Office's data switching discussed in the next section. Based on this lead derived from Government support, Siemens has entered the U.S. market and sold its modern packet switching system to the domestic record carrier and to one of the international record carriers based on price and physical size. N. V. Phillips has provided its system to a second international record carrier.

IX. Data Switching

A review of progress in the data switching area shows that an unquestioned technical leader is BTL (17). In Europe, considerable effort is being undertaken to provide comparable facilities, a description of which (with supporting additional references) is found in Reference 20. Japan, Canada and Australia are also planning to implement public switched data communications systems.

In support of this statement on BTL leadership, a statement has been made by a Japanese official that Japan lags by two to three years in this area behind the United States. As a consequence the Japanese Government, in cooperation with the four main manufacturers, intends to make an investment of $160,000,000 (exclusive of transmission lines) to bring Japan to the forefront in this area (18). A corresponding position has been expressed for France, indicating that by 1975 that country expects to lag 5 years behind the U.S. in data switching as against a 3 year lag in the computer field (19). The French Government is, therefore, supporting a program of external studies in this area of almost $30,000,000 over the next five years in an attempt to maintain its industry capability in this area (1). It has been previously noted that German Government indirect support has been placed on electronic data switching, leading already to the success in export by the German firm Siemens. In the United Kingdom, British Post Office support has gone to two British companies for work in this area (6). In Switzerland a total integration of all forms of switching, including data, is receiving support from the Government (4).

On the other hand, no U.S. manufacturer other than the Western Electric Company is likely to have modern data switching products on a time scale matching overseas manufacturers, unless some special steps are taken. The reasons don't seem to be a consequence of lack of research in the U.S. in this area, which, as noted above, is considered to be ahead of the world. One reason may be ascribed to the previously referred to present policy on access of other manufacturers to research in BTL. However, as so much appropriate technology is available as a fallout from the ARPA network, this alone does not seem to be a compelling reason. A more likely reason is the lack of willingness of manufacturers' managements to make such large investments of R&D funds (including field trial exchanges) when they observe their overseas competition being partially financed by Government agencies (PTTs). Thus, to the U.S. domestic record carrier, the three international record carriers, and the one data oriented miscellaneous common carrier, the choice is currently left to looking for foreign products, or of themselves financing a U.S. development directly, or indirectly, and including it in the price of equipment. As the recent trends show in telex switching, the choice of foreign products is more probable in the absence of incentives to U.S. manufacturers to get them to a comparable level, including initial working switching exchanges.

To permit fair competition between manufacturers supporting various classes of common carriers, this support should be structured in such a way as to give parallel benefits to all industries for comparable R&D via such means as shared cost reimbursement for R&D, or double deduction from income taxes for R&D in this field. Even with this type of support to industry, it might be worth while to provide an additional incentive by having the General Services Administration and/or Department of Defense call for competitive bids for modernization of their own administrative systems in a direction which would benefit U.S. manufacturers by proving the results of R&D through construction of comparable exchanges to those being financed by overseas governments. In this manner, U.S. manufacturers would operate on a comparable basis with foreign suppliers when bidding on the future requirements of the record carriers.

Most of the research necessary to support data switching is of a type analogous to that supporting the computer industry. Nevertheless, additional grants by the National Science Foundation to universities and non-profit corporations would help to stimulate additional research, and graduate level work in engineering on data switching.

X. Summary

As this study of telecommunications switching has shown, many other countries prepare their national manufacturers for exporting and for meeting import competition through a multiplicity of incentive schemes. ATT has provided the level of funding necessary for the Bell Telephone Laboratories to meet and surpass in technological achievement the rest of the world in those specific areas destined for potential use in the Bell System. This has, however, left certain product areas where Bell does not operate without adequate R&D support to U.S. manufacturers. It has also left the U.S. without exportable switching products. And finally, in those areas where competition has been opened up by recent FCC decisions, U.S. manufacturers, other than the Western Electric Company, have been left at a disadvantage with respect to foreign manufacturers.

As many foreign manufacturers receive Government incentives and the U.S. manufacturers do not, it is concluded that it would be desirable to establish incentives in selected areas of telecommunications switching. To be effective, this support for R&D should begin at universities with specifically directed NSF grants, extend through industrial research and development (with the Canadian PAIT/IRDIA programs forming an attractive pattern to emulate), and include provision for lease or purchase by Government agencies of working advanced switching systems.

Such a program would place a number of competing U.S. switching manufacturers on a par with their overseas counterparts,with the attendant potential benefit to the U.S. balance of payments of reducing imports and fostering exports.

It should be emphasized that in the limited time allowed for this study, only a superficial look could be taken at the area of telecommunications switching. In any extension of the work of this Panel, more complete coverage could be made of this field.

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RESEARCH ON THE COMMAND AND CONTROL OF RAIL TRANSPORTATION

I. Introduction

A preliminary investigation has been carried out on the command and control of rail transportation, both in the U.S. and overseas. While this is only one narrow segment of transportation research all of which potentially merits similar investigation, it was chosen for review to be consistent with the focus of the Panel's parent Committee on Telecommunications as the latter expressed thoughtfully in the following passage:

In its report "Communications Technology for Urban Improvement", the NAE Committee on Telecommunications saw the role of communication technology primarily to be supportive of that mode of urban transportation now desperately in need of special emphasis-mass transit. Further enhancement and even subsidization of private individualized transportation were felt only to aggravate current problems. The Telecommunications Committee came out strongly in favor of using communications to provide the urban public with improved accessibility to mass transit systems (20).

As a general observation, research on this subject is at a technological level significantly below that encountered in other areas of telecommunications. While research in telecommunications is eagerly studying new materials technologies (e.g. optical fibers) and advanced systems architectures (e.g. inter-computer communications), research worldwide in command and control of rail transport appears to be cautiously grafting simple hierarchical control systems based on current technology computers on top of automatic block systems constructed of electromechanical components. Apparently, this cautious approach to research is traced to the twin considerations of safety and levels of R.&D. funding.

An overriding consideration of rail transportation is safety, both for reasons of preservation of human life and for the high cost of a failure in potential damage to property. As such, railway signaling has evolved not only in a "fail-safe" mode, but in one where innovation must pass a series of slowly ascending levels of trial before being generally accepted in the industry. Under these conditions innovation has tended to be built on thoroughly proven component technology. The low mean-time-between-failure of many modern electronic sub-systems is an anathema to the railway command and control engineer. In practice he insists on analytical proof that any failure, no matter how small, will lead to neither loss of human life, nor major property damage. An excellent justification for such a conservative attitude can be found in the accident which occurred October 2, 1972, on the Bay Area Rapid Transit (B.A.R.T.) system with damage to a car and injury to 5 people (21). Its cause was attributed to a malfunctioning quartz crystal (22). A result has been a leaning of such research as is done towards systems architecture of a straightforward nature.

The second consideration is that of low R.&D. funding levels. In recent years gross investment in rail transportation has been low as the high technology fields of air and space have preoccupied governments, as the poor financial condition of the U.S. railroads and metropolitan subways has kept down the incentive to invest, and as the high tax revenues derived from vehicles and the petroleum products they use have tended to be plowed back into roads, thus worsening the competitive position of the railroads and their capability to invest. For every dollar invested in rail transport, only a limited share can be invested economically in command and control equipment. In practice, priority of investment is often given to civil work on right of ways, and to train equipment, leaving command and control equipment to be procured belatedly against a limited fixed budget. Yet without a command and control system, the right of way is worth no more than a hole in the ground. Limited investment in command and control equipment has led to limited incentive for the companies who manufacture such equipment to spend heavily on R.&D. in this field. Despite this condition, a number of manufacturers described subsequently have maintained a technological capability which could be expanded readily at any time the potential appeared for increased levels of R.&D. funding.

II. Suggestions For Future Research

Arising from the investigations made in this area are a limited number of suggestions for future research. Some of this research could be directed towards university laboratories, while other items may need the specialized expertise of industrial laboratories to provide effective answers.

A. Automatic Train Operation and Control System Organization (Linear Routes)

1. Study train location via block organization as used in the U.S. as against transposed wire schemes under trial in Europe. Technical (speed and headway limitations, availability of adequate bandwidth for control and for reverse channel capability to indicate control has been implemented correctly), economic (first and operating costs) and safety comparisons are all involved.

2. Application of advanced computer techniques (e.g. micro-processing, micro-programming, etc.) to meet the need for distributed "fail-safe" direct computer or logic control of switches, signals, etc., now carried out by electromechanical relays.

3. Systems architecture alternatives to the present trend toward simple hierarchies. Processor to processor communications security and telecommunications traffic flow in a distributed control structure. Flexibility for continued growth of served right of way in various control structures.

B. Command and Control for Two Dimensional Route Structures

The advent of "People Movers" strengthens the need for traffic flow research into effective sharing of common route sections under criteria of human dissatisfaction with delays substantially different from normal telecommunications traffic. Even on linear route structures such research would be helpful to devise more effective strategies for handling the merging under abnormal conditions of serious delays on one of the linear branches.

C. Mathematical Modeling of Train Networks

"Railroad operations can be likened to a set of interacting control loops (e.g. passenger and freight traffic) which are multi-variable, non-linear and with time-variable parameters, and whose system time constants range from minutes (response to failure conditions) to many months (major review of passenger time tables)" (28). Research is needed to seek effective mathematical system designs and algorithms to model such systems easily and economically on a computer and thereby identify where effective developments can be introduced to improve system performance.

III. Summary of Significant Programs

A. Definitions

For the purposes of this summary, it is convenient to categorize rail command and control systems into those involving control only versus those involving automatic operation, and also into applications to various route structures.

The following definitions are applicable to control versus operations (3):

"Automatic Train Control (ATC)

"ATC is the term for various safety systems that have been in use since about 1922. One common type forces the driver to operate safely and will bring the train to a complete stop if he exceeds a speed limit or fails to apply brakes after receiving a speed decrease signal.

"Automatic Train Operation (ATO)

"ATO is a term used to mean full "hands off" control. It includes a number of functions:

1. Speed command recognition
2. Speed regulation
3. Position stop - used for transit to make a controlled deceleration to stop at a specific platform location.
4. No motion - used to prevent opening doors in motion.
5. Safety functions analagous to ATC"

The application of command and control systems on various rail route structures can be categorized as follows:

Category A. High Speed Interurban Systems

Modern rail transport systems employing heavy trains with substantial headways at speeds up to 200 km/hour (120 MPH) over linear route structures comprising arrays of loosely interacting lines with infrequent intersections.

Category B. High Density Linear Route Urban Systems

"Modern rail rapid transit systems employing heavy trains operating on the order of 100 second intervals at speeds up to 130 km/hour (80 mph)* over linear route structures comprising arrays of loosely interacting lines." (8-Cat.I)

Category C. Urban Distribution Systems

"Distribution systems for major activity centers employing vehicles that are much lighter and smaller than rapid transit cars operating as one or two car trains at headways on the order of 20 seconds at speeds up to 50 km/hour (30 mph) over essentially linear route structures." (8-Cat.II)

Category D. Personal Rapid Transit Systems

Also called "People Movers" (1,23) and "People Moving Vehicles" (PMV) (1).

"Personal rapid transit systems that approach the operational flexibility and ready availability of the private automobile. These systems employ automobile-size vehicles operating at headways on the order of five seconds at speeds up to 30 km/hour (20 mph) over route structures that are two dimensional networks with strongly interacting segments." (8 Cat.III)

B. Country Programs

The research work on these categories will be reviewed in the following study for the U.S., West Germany, Japan, Belgium, France, United Kingdom, and Sweden to the extent that information was readily obtainable. In reviewing the published papers a dramatic contrast in quality was noted between those by the authors in the U.S. and overseas. U.S. authors tend to be terse, write in a qualitative nontechnical vein and be affiliated with manufacturers. Overseas authors tend to be more communicative, more technical in level, and be affiliated with the Government-owned railway administrations. This may be interpreted, to some extent, as a reflection of the competitive procurement policies in this country where manufacturers are unwilling to share the fruits of their own research with competitors versus the tendency in overseas countries for long-term joint assocation between the railroad administration and national manufacturers, often on a territorial allocation basis.

*Speed limits raised from the original text to reflect working limits on B.A.R.T.

1. United States

The most advanced work on rail transport is concerned with People Moving Vehicles (PMV) which are seen as the future rail systems that approach the operational flexibility and availability of automobiles over two dimensional route structures (1,8,23). These are Category D systems involving automatic operations. Substantial technical problems will be involved in the command control systems associated with such systems which exceed those of more traditional systems by the need to select between routes and merge from several routes at convergence points. None of the traffic problems associated with this switching/merging function appear to exceed, for example, those already long encountered by ATT in the routing of telecommunications traffic. Nevertheless, there is a substantially different impact of a lost PMV as compared with a lost telephone call, so that the system architecture must be designed for reliability. To date experimental systems in Morgantown, West Virginia and planned for Denver, Colorado work initially on linear routes and have not yet faced the two dimensional control problem. This type of product has a high potential for international exploitation, with an initial installation at the International Oceanographic Exposition on Okinawa. (36)

Category C (Urban Distribution) systems are largely in the proposal state (8) and provide for vehicles much lighter and smaller than Category B (High Density Urban) systems over essentially linear routes. In common with other linear route systems, technology is required for longitudinal control, automatic protection, and automatic operation. Lateral control is normally achieved by physical restraints, but some proposals have been put forward for electronic control with respect to an electrical guidance wire (1). The Tampa Airport system (11) has some of the features of this category, but without the full range of control needed for multi-vehicle operation on the same right of way.

Category B (High Density Urban) systems of recent vintage include the PATCO system (3,10), the Bay Area Rapid Transit (B.A.R.T.) system in California (4,5,8,37,38,39) and the Washington Metropolitan Area Transit Authority (W.M.A.T.A.) system under construction in the District of Columbia (8). From the limited published information on this latter system, it seems to follow some of the philosophy of B.A.R.T., with the additional innovation of CRT displays instead of mimic diagrams for the man-machine interface.

The B.A.R.T. system has clearly the most comprehensive command and control system in current use today, and as such serves as the benchmark against which to calibrate the work in other countries. As will be seen below, several other countries have railroad command and control systems in design or use which rival that of the B.A.R.T. system, and in some areas show signs of leading it. With the designers of B.A.R.T.'s command and control system (Westinghouse) having obtained an order for a similar system in Sao Paulo, Brazil, it is clearly a factor in U.S. export markets, but has no clear lead as, for example, does the U.S. computer industry.

Its automatic operation is carried out by a number of integrated sub-systems (designed by Westinghouse Electric, except where noted):

- An automatic vehicle control system in each car provides the functions of decoding the speed command sent from the wayside, automatically maintaining speed at the level set by the central computer, protecting against over speed, braking, generating identification signals, and stopping at the midpoint of each station platform.

- Wayside controls set the speed of trains by means of a block system with up to 31 blocks per station. They also provide information on block occupancy, and transmit control signals to the trains.

- Station controls set basic operating conditions for blocks in their area (such as maximum speed in each block), pick up identification signals from trains and forward them to the central computer, and provide safety of trains on the route by sending diminishing speed signals to trains following each operating vehicle in proportion to the amount of headway.

- Interlocking control of the traditional gravity relay type protect branching and merging points where the present routes intersect.

- Automatic yard control in each yard identifies vehicles, assembles trains, and tests the operation of brakes, doors, etc., before trains pass on to the main line (Philco-Ford and Wismer & Becker).

- A digital transmission (of wired logic at 1200 bauds) system (DTS) interconnects the central computer and each station.

- An automatic platform display system in the distributed computer (PDP-8) control presents news and advertising subject to a priority interrupt for train destination taken from the same information sent by the train to the central computer (Stewart Warner).

- An electronic computer center in Oakland monitors all train movement from the identification signals sent from each station via the DTS, compares the arrival time to the scheduled arrival and sends back via the DTS signals to speed up or slow down the train. These adjustments can achieve a 10% reduction in travel time between adjacent stations (with the station control ensuring no speed limits are violated), or up to a 50% increase. These adjustments apply only in the four linear segments of the route. If a train is so delayed that it cannot make its schedule "slot" at a branching/merging point, the computer throws control to the system manager to determine which of several recovery strategies is to be employed.

From the standpoint of guiding research in this area, it is important to note that despite its complexity the B.A.R.T. system has the following limitations.

- It has limited backward information flow, covering only 6 bits of destination, 4 bits of train serial number and 4 bits of train length, and this only from immediately before each station, not from each block. In effect, therefore, all safety is based on redundancy in the forward direction only.

- Being based on audio frequency track circuits, it has limited forward transmitting bandwidth to the vehicles.

- Train detection is only by shunting the tracks. An insufficient shunt will not show a train's presence to the station control. A fault could indicate a train where none exists with accompanying inconvenience to passengers on following trains which are forced to slow down.

- Despite the complexity of the computer center, it optimizes four linear routes separately and does not attempt to manage the entire system from a traffic flow aspect under major disruption of schedules.

Enumeration of the points immediately above is not a criticism of the B.A.R.T. command and control system, nor of its designers. Rather, it is a synthesis of features which other railroad administrations overseas have insisted upon for their own systems. Only detailed study by competent researchers can adequately assess the pros and cons of the above competing alternatives. Although it is clear from a review of the B.A.R.T. system that it has many problems still to resolve (38), most of which are derived from too much innovation in a single system, and too many interfaces without a single overall contractor, it is one of the best urban transit systems in the world today from the standpoint of customer satisfaction and has no "bugs" as yet identified which cannot be cleared by the determined effort which is being applied.

Category A (High Speed Interurban) systems commissioned recently include the Muskingum Electric Railway (3,9) which is operated fully automatically and a number of automatically controlled systems (3). The most advanced control systems include continuous inductive loop communications and intermittent control from passive wayside devices, but still have much traditional technology (e.g.,redundant relays) for reasons noted in the introduction to this study. Some computer technology is used in some classification yards (2) and microwave technology is proposed for rail-highway grade crossing control systems (6). For these more cost effective systems to be applied widely, proof of reliability will have to be demonstrated.

2. West Germany

In categories D (Personal Rapid Transit) systems and C (Urban Distribution) systems, respectively, technical proposals have been put forward by a national manufacturer for conveyor belt type systems, and linear route systems using magnetic cushions. The former needs limited control, but has the potential for high risk to passengers should a condition result in a departure from zero relative velocity at any transition point between belts, or between a belt and a rotating platform. The second will need as sophisticated a control system as for similar proposals in the United States. However, no reference was obtained on research work of an advanced nature in this area.

The German manufacturers, AEG and SAG are proposing designs, and SEL (ITT) in its current installations, apply the same control systems to both Categories A (High Speed Interurban) systems and B (High Density Urban) systems (12). That is, modern automatic control is designed for interchangeable use on high speed intercity routes and high density (low headway) urban routes, involving similar hardware and considerable commonality of software. As recommended by the Union Internationale des Chemins de Fer (UIC) (an international organization of railways in Europe), data transfer is via high-speed data transmission over an inductive loop laid between the rails along the line which is periodically transposed so that it also provides train location information. In a typical Category A (high speed interurban) application between Hamburg and Bremen, Germany, a central control system of triplicate minicomputers (16 K memory) interrogates all trains in a 40 km (25 mile) section of the route in a time sharing mode, each at intervals not longer than 800 microseconds. Trainborne equipment announces its location and speed and receives speed instructions from the computer which are evaluated to initiate speed changes. In addition, the computer interrogates all existing computerized district control centers and electromagnetic component interlocking equipments on the route for status information, and provides orders for control of signals, level crossings and switches.

The transposed loop (13) has the technical advantage over the control system used on the Muskingum Electric Railroad (9) of being balanced both against electrical interference (as it is transposed) and of being at ground potential with respect to the traction power line. In addition, it functions as a quasi-continuous block system with positive train detection down to at least the interval of transposition by simple means such as counting phase reversals. Because of its transposition scheme, it has the usable bandwidth of a telephone open wire carrier system, or well in excess of 100 KHz, with equally available capability of transmitting to or from the train. In its inherent capabilities, the transposed loop meets three of the four limitations indicated above for the B.A.R.T. system. In effect, B.A.R.T. uses these capabilities for station platform approach (flare) control, but not elsewhere on the route. Finally, as the transposed loop (in several variations of transposition distance) has been standardized by the U.I.C., it may be specified by railways in developing countries, with the result of placing U.S. manufacturers at a competitive disadvantage, if they do not also study and master this technology.

It should be noted that the approach in West Germany is for indirect computer control through existing signal towers. It has not yet been determined whether direct computer control of signals without local interlocking equipments is possible with safety, or if it is economical.

Both the German Railways (Bundesbahn) and the Ministry of Development are interested in research on even higher speed trains with the latter reportedly providing 30-80% support to industry programs. A Government trial track is to be installed not far from Augsburg, Bavaria, with a total length of 72 kms to provide for trials of new trains at speeds of up to 350 km/hour (220 mph). Support may be expected to include the development of command and control systems adequate for this velocity.

3. Japan

In categories C (Urban Distribution) systems and D (Personal Rapid Transit) systems a slow speed (30km/hour monorail has been proposed for Tokyo (32). Also limited information was published on work being done by Mitsui for the "VONA" (Vehicle of the New Age) stated to be a 6 to 12 car, 40 km/hour train with computerized ATO with the novel feature that "when the train arrives at the terminal, the circular platform turns with it at a rate of 2 km/hour" (33). Notwithstanding these national efforts, import of U.S. Boeing technology is contemplated by the Kobe Steel Company (36).

Category B (High Density Urban) systems are under active development in Japan. Specific installations have included the Monorail at the Osaka Exposition (Hitachi), the Sakaisuji Line (Toshiba) (14), Sapporo (Hitachi) (15), and the world's most widely used monorail between Haneda Airport and Tokyo (Hitachi).

The Sakaisuji is a computerized automatic train operation which controls train schedules as well as signals and switches. The Sapporo command and control system comprises separate computer sub-systems for train operation control, power supply control and supporting business operations.

Category A (High Speed Interurban) systems include those for the New Tokaido Line and New Sanyo Line (7). The control system is based on ATC, and centralized train control (CTC). In order to operate the whole line efficiently over 1000 km (625 miles), a computer-aided traffic control system (COMTRAC) has been developed. The functional operation of this system is analogous to that of the German Railways in that the computer control is indirect via the CTC system. The essential difference between the Japanese and German systems is that in Germany distributed control is used for each 40 km (25 miles) of route, while in Japan the control system is centralized in Osaka. COMTRAC's sampling speed is about one half that used in Germany. COMTRAC is based on a 32K memory, 2 micro-second access duplicated computer with a 16K, 1.6 micro-second satellite for controlling and adjusting schedules, and is thus by computer standards not a very complex system. The CTC system is modern, but still based on relay technology. Because of the extreme distances over which control is exercised, primary responsibility for safety rests in the CTC system.

In ancillary systems, the Japan National Railways (JNR) has experimented with a micro-wave (Gunn diode) doppler radar speedometer in marshalling yards and a laser detector based automatic car identification system. Basic research is beginning on ultra-high speed railway systems at JNR's research laboratories planning towards a 1980 service date. JNR has a very modern outlook on the use of computers and by the end of 1971 had about 80 computers of various sizes in use in its operations (34).

4. France

The Paris Metro has recently built a new Category B (High Density Urban) line at 100 km/hour (62 mph) with conventional block control for traffic safety, but with a centralized control for train traffic, passenger traffic measurement, passenger information and communications with sub-systems provided by CII, CGA, AMICA, HALBERTHAU and CGCT (ITT). The automatic control computer exercises control via a dual computerized remote indication and control system (2 x 12K of core plus 2 x 2 MB of drum memory) handling secure telegrams over 2400 baud data links, and providing 16,000 indications and 6,000 controls.

This remote indication and control system provides a function analogous to the digital transmission system in B.A.R.T. The essential differences are that the French system is processor controlled (while B.A.R.T.'s digital transmission system is wired logic), that the French system's speed is twice as high, and that its total information handling capacity is appreciably greater, particularly in the train to control center direction. This remote indication and control system appears to be the most advanced in use in rail transportation today. Nevertheless, systems of this technological level are available in a number of countries generally having been applied first to the remote control of electrical power transmission.

In Category A (High Speed Interurban) systems, the French Railways (SNCF) has been a leading experimenter on high speed trains. Tests in 1954 and 1955 went as high as 331 km/hour in one section of route (35) and the French were among the earliest to adopt 200 km/hour regular train service. Publications through 1969 (30, 31, 35), however, do not disclose more modern signalling methods than block operation (with look ahead) and speculative comments on transposed wire systems as described above under West Germany. Time and effort did not permit a more careful review of research in this area in France.

5. Belgium

The application of electronics to centralized train control in Belgium, is described in Reference 16. This is wired-logic technology applied to a transposed inductive loop as described above for West Germany.

6. United Kingdom

The most recent Category B (High Density Urban) system in the United Kingdom is the Victoria Line in London (17, 18). This is a wired logic automatic operation system comprising a safety sub-system and a train command sub-system, transmitted via the running rails. Speeds are low, 80 km/hour (48 mph maximum); however, trains are separated by a close headway of only 82 seconds.

Investigation by the British Railways Board (19) has shown that up to 200 km/hour (125 mph) their existing signaling systems would be satisfactory on Category A (High Speed Interurban) systems, but new and additional command and control systems would be required for speeds of 240 km/hour (150 mph). Work does not appear to have gone as far as in West Germany and Japan, although towards the end of 1972 a trial of a computerized CTC unit was scheduled to begin in Glasgow, and dual miniprocessor control (aboard the train) of speed and braking is being evaluated as a pilot scheme in another location (29).

A longer range study of railway freight operations is being conducted by the research department of British Railways (28). This program covers modern additions to the present network (as described immediately above), a computer-based overlay to the present interlocking systems, and looks ahead to development of a comprehensive management information system (called TOPS-Total Operations Processing System) to be operational by mid-1975.

7. Sweden

Although no direct information was obtained from Sweden on research in this area, an indication of its present status may be obtained from the installation by Sweden's largest electrical manufacturer (ASEA) being planned for a mining railroad in Colorado (27).

This is a slow speed (40 km/hour or 25 mph) railroad with automatic train operation, automatic train control, and data transmission systems. The ATO control system is basically a speed control system with three speed references received from the ATC system. Individual slip control is incorporated on each locomotive. The ATC system (developed by SAAB-SCANIA) is a block-signaling system. It has, however, finer control than a normal block system as a number of antenna loops are used within each block for transmitting the programmed speed command. The last antenna loop in each block provides occupancy status of each block. The data transmission system is over coaxial cable with 400 channels in the band from 200 to 300 KHz. Each channel has a maximum speed of 15 bauds. Although each of these systems has novel features which would merit further study as to economic effectiveness, they are in the nature of engineering developments rather than the results of advanced research.

IV. Comparative Assessment of Research Work

The research overseas on command and control of rail transportation appears most advanced in West Germany and Japan. In these and other countries, a general innovation lag with respect to computers and telecommunications is evident for reasons covered in the introduction. In all countries, including the U.S., R.&D. appears to suffer from funding at too low a level to match the pace of the evolution of the computer and public telecommunications industries, let alone their counterparts in the defense/space areas.

Where comparative statistics could be obtained, these have been included in comparative charts attached for Categories A (High Speed Interurban) system and B (High Density Urban) system. A tentative conclusion is that a potential lead in this area may be being built up in West Germany and Japan through their administrations' aggressive efforts in speeding up service in Category A and the design of command and control systems potentially applicable to both Category A and B use in those countries.

No comparative statistics were obtained on systems in Categories C (Urban Distribution) system and D (Personal Rapid Transit) system, but continued monitoring of this area would appear prudent.

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Comparative Chart
Category A - High Speed Interurban Systems

	U.S.	U.K.	France	West Germany	Japan
Indirectly Computer Controlled Systems in use or trial	X			X	X
Maximum Speed (km/hour) in use or trial		160	200*	200	210
Maximum Speed (km/hour) planned		240	300	350	500
Computer core memory size				16K	32K & 16K
Computer access time (μ sec)				1.5	2 & 1.6

*1955 tests went to 331 km/hour (35)

Comparative Chart
Category B - High Density Urban Systems

	U.S. (BART)	U.K.	France	West Germany	Japan
Indirectly Computer Controlled Systems in use or trial	X		X	X	X
Maximum Speed (km/hour) in use	128	80	100		70
Minimum Headway (sec.)	90	82	138		
Computer Core memory size	40K*		12K**		
Computer access time (μ sec)					

*Plus 375K of disc. The standby unit which handles housekeeping duties and simulation when not on-line service, has 52K of core plus 1.5M of disc memory.

**Remote control and indication system only.

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MICROPROGRAMMING

All digital computers consist of assemblies of hardware which either store, route, or process (combine algebraically) bits of data. In the simplest computer, the assemblies are simply wired together in a permanent manner; the computer then performs one unchangeable operation whenever it is presented with input bits. Its internal "logic" is mechanized by hard-wire connections; its only "control" is the on-off switch. Its "instruction set" simply describes its one operation. It is inflexible but, for some applications, may be faster and cheaper than any competitor. On the other hand, its marketability might be very limited!

The next most complex computer would have some toggle switches on it which could permit the user to change the "hardwire configuration" in ways which would affect signal storage, routing or processing. Several "logics" are now possible and the instruction set is more complex since it must describe what happens for all possible positions of all the switches. The "control" is now a full set of switches. Obviously, by changing switch positions during the operation, one could perform a whole time sequence of operations on the original data bits. The switches might control anything from the smallest piece part in the computer to a whole major assembly. Even at this primitive level of computer we can see the tradeoffs that must be made by the manufacturer as he tries to produce a marketable product:

1. Too few switches and the applications are too few.

2. Too many switches and the computer becomes expensive, the wiring more and more complex, and the probability of successful operation under all switch conditions becomes marginal. Furthermore, if the manufacturer intends to produce better and better computers in the future, the more switches and possibilities provided to the user, the harder it is to guarantee that the next computer in the series can still do the job of the present one, especially if the old "instruction set" which says which switch does what is to be retained. Users who have invested major amounts of time and money in figuring out elaborate sequences of switch positions ("software") are going to be particularly concerned with preserving this investment as long as possible.

As a result, the manufacturer comes up with a configuration of hardware and switches (an "architecture") which he hopes has enough applications to be a marketable product. Most users will be satisfied if the manufacturer has done his job well. There will always be some users who will find the architecture cumbersome and inefficient for their purposes and for whom a slightly different set of switches and instruction sets might have made a great difference. The special problems of these users are often solved by adding other special purpose equipment ("associative processing"); a typical example is a simulation of aircraft performance using actual aircraft hardware as part of the computer-assisted setup.

There is also the alternate possibility of the user physically modifying the manufacturer's hardware (architecture), but clearly this could lead to trouble unless very skillfully done. At the very least, the manufacturer's "warranty" is probably voided in that the user can't reasonably expect the manufacturer to guarantee that the computer will still work properly, nor to guarantee compatibility with other computers in the manufacturer's line. However, the user may be much better off if the modification is well done, and if he has no concern over compatibility with future machines.

With this background it is fairly easy to see the impact of very new technology on "microprogramming". Microprogramming as a word traces back to the early 1950's. Its purpose, then and until recently, was to try to organize and discipline the process of deciding on computer architecture. As such, microprogramming was generally an aid to the computer designer rather than the user. As might be expected from the foregoing discussion, manufacturers were reluctant to have the users tamper with something as basic as computer architecture. But then, within the last few years, it became possible to build "chips" containing hundreds to thousands of computer elements each. The nature of the technology led to extremely high reliability per chip. But clearly a chip of so many elements which was "hard-wired" to perform only one function would be too inflexible for general use.

This problem was solved by having a number of connections to the chip (typically dozens), equivalent to switch connections, by which the same chip could be made to perform different functions. One obvious advantage of such chips is that a computer can now be made with many identical chips, with the external wiring to their connections determining what function they each perform. Another straightforward improvement is to have the external wiring changeable by using prewired plug boards. A step beyond that is to use computer cards rather than plugboards. Conceptually, the wiring, the plug boards and the computer cards are all forms of "fixed memory" specifying the "control" or "architecture" of the machine.

Enter now another new technology: cheap, reliable, and fixed memory and the possibilities for creating many different architectures abound. Indeed, computers built around such technology can be made to look like (emulate) other computers' architectures, thus helping to break the overly-tight relationship between specific computer hardware, the instruction sets, and the user's software.

Conceptually, one simply tells his own (host) computer, by changing the fixed memory which controls its architecture, to "become" another (target) computer for which one has software already available. In practice, hardware details can still cause trouble, particularly if the host and the target computers are quite dissimilar at the hardware level; thus, if one replaces his own computer by a new model, the fixed memory controls developed for the first computer are unlikely to be directly applicable to the new model. Typical problems that arise are those involving system synchronization, time delays, word length, techniques for handling data overflow or discard, etc.

And finally, one can replace the fixed (read-only) memory of the architecture by one which can be electronically changed prior to, or even during the solving of a problem on the computer. One can thus literally change computer architectures in midstream of a problem, taking advantage of the best properties of different architectures as one goes along. This whole new world of technology is usually labeled "microprogramming".

As computers and telecommunications become increasingly linked into very fast, high capacity automated systems, microprogramming will help to enable these systems to operate with greater efficiency. Heretofore, the computer and telecommunications technologies have tended to go their separate ways and have not been tied sufficiently closely to bring about the full range and flexibility of their potential as parts of a combined system. As computer communications networks grow in size and become international in nature such compatibility will be essential to their effective functioning.

I believe one can now draw the following management conclusions about microprogramming:

1. In the past, the principal direct benefactor of microprogramming was the manufacturer, with the user benefiting indirectly through the better computers being offered through the years. It is now possible for the user to take direct advantage of microprogramming as well by changing the

basic architecture of his computer; however, at present, the user must be a relatively sophisticated one (e.g., a Federal agency, a major industrial firm, etc.).

2. A new division of labor in the computer business is predictable, with the "chip" manufacturers increasingly dominating the hardware end and the computer suppliers increasingly concentrating on producing "different computers," including those of their competitors, by micro-programming different architectures.

3. The United States is unlikely to fall behind in this area. It is presently far ahead in the hardware technology and in the understanding of the techniques of micro-programming. It is attacking with some vigor new problems such as multi-level security with one machine, generation of software prior to the commitment to hardware, efficient processing of radar and acoustic signals, and application of computers to avionics.

Supplemental research funding by the NSF would appear unnecessary. On the other hand, a close watch on this field by the Department of Commerce should be encouraged since the United States has no monopoly on inexpensive solid state technology, or on the mathematics of computer design and use.

A combination of good decisions by foreign competitors and unfortunate ones by US firms, particularly in "chip" design and read/write storage, could lead to a serious loss of market for periods as long as 3-4 years.

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SPEECH ANALYSIS

Speech analysis is the process which extracts the information-bearing components of speech and converts these into some form of a code. The elements of speech sounds are phonemes, syblets, syllables and words. A phoneme is the smallest speech unit that serves to distinguish one utterance from another. A syllable consists of an uninterrupted unit of utterance and contains one or more phonemes. However, even in what is considered to be a syllable, there may be some voiced and unvoiced interruptions. A syblet is a part of a syllable bounded by such interruptions. A word is the smallest unit of speech that has meaning when taken by itself and consists of one or more syllables.

The objective of speech analysis is to recognize speech elements. Therefore, the number in each category becomes important because the complexity of the analyzing system is a function of the number of speech elements involved. Forty phonemes, 800 syblets, 1400 syllables and 10,000 words constitute the major part of the American language.

In the selection of speech elements for analysis, any subdivision of a word or syllable which a machine can carry out and classify reduces the total number of speech elements to be recognized. At the present time, the speech elements which appear to offer the greatest promise for analysis are an optimized selection of syllables, syblets, or phonemes according to whichever can be segmented and analyzed.

In order to analyze the different speech sounds there must be some means for the segmentation of the flow of speech. The segmentation involves words, syllables, syblets and phonemes. A boundary occurs when the sound amplitude drops to zero, or near zero, and the transition takes place from voiced to unvoiced sounds. In general, the vowels constitute the voiced sounds, and the consonants, the unvoiced sounds.

A sound wave may be completely described in terms of amplitude and frequency of the components and the time. Therefore, the fundamentals of any analyzing system must be based in some manner upon amplitude, frequency and time. The real trick in speech analysis is to employ the three fundamental parameters in such a manner that the speech elements can be differentiated along unique features, characteristics and procedures which lead to the ultimate objective, namely, recognition.

The main features, characteristics and processing required for the recognition of speech elements are shown in Table I on page 207.

The first process is segmentation by amplitude pauses, voiced and unvoiced, and voiced and unvoiced transitions. In the voiced elements there are initial vowel and non-vowel sounds.

The speech sounds are normalized with respect to amplitude to compensate for difference in loudness, and with respect to time intervals when there are no significant changes in speech sounds.

The envelope, spectral distribution and time as depicted in Table I provide specific information on the recognition of the speech sounds.

Quantization and data reduction are employed for further classification of the speech sounds to facilitate recognition.

The instrumentation required to carry out the processes depicted in Table I is indeed quite complex and beyond the scope of this brief summary.

There are two types of speech input operations, namely, a cooperative speaker, where a person is willing to speak a set of words so that the system will adjust to dialect, etc., and the uncooperative speaker where the person is not required to say any words. In the cooperative type of operation, an accuracy of 98% or better can be achieved. For an uncooperative speaker, the accuracy may be quite high for some speakers and very low for others.

The speech elements are converted into a code. The code may be used for the transmission of speech by the use of a speech synthesizer, the input to a computer, the control of machine operations, etc. At the present state of the art, the applications must be restricted to limited vocabularies and cooperative speakers.

If the speaking rate is 90 words per minute, the bandwidth required for the transmission of speech employing 10,000 words is depicted in Table II. For monosyllabic words, the speaking rate is 150 per minute. The number of syblets is twice that of words. The approximate number of phonemes is four times that of words.

The frequency bandwidth for the conventional analog transmission of speech is 3000 Hz. This corresponds to a bit rate of 30,000 bits per second for a signal to noise ratio of 30 dB. Referring to Table II, it will be seen that there is a tremendous saving in bandwidth by the use of speech elements. The data of Table II is for a signal to noise ratio of 30 dB. The data of Table II represents only the recognition aspect of speech and does not include accent, inflection, tone, etc., and artistic properties of speech which would increase the bit rate.

The importance of speech analysis for speech transmission, input to computers, control of machines and other applications provides the reason for the extensive research programs.

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PROCESS FOR RECOGNITION OF SPEECH SOUNDS

The main features, characteristics and processing required for the recognition of speech sounds

- Segmentation
  - Amplitude pauses
  - Voiced-unvoiced-voiced
  - Unvoiced-voiced-unvoiced
- Normalization
  - Amplitude
    - Absolute
    - Relative
  - Time—no change
- Envelope
  - Growth
  - Duration—steady state
  - Decay
  - Bilateral unbalance
- Spectral Distribution
  - Absolute
  - Relative
  - Pattern
- Amplitude Distribution
  - Absolute
  - Relative
- Time
  - Absolute
  - Relative
  - Epochs
- Quantization
  - Frequency
  - Amplitude
  - Time
- Data Reduction
  - Compilation
  - Manipulation
  - Logic applications
  - Programming

Table I

TRANSMISSION CHARACTERISTICS OF SPEECH ELEMENTS

Speech elements	Number of speech elements required	Transmission of speech elements per second	Transmission rate, bits per second	Transmission bandwidth, in Hertz
Words	10,000	1.5	21	2.1
Syllables	1,400	2.5	27	2.7
Syblets	800	3.0	30	3.0
Phonemes	40	6.0	36	3.6

Table II

SPEECH SYNTHESIS

Speech synthesis is the process of producing speech from some sort of a code. There are many forms of speech synthesizers as, for example, an electrical analog of the vocal tract, spectrum reconstruction techniques, computer simulation and recorded speech elements.

The analog of the vocal tract consists of electronic frequency and hiss generators coupled to electrical resonators. The generators simulate the glottal source and noise sources. The electrical resonators simulate the mouth and nose cavities. The electronic generators and the electrical resonators are controlled by the coded input. Very intelligible speech can be obtained from vocal tract analog systems.

The spectrum reconstruction speech synthesizer, as the term implies, constructs the spectrum of the original speech from a code input obtained from the analysis of the original speech. The first development was the Voder consisting of a buzz source and a noise source connected to 10 contiguous band pass filters. The frequency and filters were controlled to produce the speech sounds.

The Voder can also be operated from a speech analyzer and thereby produce speech transmission. These systems are termed Vocoders. Many types of Vocoders have been developed for the transmission of speech.

The approximations of vocal transmission can be represented by linear differential equations. Such equations can be approximated by difference equations which can be programmed in a digital computer as arithmetic operations upon discrete values of the variables. In this manner, speech can be produced by a digital computer.

The speech elements such as words, syllables, syblets and phonemes, can be recorded on tracks on a magnetic drum and reproduced by means of a track selector. A decoder actuates the track selector from the coded input. This type of speech synthesizer has been in use for many years, calling out the floors in an elevator, giving the time by telephone, providing speech output from computers, etc. There are many versions. In some, words are used, in others, phonemes and syllables are combined to form the words.

From the standpoint of performance and applications, speech synthesis is more advanced than speech analysis.

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TELECOMMUNICATIONS RESEARCH STUDY

I. General Remarks

After reviewing the summaries of telecommunications research and development provided by the Department of Defense (DoD) and NASA, one is impressed by the sheer magnitude of the effort being sponsored by these agencies. When one adds to this the extensive basic and applied research effort at Bell Laboratories and the research and development programs of the independent laboratories, it would appear that telecommunications research in the United States is being carried on at a very substantial level.

It is true that DoD and NASA sponsorship is (and probably should be) directed increasingly toward mission-oriented applications, but it must be acknowledged that in the past much of the best basic research has been sponsored by these agencies.

Supposedly, it was the intention that the reduction of basic research support by DoD and NASA would be made up by increased allocations to NSF, but in fact the increase to NSF has been but a small fraction of the amount required. The net result is that the support for basic research in this country has decreased drastically.

Undoubtedly the panel will wish to address this problem in formulating its recommendations regarding telecommunications research. How to do this without appearing to come up with "just another self-serving committee report" will be a challenge which must be met.

II. Suggestions for Future Research

The following are some suggestions for research directions, or specific research areas suitable for work in a University laboratory. It must be acknowledged that the present University research effort in telecommunications is miniscule compared with that of an industrial laboratory such as Bell Laboratories, but for reasons indicated elsewhere in this report, it is important nonetheless.

A. Message Processing for Efficient Transmission

A great portion of messages transmitted are highly redundant. This is especially true for speech and image signals. Reducing this redundancy reduces the required capacity of the communications system many fold. Research is strongly needed in fast and real-time algorithm which can be implemented on a small computer.

B. Data Traffic Organization and Message Switching

Transmission facilities can be minimized by sharing. Traffic flow in a network can be organized to increase thruput and reliability. Methods of optimum control of traffic flow in a network are urgently needed. Some consideration should be given to dynamic relocation of transmission paths.

C. Network Optimalization

Sharing of transmission facilities can be accomplished by networks of channels which share the flow of messages. Research is needed in the optimalization of design layout which increases message flow and makes optimum use of transmission facilities.

D. Transmission Reliability, Coding and Security

In data transmission reliability is extremely important. We need methods of ensuring accuracy of transmission, including error detection and retransmission and forward error correction. Emphasis should be on simple methods that can be implemented easily and economically on a computer.

E. Efficient Modulation Methods

Efficient modulation methods should be developed to make the best use of frequency bandwidth. Multiple level schemes should be developed to take advantage of the high signal to noise ratio of some transmission media.

F. Pulse Code Modulation

Time domain multiplex methods should be studied along with the synchronization of such systems. Generalization of Pierce's model and Sandberg's model should be investigated in a manner that includes practical sources of error.

G. Digital Filtering

A better understanding of the errors in digital filters is needed. This aspect is crucial in determining the performance of digital filters.

H. Electromagnetic Environment Control

In order to control the quality of the electromagnetic environment the best approach seems to be the use of adaptive power control, i.e., reducing the radiation of each transmitter to the minimum required level of radiation which will achieve the desired quality of received message. The appropriate research effort is, therefore, to seek effective algorithms and system designs for accomplishing this type of control and to analyze the dynamic performance of such a system.

I. Low-loss Microwave and Millimeter Wave Transmission

Of the many papers presented at the 1972 International Scientific Radio Union (URSI) General Assembly in Warsaw, two hold out prospects for practical transmission systems with reduced attenuation at millimeter wave and microwave frequencies. The "frame beam-waveguides" described by an Italian group from C.N.R., Florence, P. F. Checcacci et al, represent a new class of the beam waveguide, originally described by Goubau. The new class consists of a series of equispaced dielectric frames only slightly larger than the beam cross section. Experimental tests show a measured attenuation about one-half of that for an iris waveguide having the same cell sizes.

A new type of coaxial waveguide described by H. M. Barlow of University College, London, is capable theoretically of sustaining "dipole-family" modes, in addition to the usual circularly-symmetrical waves and the waveguide modes that arise when transverse resonance is permitted. The lowest order screened dipole mode propagates (theoretically) throughout the spectrum with an attenuation of about one-third or less of the corresponding circularly symmetrical mode. The practical problem that remains to be solved is the construction of coaxial guides whose walls have the required (non-zero) reactive impedence demanded by theory. Although skepticism is likely to prevail until the theoretical results have been verified experimentally, the goal of reduced attenuation is of sufficient economic importance to warrant considerable further effort.

J. Telecommunications Education

The need for more engineers trained specifically in telecommunications has been raised by Dr. Kandoian and other members of the Panel. There is good reason to believe that an increased output of telecommunications engineers from some of the larger departments of Electrical Engineering could be achieved fairly easily and quickly. Most departments have a flexible curriculum which permits a considerable degree of specialization in the senior year. In addition, a year of graduate study in telecommunications engineering could provide well-trained experts at the M.S. level. What is needed, besides faculty competence and interest (both of which exist at many schools), is modest support for research projects and graduate assistants in this area. In most of the better schools all new staff are expected to engage in research as well as teaching in order to maintain knowledge and competence in their fields. Faculty salaries can be paid largely from University funds, but support for research equipment and research assistants must come from Federal or industrial sources. Funding of modest telecommunications research grants by NSF, for example, could have a marked beneficial effect on the output of telecommunications engineers.

K. Devices for Telecommunications

For an authoritative, comprehensive survey of the needs and problems in the device area, one can hardly do better than to examine the appropriate sections of a study by a distinguished panel of experts under the chairmanship of the late Jack Morton of Bell Telephone Laboratories. This report of the National Materials Advisory Board entitled "Materials and Processes for Electron Devices" was published in May 1972 by the NAS-NAE. It surveys in depth the materials and processes for solid state electronic devices, identifying problems, considering possible solutions, and making recommendations.

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COMMENTS BY E. RECHTIN ON "TELECOMMUNICATIONS RESEARCH STUDY"

Message Processing for Efficient Transmission

A better case can be made for the high redundancy of speech than for that of images, unless the latter are either stationary or move very slowly compared to the picture framing rate. Some speech compression systems have been built which show that essentially the same quality of speech can be achieved at 2400 bits per second as at (uncoded) 48,000 bits per second; a further compression of more than a factor of about 10 seems unlikely for any reasonable cost. Thus, for speech, the problem is to realize this factor of a 100 or so in a practical and inexpensive way. Efforts to compress typical television signals show less promise; the exception is fixed displays and computer outputs for which the reader can afford to wait a few seconds.

Data Traffic Organization and Message Switching

Another technique of interest is "saturation routing" in which the telecommunication system is probed for open pathways between signal source and the signal recipient. The algorithms for this dynamic relocation of transmission paths in a large communication network do require research.

Network Optimalization

Another challenge is the design of "precedence systems" in which higher priority calls can preempt those of lower priority. Existing precedence systems are relatively primitive and tend to saturate during crises when all the users escalate their precedence until their calls get through. The call completion rate for most users,therefore, drops abruptly during these conditions.

Transmission Reliability, Coding and Security

Some of the better and more recent payoffs have been in the treatment of the kinds of non-Gaussian errors which are characteristic of many channels, including telephone circuits, HF links, and ELF links. These links are characterized by "hits" rather than a typical Gaussian "noise level" with results that are particularly bad for digital transmission.

Efficient Modulation Methods

We have tended to concentrate on optimal use of an assigned frequency band rather than on minimizing the channel to channel interference. It might be an interesting research project to derive the best in-channel modulation, subject to the constraint of specified out-of-channel interference.

Pulse Code Modulation

Of particular importance these days is the synchronization of pulse code modulation systems for mobile platforms, particularly aircraft.

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