Compunications Network Management

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PREFACE

How growing competition will influence the effectiveness and efficiency of compunications facilities or services is a controversial matter of some importance to both clients and suppliers of these facilities or services.

Network management is one focus of controversy. To caricature one extreme position on network management, only AT&T's leadership and dominance are up to doing it right. To caricature the other extreme, the invisible hand in an unfettered competitive market can do it better.

Such extremes are rarely expressed nowadays, although they abounded in rhetoric as recently as 2 or 3 years back. Currently, a milder and less certain tone is being heard in debates, as illustrated by the National Telecommunications and Information Administration's expression of the national security community's concern that "total reliance on competitive forces...may result in the impairment of the carriers' ability to maintain a national network management structure. Carriers facing competitive pressure may not have the incentive to jointly plan...[or they may]...simply as good business practices, have the incentive to jointly plan in such a way that national security and emergency preparedness needs may largely be met."

In order to formulate policy in this area five basic questions must be considered: manage <u>what</u>, <u>why</u>, <u>how</u>, <u>to what extent</u>, and <u>at what cost</u>. In this paper, Robert H. Klie addresses the questions what and why in the belief that better understanding and perhaps agreement on these points can shed some light on how and how much to manage.

What must be managed is described under the headings of Network Planning; Design, Development and Facility Implementation; and Operation and Use.

Why manage is discussed in terms of linkages among networks. Truly isolated networks may, by definition, be managed as much or as little and in any way whatsoever without affecting anything other than themselves and their own clients. But coupling between apparently isolated networks may occur beyond the control of suppliers or clients as, for instance, when a United Parcel Service strike floods the mails and the bus lines. Moreover, no network is immune to failure: the need to maintain or restore service by drawing on alternative resources from within or outside one's own subnetwork or network gives the most dramatic (albeit far from only) answer to the question "Why manage?" General Paschall's appended account of his operational experiences in managing military satellites illustrates management of network failures through vivid specific examples. Some may view his story as a horrible example of what may -- or will -- happen under any deviations from Bell System management practices. Others may see it as shining proof that alternative practices serve more than adequately. Such differing views frame the policy debate but do not resolve it.

Beyond emergency relationships between otherwise isolated and separately owned and managed networks, there may be intentional linkages for the joint supplying of what the ultimate client sees as one facility or service. Or a service supplied by one entity may be rendered in part or in whole over facilities supplied by another entity. For example, such Bell System competitors as SPCommunications and MCI interconnect their own long-distance transmission facilities with local Bell System facilities. Service competitors such as Graphnet and GTE-Telenet lease some of their facilities from the Bell System.

Network costs will be incurred under any kind and degree of management, but the evaluation of such costs -- and benefits -- across the wide range of possible network management options is a difficult task. Klie addresses this point in respect to the questions of what and why, but much more detailed analyses are necessary in the light of how and to what extent.

I sensed in the critical comments of the reviewers of a draft of this paper little disagreement with Klie's description of what needs to be managed or indeed why it needs to be managed to some appropriate extent. Disagreements grow sharp, however, over how much management is appropriate under what circumstances and over how best to manage. Klie's paper is therefore only a first step. The next steps in assisting policy formation are to define various alternatives, to assess the likely impact of these alternatives on the diverse affected interests among both suppliers and clients, and to establish mechanisms for the evaluation of costs and benefits. These steps remain to be taken.

Robert H. Klie, the paper's invited author, retired from Bell Laboratories in 1978. Lee Paschall's Appendix is based on a speech that he delivered while he headed up the Defense Communications Agency and that he subsequently edited for publication at the Program's request.

Anthony G. Oettinger

Note: For a prior analysis of a more limited aspect of network management see A Technical Analysis of the Common Carrier/User Interconnections Area, a Report of the Panel on Common Carrier/User Interconnections, Computer Science and Engineering Board, National Academy of Sciences, to the Common Carrier Bureau, Federal Communications Commission. National Academy of Sciences, Washington, DC, June 1970.

TABLE OF CONTENTS

INTRODUCTION

Networks for modern communications are becoming more diverse in regard to ownership, types of services rendered, and operating responsibility as a result of advances in technology and because regulatory agencies are changing their views of how the public may best be served. This paper is devoted to describing and discussing the principles and processes of network management and to pointing out the importance of adequate management so that all aspects of service, ownership, and operations are carried out efficiently and economically. The risks of providing inadequate network management, high in terms of economic and service inadequacies, are pointed out in relation to the benefits of providing full and responsible management throughout the life of any network. However, the extent to which network planning must be integrated cannot be prescribed. The existing communications network is not now a monolithically planned structure. It has evolved and will continue to evolve from a lot of negotiations which must necessarily be based on the acceptance and use of network planning.

It is recognized that network management principles and processes are familiar to many readers, especially to those in the technical community devoted to the exercise of such responsibilities. However, in the present environment of expansion and change, many people who are not so involved may benefit from an understanding of the multidisciplinary skills required in network planning so that they may effectively contribute to the establishment of sound policy.

Two types of networks, service networks and facilities networks, must be considered in relation to network management. Service networks include the aggregation of customer terminals, loops, trunks, switches, processors, and maintenance equipment required to provide end-to-end service to network users. An obvious example is the network that provides message telephone service throughout the United States and most of the rest of the world. Facility networks are combinations of communications media and equipment used to implement service networks by providing the necessary component circuits. Thus, while service networks are designed primarily to meet customer needs and facility networks are designed primarily for economy and flexibility, it is clear that there are strong interactions and interdependencies between the two. Either type may perform poorly, be unreliable, be excessively costly, and/or fail to provide desired services if it is not adequately managed.

This paper is a contribution to the Program on Information Resources Policy which has been established to mark trends, discuss strategies, and lay out policy options and consequences in a broadly-defined, changing world of communications resources.[1] Various types of facilities that exist or are expected to become available under diverse ownership in the near future are or will be major elements of this new world. In addition, the way in which these facilities are combined to form facility networks in support of service networks and the manner in which networks of both types are managed are basic to the efficiency of use of information resources. Thus, while this paper is not concerned directly with establishing policy, it is intended to provide a foundation upon which policy decisions can later be addressed.

Recently, there has been a burgeoning growth in the number and complexity of communications networks composed of segments provided and operated by a number of suppliers. This growth, especially notable in respect to service networks, is a result of large users striving to reduce their communications costs by selecting least-cost alternatives for individual segments of their networks. A facility network is an aggregation of transmission, switching and signalling systems. Facility networks may be interconnected to provide links in service networks. Service networks may sometimes be further interconnected in various and complex ways that can result in challenging problems of performance and operations.

Providers of network segments may have economic, performance, and operating objectives that are quite different from corresponding parameters of segments provided by competing suppliers. Such differences can result in service deficiencies ranging from modest impairments to unworkability. One way in which such incompatibility may be manifested would result from the use of a link or entity which has been optimized in some manner without regard to interface or interaction problems with other entities in the network. Such suboptimization, made at the expense of the overall network, may result in operating inefficiencies and high cost or may even create inoperable conditions. For example, a low-cost transmission system optimized for speech signal transmission might appear to be an attractive link for a portion of a large facility network. As network operation evolves, it may become desirable to use that link for data signal transmission and, to make this possible, substantial sums might have to be expended to redesign and modify the terminal equipment to make data signal transmission possible. Advance planning might have resulted in the installation and use of different equipment for that link making it suitable initially for the transmission of data signals.

If satisfactory service is to be rendered to the user or customer, it is essential that overall operation of multisegmented service and facility networks be coordinated by a carefully planned network management process. This process consists of a broad spectrum of work activities that should be thoroughly documented and carried out according to specific procedures. Included are the establishment of service objectives and transmission, switching, and maintenance plans to guide the design, implementation, and operations of individual segments and the overall network. These responsibilities define network management as an ongoing process.

Policy decisions regarding service networks and the facilities that must be provided to make them feasible are constantly being made and must continue to be made by managerial, legislative, administrative, and regulatory bodies as technology evolves and as new forms of services are introduced. In certain situations, the assignment of responsibility for network management may itself be a subject for which sound policy must be established. Such policy decisions can only be made logically on the basis of accurate information about facilities, a knowledge of the economic, political, and market environments in which issues must be resolved, and a deep appreciation of the importance of properly managing the multifaceted, multiply-owned, and increasingly competitive facility networks that provide the circuits of the service networks. The constraints that must be considered when applying network management principles, including the state of the technology and the economic, political, and regulatory environments, must also be taken into account. Two examples of how the design and structure of facility networks may be influenced by such policy decisions are the regulatory rulings on (1) the allocation of satellite and submarine cable circuits that are used for communications between the United States and foreign countries and (2) the number and use of protection channels that may be provided in microwave radio transmission systems.

Existing and anticipated service and facility networks may be multifaceted from a number of points of view. They may provide a wide variety of services that include voice communications, video signal transmission, and data communications between computers and other types of business machines. They may be used by a combination of several providers of these services and they may be made up of facilities and terminal equipment that have been furnished by different manufacturers and vendors. Portions of the networks may be managed by a variety of independent organizations and they may be regulated by local, state, federal, and/or international agencies. Finally, they may be owned by a number of entrepreneurs whose interests may be compatible or in conflict with one another. Thus, there is a wide variety of services, signals, users, facilities, manufacturers and vendors, managers, and regulators; economic and efficient operation can only be expected if the service or facility network is carefully planned, designed, implemented, maintained, and operated according to a coordinated management process.

Where a single organizational structure exists, such a process can be imposed. However, where several organizations are involved, this process is no less important and requires carefully documented plans and procedures that are accepted by all participants. Some form of responsible agency or authority acceptable to all concerned is needed to perform the management function. An example of this mode of operation is the international telecommunications network which is made up of the national networks of many countries. The interconnection and operation of these networks as a single global network is guided by three major committees of the International Telecommunication Union (ITU), a specialized agency of the United Nations which recognizes it as the sole specialized agency competent for telecommunications.

The need for network management and the extent to which such expertise must be applied to a specific situation are, of course, functions of the size and complexity of the network. With little risk, small, compact networks serving a limited area and a limited number of terminals may be constructed with a minimum amount of network management effort. If service is unsatisfactory, corrective action can easily be taken, usually with a minimum of economic or other penalty. As network size and complexity increase, the risks escalate rapidly and the costs involved in taking corrective action in the event of unsatisfactory performance also increase rapidly. It is difficult to specify a cross-over point between low risk and high risk situations or between low cost and high cost corrections. Recognition of such cross-over points is a matter of judgment based primarily on experience.

The four major components of the network management process are (1) planning, (2) design and development, (3) implementation and (4) operation and use. All of these components interact with the others and each must be regarded as iterative. Adjustments and compromises must be made almost continuously as the network evolves. The first three of the components are applicable prior to the initiation of service on a network or on a new addition to a network. Operation and use, on the other hand, are keys to sound network management once service has begun. Included in this category of management functions are maintenance, rearrangements, service restoration, and feedback. Ongoing measurement of service performance and the feedback of measurement results are needed in order to regulate the management process. The worth of a network depends primarily on the customer's perception of the value of the service and, thus, measurements of performance must include the measurement of customer subjective reactions to service as well as the objective measurement of parametric performance criteria.

NETWORK PLANNING

As in any large enterprise the planning function is prerequisite to all other activities associated with the management of a communications service or facility network. Planning is also an on-going function that must be carried out as a network grows in size and complexity. The establishment of network standards, efficient design and development, implementation, maintenance, user operating and use guidelines, and documentation all depend on sound and thorough planning. Some of the important elements of planning include the specification of the types of customers to be served and their service needs, service objectives, characterization of the types of signals to be transmitted, the selection of required facility types, the development and definition of network topology, and the specification of a number of network operating characteristics.

Customer Types and Service Needs

In the planning of a communications service network, it is essential to know the types of customers to be served and their service needs. If a large number of business and residence customers are to be provided switched message telephone service, the needs of such customers would be well served by a network having features such as those of the direct distance dialing (DDD) network of the telephone industry in North America. If a new network is to serve a large number of business customers with a need to interconnect flexibly many voice-frequency data terminals, the network might be similar to the DDD network in its topology but could require substantially different signalling and switching systems because the statistics of data messages are quite different from those of telephone connections. Broadband analog connections to serve the needs of a video network or high-speed digital connections between large computers would require yet other approaches to network design. Whether such services were to be fixed (point-to-point or multipoint) or switched would also have a strong impact on the entire structure of the service network and its topology as well as on the network of constituent facilities.

If the network under consideration is to be provided for a single large customer or for a group of customers with a high community of interests and well-defined service needs, the specification of those needs could be straightforward but complex. If it is to be provided as a common carrier network with a wide variety of customers, it may be necessary to conduct marketing studies to determine customer needs for network planning purposes.

Special features required to satisfy customer needs may also influence the network design and, wherever possible, must be planned in advance. For switched voice services, such features might include voice conferencing, abbreviated dialing, alternate routing, mobile services, and many others. Data service requirements might include a store-and-forward feature, machine language translation in the network, selectivity of transmission rates, and others. Automatic billing might be desirable or required for either type of service. If video services are to be furnished, conference arrangements may be needed. Signalling and switching requirements might have to be compromised or adjustable to satisfy data service requirements, where holding times tend to be somewhat different from those found in networks devoted primarily to voice service. All these features and many more must be considered in the planning, design, or modification of a communications network.

Signal Characterization

In planning a new network or a network modification, the characteristics of the signals to be transmitted must be defined in terms of format and tolerance to impairments in order to relate bandwidth or digital transmission rate requirements to facility capabilities. Parameters other than bandwidth and digital rates must also be known so that adequate planning may be carried out in respect to the choice of terminal modulating equipment and the possible necessity for processing the signals to make them suitable for use on transmission and switching facilities. Speech signals, analog and digital data signals of a wide variety, and picture signals are commonly transmitted and may require bandwidths ranging from the voice-band, or less, up to about six megahertz.

Performance Objectives

Every aspect of service network performance must be related in the planning process to a realistic and achievable set of performance objectives. These must include such transmission objectives as the signal-to-noise ratio, impulse noise interference, delay and delay distortion, and bandwidths for all the signals to be transmitted. Switching objectives must include permissible dial tone delay, blocking of calls, time to establish connections, special features, and alternate routing. Signalling objectives must be established in a manner consistent with the numbering plan to be used and with the established switching objectives. Objectives must also be given for all other aspects of network performance such as circuit availability, reliability, stability, and maintenance of service.

Facility Selection

When customer service needs are known and signal types and performance objectives have been established, a first attempt can be made at selecting facility types to support a new service network. Selection depends on many factors not the least important of which is economics. In addition, the characteristics of transmitted signals, traffic volume, the required degree of reliability, and customer requirements in respect to special features must all be considered relative to the capability of each physical facility entity to fulfill the needs. The compatibility and interconnectability of facility entities must also be given adequate attention during all phases of the planning process.

Topology

The placement of switching nodes, the interconnection pattern of transmission facilities between and among these nodes, the provision of routing and alternate routing arrangements for various connections between nodes, the time dependence of traffic loads, the sizing of each entity, and a signalling plan for switched connections that provides flexibility and the means for growth, decline, and/or change in the network all comprise or relate to network topology. The complexity of these topological features depends on the size and complexity of the network itself and on the complexities of the services to be offered. In addition, the size of each entity in the network is directly dependent on the volume of communications to be carried by that entity. Thus, reasonable estimates of busy-hour traffic volumes must be made throughout the planning process. As in nearly all other aspects of network planning, the determination of topology must be regarded as an iterative process and must be carried out irrespective of who owns or manages the network or its entities.

Operating Characteristics

Interwoven with all other aspects of network planning is the necessity for developing an adequate specification of operating characteristics in order to meet satisfactorily the desired standards of quality in respect to transmission, switching, signalling, maintenance, and operations. To achieve and maintain such standards, it is necessary to establish comprehensive plans for each of these major categories of operation.

Transmission Plan. Transmission quality in a communications service network is strongly dependent on the provision of a viable transmission plan. Even simple networks cannot be assembled and expected to operate satisfactorily unless adequate transmission planning is undertaken at the outset. This is so because there are so many trade-offs and compromises to be considered. Gains, losses, impedances, echoes, delays, noise, crosstalk, and other parameters are all highly interactive and must be carefully balanced relative to one another and relative to operating requirements if satisfactory performance is to be achieved. Economic or operating disaster is a likely result of trying to construct a communications network without first developing a sound transmission plan, especially if the network is large and complex.

Switching Plan. A large service network intended to provide switched services must incorporate a switching and numbering plan consistent with the needs of the services involved in terms of its uniform applicability throughout the network, in terms of flexibility in respect to the variety of services to be provided, and in terms of graceful and economic growth. Where no switching is involved, such a plan is unnecessary and, in simple networks, the switching plan might also be quite simple. However, the importance of providing such a plan, where appropriate, cannot be over-emphasized. The technical and economic penalties of incorporating such a plan by retrofit on switching machines not initially designed to provide needed switching functions may be severe. The lack of an adequate plan or the introduction of unanticipated changes in a service netowrk may interact in serious ways with existing facility entities.

Signalling Plan. No matter how simple the network, means must be provided for the called station to be signalled when a connection is to be established. This requirement implies further that the calling station must be provided the means for initiating such a signal. As the complexity of the network and the number of switching nodes and features increase, signalling requirements also increase in complexity. Where switching is used, supervision of the connection is necessary; i.e., signals must indicate that a connection is desired or established and must also indicate when a circuit is to be disconnected. Similarly, signals must indicate busy and idle circuit conditions.

Conceptually, the signalling function is extremely simple -- a push-button and buzzer or light -- but, in a complex communications network, the provision of adequate address and supervisory signalling at a reasonable cost is a challenging problem. Signalling systems must be compatible with all of the switching and station equipment to be used and must be capable of operating efficiently over the transmission paths of the network. Signalling must be used not only by calling and called stations but also by all switching systems used in the connections. Thus, planning for signalling must go on concurrently with the planning for switching and transmission facilities.

Maintenance Plan. Maintenance includes the surveillance and measurement of operating facilities and all activities associated with the detection, location, and isolation of trouble conditions together with the dispatch of personnel to effect needed repairs or adjustments. Surveillance and measurement are continuous activities that are essential in determining that the network and its component facilities are meeting performance requirements. Such activities must be carried out on all facilities used in providing service to the network customers. As networks have grown in size and complexity, problems of providing for equipment repair have increased. Furthermore, where multiple ownership of facilities is involved, the problem of detecting and isolating a problem to a particular segment has become increasingly difficult. Test facilities must be capable of detecting real and incipient troubles and must provide efficient and economical means for locating and isolating faulty equipment, often remotely.

As previously mentioned, network management includes the function of measuring operating parameters and customer reactions relative to system performance and feeding back the results of such measurements so that corrective action can be taken where necessary. Thus, maintenance plans must include the provision of suitable equipment and programs to achieve the desired results. Planning for the provision and use of maintenance facilities and programs is an essential part of overall network planning.

Operating Plan. The specification of an operating plan includes the provision for alternate facility utilization in the event of failure, of plans and facilities for emergency, temporary restoration of service in the event of major failures, for the assurance of circuit quality under normal operating conditions, and for the control of switching and transmission facilities in the event of traffic overload. As service networks have grown in size and complexity and as switching machines have evolved, networks have become less tolerant of traffic overloads. Now, instead of the gradual deterioration of service experienced with switching systems of earlier design, the sudden introduction of a traffic overload with modern electronic systems may result in near catastrophic failure. Thus, modern networks are far more dependent on dynamic management than was true in earlier networks. These facets of operations are all dependent on the size and complexity of the network and on the degree of service reliability that has been established as an objective for the network.

DESIGN, DEVELOPMENT, AND FACILITY IMPLEMENTATION

When the planning stage of service network management has progressed to such a point that major parameters can be identified and defined with reasonable confidence, the design and development of the network may be started. As design and development proceeds, facility specifications must be started because each step in the design process has serious and interacting implications in the selection of transmission, switching, signalling, maintenance, and operations facilities. As the network design evolves, it is essential that facilities are or can be made available to provide the services desired and that features and performance criteria can be met within the existing state of technology. After network design and general facility specifications have been crystallized, facility implementation may begin by placing orders for the appropriate equipment and by initiating the necessary engineering work associated with the project.

Network Design Specifications

Network design is an extension and fulfillment of the network planning procdss. Service types, signal characteristics, service features, network topology, and operating requirements must all be crystallized so that implementation and operation may finally be undertaken.

Network Features. As the network evolves from planning towards implementation, features required to satisfy customer needs must be incorporated in the design. Since there is no specific network now being considered, such features cannot be uniquely described here. However, it is necessary to determine if the network is to provide predominantly analog services such as voice and video, if it is to provide a predominance of digital services, or if the services are to be mixed. Such a determination may have a strong influence on the selection of the types of facilities to be used. Some limitations and constraints must be recognized and dealt with when analog and digital services are to be served by a common network. If the network is designed to provide just one type of service and to transmit only one type of signal, a resulting major penalty may be the lack of flexibility.

Design decisions regarding facility network features must also be made with the volume of communications in related service networks as a serious consideration. Economy of scale may lead to one conclusion where volume is high; low volume requirements might lead to a quite different selection of facilities.

Network Topology. Topological details must be thoroughly specified in the process of service network design. Distances between network nodes, the volume of communications to be carried over each transmission route, the amount and nature of switching at the nodes, the character of the terrain traversed by transmission facilities, the distribution of customers (and, therefore, of network terminals), and the environmental operating conditions for each entity of the network must be known in considerable detail to permit suitable facility specification. If the network facilities are to interconnect with one or more other networks, interface and operating requirements must be established in great detail. Such requirements must include all aspects of network management - transmission, switching, signalling, and operations.

Operating Features. The selection of facility types to satisfy service network objectives can only be accomplished after operating features have been specified in considerable detail. Overall requirements on reliability, survivability, and stability must be given; switching features and options (connection times, holding times, alternate routing, numbering plan, customer options, signalling features, etc.) must be determined; end-to-end performance requirements must be derived; and allocations of all requirements and costs to individual entities must be derived in a manner consistent with the overall network objectives.

Sound network management must permit some latitude for compromise in the allocation of service network performance objectives. It is often found that end-to-end objectives can be met more economically when allocations are adjusted between certain portions of a service network or between facility network entities than if the original allocations are rigidly observed. However, care must be exercised so that the basic objectives are not exceeded when other combinations of entities are used or when the network grows.

Facility Design and Implementation

Each system, segment, or individual entity of the facility network must be specified in sufficient detail to permit logical implementation of facility and service network plans. The specifications must be made in sufficient detail so that all network design objectives may be met. Functional needs, technical performance, and traffic capacity specifications must all be considered.

After specifications have been determined and documented, each facility to be used in a network must be procured or manufactured on the basis of previously established requirements. Allocated costs and performance parameters must be carefully weighed; both must satisfy established criteria but care must be taken that performance parameters, especially, are well controlled. If performance is poor, customer reaction is adverse; if performance is too good, costs are likely to be excessive. Traffic volume and operating feature requirements must also be met.

All facility types must be selected for implementation with equal care; each plays a unique and vital role in satisfactory network operation. Thus, transmission, switching, signalling, maintenance, and operations facilities must all be provided according to network plans and, in addition, each must be compatible with all the others. Many of the processes are described here as they would apply to a newly conceived network. It must be appreciated that essentially all network management functions apply equally to new networks and to existing networks undergoing change or expansion.

Performance Requirements. An essential function in network management is that of specifying facility performance requirements for each segment or physical entity in the network. As mentioned previously, such requirements are derived from requirements established for the overall network; they must be allocated to each link or entity in a manner consistent with network planning considerations and cost/benefit analyses.

To achieve satisfactory network performance, the specification and allocation process must be carried out for transmission, switching, and signalling entities. In large and complex networks, it is usually uneconomical to provide fully satisfactory service on every possible connection under every conceivable set of circumstances. Thus, it is necessary to conduct statistical analyses of objectives, network performance, and customer (or user) satisfaction in order to arrive at an acceptable and economical level of network operation. Some measure of satisfactory operation must be developed. One such measure, used in the national network of the United States, is based on a grade-of-service concept which relates test results to customer subjective opinions of various types of impairments.[2]

For transmission systems, there are many performance requirements that must be specified in accordance with those covered under "Planning." These include the signal-to-noise ratio, gain and delay distortions, hits and dropouts, absolute delay, and others. Most of these apply to analog systems and, especially, to analog signal transmission over any type of system. Most apply also to digital systems and signals as well. In this case, the error rate in transmission is also a critical parameter.

For switching systems, there are other requirements to be specified -- for example, dial tone delays, the number (or percentage) of blocked calls, and switching errors (wrong numbers, no connects, false busies). In addition, it is necessary to specify for each switching entity the need for switching local, tandem, or toll calls or some combination of these.

If the network is one in which alternate routing is a feature, the switching and signalling functions must be coordinated and specified in detail to satisfy this requirement. The speed of signalling and of establishing connections must also be specified to satisfy service requirements for the types of services to be provided - voice, data, facsimile, etc.

Operating Characteristics. Among the many facility requirements that must be specified in detail are those relating to operating characteristics. The reliability and stability of each facility network entity must be established on the basis of allocations of the overall service network reliability and stability requirements. Maintenance procedures consistent with the type of maintenance equipment to be used must also be established and thoroughly documented. The compatibility and interconnectability of each entity relative to all other entities with which it is to operate must be assured by the detailed specification of all interface requirements. Requirements on privacy established for the service network must be observed within each facility network entity. Transmission, switching, and signalling system performance under traffic overload conditions must all be specified in such a manner that network requirements are not abrogated in the event of failure or emergency operating conditions. Customer features, service capabilities, and flexibility in application for each entity must be consistent with network objectives.

To summarize, the specification of facility designs must be documented in all respects so that each entity performs in a manner that permits network design specifications to be met. Implied is a systematic approach to the control of quality at the time of network and/or entity design and throughout service life. To achieve such quality control, network requirements on all parameters must be divided and allocated to the entities so that all parts may operate together economically.

Traffic Capacity. Each facility network entity must be designed for the amount of traffic to be carried by the one or more service networks using the facility. The determination of traffic involves statistical studies of the expected number of calls to be carried, the holding time for each, and the time consumed in signalling. For each of these parameters, there are wide variations with time and circumstances that must also be considered in the statistical studies. These include variations associated with time of day (busy hour versus non-busy hour), seasonal variations, and variations caused by exceptional events such as storms or other natural or manmade disasters. These matters all fall within the concepts normally considered as traffic engineering.

In addition to the parameters involved in the traffic engineering studies, the bandwidths and digital rates of signals to be switched must be established. Traffic, bandwidth, and digital rate parameters all have a direct impact on the required bandwidth (or bit rate) of transmission systems and on the transmission characteristics of switching systems.

Transmission. Facilities must be provided to permit the transmission of a variety of signal types between switching nodes and between network access points and customer premises. A great variety of systems is available and the selection of a particular type depends on a large number of factors all of which are dependent to some degree on the results of the planning stage of the network management process.

Transmission facilities must satisfy a wide gamut of requirements including bandwidth or digital transmission rate, modulation and multiplexing arrangements, transmission performance, reliability, and stability.[2] Where interconnections must be made with other service networks or with switching, signalling, and operating facilities, the interface requirements must be specified in detail. The overall performance objectives for tandem-connected service networks must also be established and documented. Generally, each such network is optimized to operate independently; when two or more are tandem-connected, degradation in quality may be expected unless prior provision had been made to do so.

The transmission mode must be determined for each entity. The determination of mode depends on signal types, the transmission medium, costs, and the part of the network in which each entity may be expected to operate. Where network connections are made directly to customer terminal equipment, two-wire or four-wire baseband transmission is often the most economical. Other parts of the network, where heavier traffic loads are concentrated, usually operate most economically when some form of carrier system is used. Such a system may be a four-wire facility, with opposite directions of transmission carried over separate transmission paths, or an equivalent four-wire facility, with opposite directions of transmission carried on the same path but in different frequency bands.

Another basic specification is that of the methods to be used for modulating and multiplexing signals and for processing line signals for transmission. Amplitude, frequency, or some form of pulse modulation are all commonly used; frequency division and time division multiplexing methods are both used extensively where appropriate.

The specification of a transmission medium must be made for each network transmission entity. The choice depends on distance and the type of terrain to be covered, costs, the portion of the network under consideration, the types of signals to be transmitted, and the nature of the services to be provided. In some cases, the choice is influenced overwhelmingly by the existence of a medium already installed. This situation is more likely to exist where a network rearrangement or expansion is under study than where a new network is being considered.

As network planning and design proceed and as preparations are made for the implementation of needed facilities, the choice of transmission medium becomes essential. Other aspects of transmission facility implementation are depenent on the choice of medium. Media in common use today include wire pair and coaxial cables and terrestrial and satellite microwave radio systems. Optical fibers, now just entering the field, give promise of providing another viable medium, especially for high speed digital transmission.

Transmission facilities vary from a single pair of conductors used for a single circuit to a multichannel carrier system of very high traffic carrying capacity. The conductors may be an open-wire line or a pair in a large multipair cable used to connect a terminal (telephone, date set, etc.) to a central location which may or may not provide switching, as required. A carrier system may also provide a connection between customer terminal equipment and the central location or, more likely, may be used to provide connections between central locations, especially in a switched network. The carrier system may employ any of a number of transmission media including wire pair or coaxial cables, microwave radio, satellites, wave guides, or light guides. The facility may be digital or analog.

The selection of transmission facilities depends on many factors including the predominant types of signals to be carried, the distances involved in transmission, the amount of traffic to be served, and the interconnectability of the new facility with existing facilities. The factors that must be most carefully evaluated are those involving the ability to meet service requirements and to do so economically.

Transmission systems are generally designed to fulfill requirements appropriate to certain positions in a network. Long-haul systems, intended for use over thousands of miles are usually designed to meet more stringent performance and operating requirements than those designed to operate over no more than a few hundred miles. Design features associated with such classifications of systems also have a strong influence on the types of transmission media that are most suitable. Wire-pair and microwave radio systems are suitable for short-haul applications; microwave radio, satellite, and coaxial systems are generally economical in long-haul applications. Initial designs have made light-guide systems appear most economical in short-haul applications but it appears highly probable that this transmission medium will find applications in long-haul situations as the technology evolves.

Modulation methods and multiplex arrangements must be selected according to network planning and design decisions and must be compatible with the transmission facilities to be used. Traffic volume, network features, signal types, position in the network, and costs all influence the selection of these facilities.

Switching. The specification of network and switching system design requirements is dependent on the types of signals to be transmitted and on the features specified in the switching plan. Basically, there are three modes of switching system operation that must be considered: these are called progressive, coordinate, and stored program control.[3] These terms may be applied to the operation of each switching entity and, equally, to the operation of the network as a whole. The three methods, as listed, are successively more modern. Stored program control, most likely to suit the needs of modern networks, requires the use of electronic switching systems to achieve the maximum speed and efficiency of switching.

The switching networks of individual switching machines may employ two-wire or four-wire space division or four-wire time division switching techniques. The choice of which is to be used depends on the types of signals to be transmitted, the position of that entity in the network, the degree to which each can best satisfy the features set forth in the switching plan, the integration of transmission and signalling systems with each switching system to be used, and costs.

The specification and selection of switching systems depends heavily on the complexity of the network switching and numbering plan, the need for alternate routing, the bandwidths or digital rates of the signals to be switched, the volume of traffic to be switched, and other considerations. As previously noted, modern networks tend heavily toward the use of stored program control for the network and for the individual switching machines used. More features can be provided and cost/benefit analyses usually show advantages to this method of switching. Interactions between switching, signalling, transmission and operations systems must be resolved and, if connections are to be made to or through other networks, compatibility must be assured.

Signalling. The complexity of implementing signalling facilities is dependent on the size and complexity of the network and the switching and numbering plans (if required). Implementation also depends on the types and capabilities of the switching machines to be used, the characteristics of the transmission facilities, and network features. As the planning, design, development, and implementation functions of network management are carried forward, signalling plans, designs, and implementation must be included.

Signalling facilities may introduce significant network costs and their selection is further influenced by the need for privacy, reliability, and protection from improper use of the network. In general, the incremental network costs ascribable to signalling are less when digital transmission and time division switching facilities are used. However, overall costs may be less in networks or network segments that employ analog facilities even though signalling costs are higher. Careful and thorough cost/benefit analyses must be made, especially where a large and complex network is involved.

Operating and Maintenance. Many types of facilities must be used for operating service and facility networks and network entities. Equipment is required to monitor and maintain the network and its constituent systems, to control its switching functions (such as alternate routing) under normal and emergency conditions, to restore service when major failure occurs, to provide billing for services rendered, and to provide manual assistance (operator services) in establishing connections. Such facilities may be controlled by manual means or they may be controlled by various degrees of mechanized equipment, even to almost complete computer control. The specification of control methods must depend on the size and complexity of the network, on the results of cost/benefit studies, and on the specific requirements established for network reliability, stability, and survivability.

For maintenance, it is generally necessary to provide for the detection, identification, and location of troubles. Manually or automatically operated test equipment must be made available for local or remote testing by manual or automatic means and for monitoring performance for the assurance of circuit quality. In some cases, the results of such measurements are used for the continuing evaluation of service performance used in regulating the management process.

The reliability of individual entities and, thus, the reliability of the network require the use of equipment that automatically tests the trunks in a switched network. In addition, vital transmission links and parts of switching machines must be provided with automatic protection switching arrangements to guarantee continuity of service in the event of a failure of a working link. In large networks, provision must also be made for the restoration of service over standby facilities (in the event of major failure) and traffic management facilities are needed to adjust network operation to accommodate operating procedures to emergency situations.

Network stability must be assured from several points of view. The gains, losses, and delays of all circuits must be maintained within close limits to assure satisfactory transmission performance. Generally, this function is designed into each transmission system so that it contributes no more than its allotted share of allowable deterioration or distortion. Overall network monitoring is often necessary to assure satisfactory performance. Frequency stability of both analog and digital transmission systems and modulating and multiplexing equipment must be maintained within close tolerances. In a large network, this need may require a network of synchronizing circuits tied in with the entire facility network.

The nature and extent of operator services depends, as do so many aspects of network management, on the nature, size, and complexity of the network. Operators may be needed to complete connections in some circumstances, to provide directory assistance, and to respond to customer communications regarding repair, installation, or business office matters. These services may be very simple and inexpensive or may be extremely complex and costly.

Implementation Processes. It is desirable once more to stress the interdependence of all aspects of network management. Thus, the choice of a transmission, switching, or signalling system or the specification of particular methods or equipment for network operations depend on the types of signals and services to be provided and on network objectives relating to those services.

The process of implementing a service or facility network and the constituent entities must be based on the planning and design and development phases of network management and must be carried out with careful consideration of each entity in respect to its position in the network and for compatibility between interfacing and interacting entities. Financial requirements must be recognized and met in a straightforward manner so that the enterprise is not jeopardized by lack of funds or by ambiguous business relationships among diverse owners. Finally, arrangements must be specified in detail for the engineering, furnishing, and installation of each facility and each appropriate interface. Each of these functions must be carried out with considerable care and skill in order to assure efficient and satisfactory performance of individual network segments and of the network itself.

Engineer. The preparation for implementing a facility network entity or a combination of entities involves the generation of detailed specifications of the size and capacity of each entity, the mode of operation, the location of equipment units, primary power availability, interconnection patterns with other units, signal amplitude control, traffic load distribution, route layout (for transmission systems), and many other types of information. All items must be thoroughly documented so that the proper equipment may be provided and installed according to a planned schedule in a manner that assures efficient and economical operation. The preparation of these specifications comprises the engineering phase of implementation, a vitally necessary step that must be considered as a legitimate item of cost which must be accounted for and controlled as any other cost.

Furnish. All of the material and equipment required for the installation of an entity must be listed in engineering specifications and must be ordered for delivery to the appropriate site according to engineering schedules. This is equally true whether the equipment can be ordered on the basis of an existing design that satisfies the specifications or if the equipment is designed and developed especially to fulfill new requirements. The decision to buy existing equipment and from whom to buy it or to provide for new design and development may be crucial in meeting established performance objectives, schedules, and cost requirements.

Install. The installation of a new facility must follow standards established to satisfy engineering criteria and must be supervised and controlled so that costs are not excessive. Floor plans and transmission routes must be adhered to so that building space and route utilization satisfy operating requirements. After a system is installed, it must be thoroughly tested and, where necessary, adjusted to meet operating specifications. As a part of the installation process, the system must be monitored for a time after it has been placed in operation to be certain that the design intent has been satisfied in all respects.

Financial Considerations. Communications network management must include a concern for and appreciation of the importance of economic analyses in the planning, design, and implementation processes. Facilities must be selected so that costs are equitably distributed among the many entities and the costs must be controlled carefully throughout the life of the network so that initial costs and operating costs are in proper balance.[4] Sources of capital must be assured and reliable.

The development of an adequate base of information regarding system and network costs may well prove to be the most difficult task in attempting to compare systems or network configurations. Cost figures required for such studies are often difficult to obtain and there is usually little to be learned about costs from the technical literature. However, it is felt that such studies are of sufficient importance that attempts must be made to compare alternatives even if only on a gross cost basis.

Where sufficient information is available, the type of analysis must be selected with care. Economic studies may be based on first costs, annual charges, or costs per unit of bandwidth or per unit of digital transmission rate. Any one of these analyses may be more desirable than the others under a given set of circumstances.

Cost analyses must cover all elements of network management. These include planning and design costs, purchase or manufacturing costs of equipment, route engineering and right-of-way costs, building and installation costs, and operating costs. With a thorough documentation of all these cost elements, economic studies can be made to determine which of several alternatives is the most economical.

It should be recognized that costs are an important ingredient in the achievement of the overall objective of providing communication services that satisfy customer needs efficiently and economically. The economics of network management sometimes becomes an over-riding factor, one that provides the basic incentive for the entire enterprise. Cost allocations and the division of revenues are important ingredients of all phases of the network management process.

OPERATION AND USE

Whatever the nature of ownership may be, network management must continue throughout the service life of the network. The responsibility for carrying out those management processes associated with operations and use, growth, changes, demands for new services, and advancing technology must be delegated to specific organizations and personnel for the total network and for segments and subnetworks.

Operating forces must be organized and supervised to assure the provision of such direct service personnel as operators in a voice network. Continued personnel support for such necessary activities as installation, rearrangements, and maintenance in every part of the network must be assured at all times.

Operational procedures must be adjusted periodically to accommodate network growth and change. Such procedures must cover the emergency restoration of service in the event of major facility failure, methods of effecting facility repairs, and methods of adjusting network operations in the face of major traffic overloads that may result from facility failure, natural or man-made disasters, or expected events such as holidays.

The success of most business ventures depends directly on the degree to which customers are satisfied with the product or service being sold. This is true in the selling of communication services as it is in any other business. However, special efforts are needed to determine customer satisfaction with communication services. Such an evaluation has three major steps, (1) to measure the performance of the network, (2) to measure the satisfaction of customers, and (3) to feed the results of these two sets of measurements back to network managers so they may be combined for analysis and corrective action where needed. These three steps are simple to state but complex to implement. Network performance measurements must be made of parameters that affect customer opinions. The measurements must relate to performance parameters of every aspect of the operation - transmission, switching, signalling, reliability, personnel contacts, billing procedures, etc. Surveys of customer opinions must also relate to all of the same parameters. The measurements and opinion results must be expressed in parametric units that can be conveniently related. Measurements and surveys must be carried out on a regularly scheduled basis so that performance trends can be identified and corrective actions can be evaluated. Once network service has begun, such programs of determining customer satisfaction may well be the keys to successful network management, particularly in large and complex service networks.

In addition to the direct support of network operations such as those mentioned above, there are many business-related problems that must be kept under constant surveillance. The use of the network by various types of customers, the types of signals to be transmitted, and the constraints imposed on network use must be followed carefully and adjusted as new customers and changes are introduced. Methods and procedures for billing for service must also be adjusted constantly as network customers and uses change and as the network expands. In every respect, network management is a dynamic process.

PLANNED AND RANDOM MANAGEMENT

The management processes outlined in this paper (planning, design and development, implementation, operation and use, performance evaluation, and feedback) may be described collectively as "planned management." It is an orderly discipline of management that must be strictly adhered to under any form of ownership if efficient, economical, and satisfying results are to be achieved in the provision of service over any large communications network. When any of the major steps in the process is omitted or if any is given only cursory attention until problems emerge, the penalties are very likely to be significant; poor service, high cost, and loss of efficiency are almost certain to be experienced.

A number of network management examples, planned and random, may serve to illustrate the advantages of applying sound management principles and some of the penalties of failing to do so. These examples are taken from some recent experiences involving the management of the telecommunications network of the continental United States, some of its subordinate components, and its interconnection with the world-wide public network now serving most countries. The Appendix describes some operational experiences with a military communication network that highlight some of the concerns with random management.

The Direct Distance Dialing Network

Until the middle of this century, the telecommunications network in the United States operated primarily on the basis of manual switchboards operated by personnel who established local and long distance connections in response to spoken commands. Some machine switching was in use but the application of this technology was predominantly in local and metropolitan areas.

The post-war growth in demand for communications services forced a complete evaluation of the existing network and the advances in technology of that era made possible the development of the plan for direct distance dialing (DDD). The subsequent evolution of the DDD network has resulted in a telecommunications system that is highly reliable, serves all parts of the country, extends by interconnection with foreign systems to most of the world, and is highly flexible in respect to the types of services provided.

The conversion from manual to fully automatic methods of switching was a massive and complex program. In recognition of these facts, it was decided that all of the network management functions previously described had to be meticulously carried out throughout the entire process. One measure of the success of this conversion and of the planned management program used is that the principles of direct distance dialing and of network management are now being successfully applied to direct distance dialing in the international network as well as to many private communication service networks.

Planning. Before any network modifications were actually undertaken, plans were made for the changes that would be required in every aspect of network operations. The via net loss (VNL) transmission plan was derived to assure satisfactory performance with the interconnection of multiple interoffice trunks.[5] Concurrently, a nationwide numbering plan was also established so that any telephone on the network could be identified by a ten-digit number. At the same time, a switching and trunking plan was also devised such that connections could be established by the use of a specified maximum number of interoffice trunks. This plan included the provision of alternate routing arrangements that permit connections to be established over any one of several different routes that might be used in the event that a call is blocked by conditions on the route first tried.[6]

New signalling arrangements had to be provided so that the switching commands initiated by a customer or operator could be transmitted throughout the network to activate switching machines appropriately. Plans for such signalling arrangements had to be coordinated with the evolving network transmission and switching plans.

Planning for network operations included the determination of a coordinated sequence of installation of new switching machines and of the conversions of thousands of existing switching machines to the new mode of operation. In addition, most of these machines would have to be equipped with newly designed automatic billing equipment. Operators would no longer be involved in making connections and thus could not make records of call details for billing purposes. Later, as the DDD form of operation evolved, automatic testing of interoffice trunks was introduced because it became apparent that with DDD trunk troubles were often undetected because of the lack of operator surveillance.

With the essential completion of the conversion to DDD and with the improvements in technology that accompanied the introduction of solid-state common control of switching systems, it became possible to plan for the use of improved controls over network operations. Such controls were to be exercised at network management centers to which data concerning traffic flow, major equipment failures, and traffic blockages were to be fed continuously. The plans for these centers included the capability of controlling network operations to optimize the traffic handling capabilities when failures occur or when overload conditions exist.

Design, Development, and Implementation. The initial impact of the planning that had been carried out was that the magnitude and nature of required switching machine changes became fully understood. As a step towards the ultimate conversion of the network, a DDD trial was conducted; customers at Englewood, New Jersey were able to dial most areas in the country without operator assistance. When this trial proved successful, modifications were started throughout the remainder of the network.

Design changes that had to be made in the switching machines were extensive. In the toll portion of the network, the switching machines had to be modified so they could recognize and process calls to distant points according to the area code dialed. Many machines had to be arranged to add, delete, or translate coded information in the dialed calls according to their positions in the network. All signalling systems had to be modified in an orderly sequence to process this new type of dialed information. In many cases, transmission systems had to be modified so that performance would satisfy the requirements established by the VNL transmission plan.

In order to coordinate the many activities required to effect the conversion, most operating telephone companies organized DDD committees to analyze reports of malfunction and to oversee corrective actions that had to be taken. These committees acted under the direction of an overall coordinating committee that supervised the nationwide operation and which provided for the necessary liaison between companies; Independent as well as Bell System organizations were included. Each of the operating company committees was made of middle-management representatives from organizations involved in the conversion such as engineering, plant, and traffic.

Operating Features. Completely new equipment had to be designed and integrated into the network in order to provide the necessary customer billing and network trunk testing capabilities. These operational features had to be introduced in an orderly manner and, in many situations, special transmission facilities had to be dedicated to the data collection and command features of both. Automatic accounting (customer billing) equipment was installed as the DDD service was extended into each area. Automatic trunk testing was introduced later in the program as larger segments of the network were converted to DDD operation.

The equipment used at network management centers grew in size, complexity, and sophistication as the DDD service expanded. Now, the control of network traffic is concentrated in just a few centers scattered strategically throughout the country.

Common Channel Interoffice Signalling

In more recent network operating experience, a number of events and technological advances have occurred concurrently to initiate a comprehensive reevaluation of signalling procedures in the national and international communications networks. As a result, a common channel interoffice signalling system (CCIS) has been devised and is now being introduced in the national network and, in a somewhat different form, in the international network.

The factors that led to the signalling reevaluation and to the adoption of CCIS included: 1) the increasing misuse of the national network by people who learned to simulate network signals in such a manner as to enable them to place long distance calls without incurring normal charges; 2) the increasing use of computers and common control switching systems (especially electronic switching systems and, most recently, the use of time division switching in the toll portion of the network) that have made possible the consideration of common channel signalling; (3) the need for improved efficiency in making otherwise incompatible signalling systems of different countries compatible with one another, a problem that has plagued international communications for decades; (4) the need for a system that can significantly reduce the time for establishing network connections between distant terminals; (5) the increasing use of certain types of advertising and political speeches that trigger very large volumes of long distance calls. With CCIS, calls of this type can be blocked or partially blocked at their sources thus preventing the network from being overloaded with a large volume of traffic destined only to meet busy signals at their destinations.

Before the introduction of CCIS, signalling information was, and still is, transmitted over the transmission channel that is then expected to be used in the ultimate connection. In this mode of operation, signals are transmitted from one office to another, changed in format when necessary, and then transmitted on to the next office. This process, repeated until the final connection is established, typically takes tens of seconds to complete.

With CCIS, a few high-speed data channels are dedicated to the transmission of coded signalling information. All offices that are involved in a connection are signalled simultaneously and the entire connection is set up at one time, a process that takes only a few seconds rather than tens of seconds. The system is computer-controlled and ecomomically solves the operating problems that led to its consideration.

All of the planning, design and development, implementation, and operations aspects of network management have entered into both the national and international aspects of CCIS-type signalling systems. The overall management of its introduction into the national network has been initiated and coordinated by the American Telephone and Telegraph Company with the initial applications centered around installations of time division toll switching machines. The system is being extended gradually into all other parts of the network as well. Coordination and management of CCIS-type signalling into the international network has been a responsibility of the International Telegraph and Telephone Consultative Committee (CCITT) of the ITU. Indeed, the field trial carried out to establish the feasibility of common channel signalling was a joint effort of the CCITT and the Bell System. It involved, primarily, international circuits through and terminating in the United States. All experience, so far, points to the successful application of this type of signalling in both the national and international networks.

Customer Service Networks

Integrated with the extensive public communications networks that serve the nation and the world are a large number of private networks that serve individual customers. These customer service networks range in size from a few telephone stations with only one or two trunks for public network connections to networks that may be compared with large portions of the public network in size and complexities. Most of these private networks share transmission, switching, signalling, and operating facilities with the public network. Most are owned and managed by an operating Bell System or Independent telephone company. Some networks are privately owned and managed and are interconnected with the public network. A few are privately owned and operated and have no interconnections with the public network.

In so far as interface requirements and operating interactions are concerned, private networks that interconnect with the public network must be managed as integral parts of the larger network if overall performance is to be satisfactory and if adequate guarantees are to be established so that public network performance is not degraded by private network practices. It is especially important that interface requirements be specified and met, that performance requirements be properly allocated, and that service objectives be documented without ambiguity. In addition, private networks must be adequately managed to assure economically and technically satisfactory internal performance.

With such a wide range of network sizes and complexities, the choice of examples of how such networks are managed is great and difficult to make for illustration here. Two that appear to offer reasonable material for discussion are Tandem Tie Trunk Networks (TTTNs) and Enhanced Private Switched Communications Service (EPSCS), both private networks available as Bell System offerings.[7]

Tandem Tie Trunk Networks. Most modern private networks are designed to operate according to an integrated plan covered by tariffs filed with the appropriate regulatory agencies. Such tariffs specify operating features and characteristics and also cover the prices that may be charged for the service. However, TTTNs are covered only by local tariffs and when they are extended to locations beyond the local jurisdiction, they are often assembled with inadequate planning, control, and supervision; in short, they are often inadequately managed.

These networks involve local switching at private switchboards with the added provision for interconnections between remote locations by means of tie trunks that provide transmission channels between switching machines. As a result of management shortcomings, restrictions are imposed on how TTTNs may be used. These restrictions are often ignored and unsatisfactory performance is sometimes observed. Furthermore, such networks are not well-organized in terms of switching and numbering plans and, unwieldy procedures must often be followed in order to establish connections to distant locations. Thus, TTTNs (regarded as a service arrangement rather than a complete service offering) are useful within a restricted range of service requirements but lack the flexibility and universality of more modern private networks.

Enhanced Private Switched Communications Service. In contrast to TTTNs, the EPSCS has been given full attention as a complete service offering in which network management principles have been applied throughout. Fully developed transmission, switching, numbering, signalling, and operations plans have been documented and are applied in each EPSCS installation.[8]

The EPSCS is designed to satisfy the needs of large users of communications services. With the use of the most modern switching facilities, many features (such as alternate routing) can be provided that were impossible with earlier private network arrangements.

High quality transmission performance has been achieved primarily by using four-wire circuits throughout the network, even on end circuits connecting station equipment to the nearby office. The four-wire mode of transmission, superior because lower loss can be inserted without incurring echo penalties, is even carried through the switching machines where two-wire transmission circuits are usually more economical.

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APPENDIX

OPERATIONAL EXPERIENCES WITH MILITARY SATELLITES

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Lexington-Concord Armed Forces Communications-Electronics Association (AFCEA)
Chapter Luncheon
Hanscom AFB, Mass.

14 April 1976

Ordinarily, when I talk to an AFCEA Chapter, I try to talk about a major policy change or some major planning initiative that we are taking. This time I've chosen something more like the "meat and potatoes" business of the Defense Communications System. I want to tell you about the operational experiences that we've had in the past year with military communication satellites. I must confess that in part, my desire to address this subject stemmed from a U.S. News and World Report story which gave the Defense Communication Agency (DCA) a rather large black eye about the performance of our military satellites. So, in part, I want to set the record straight today.

Setting the Stage

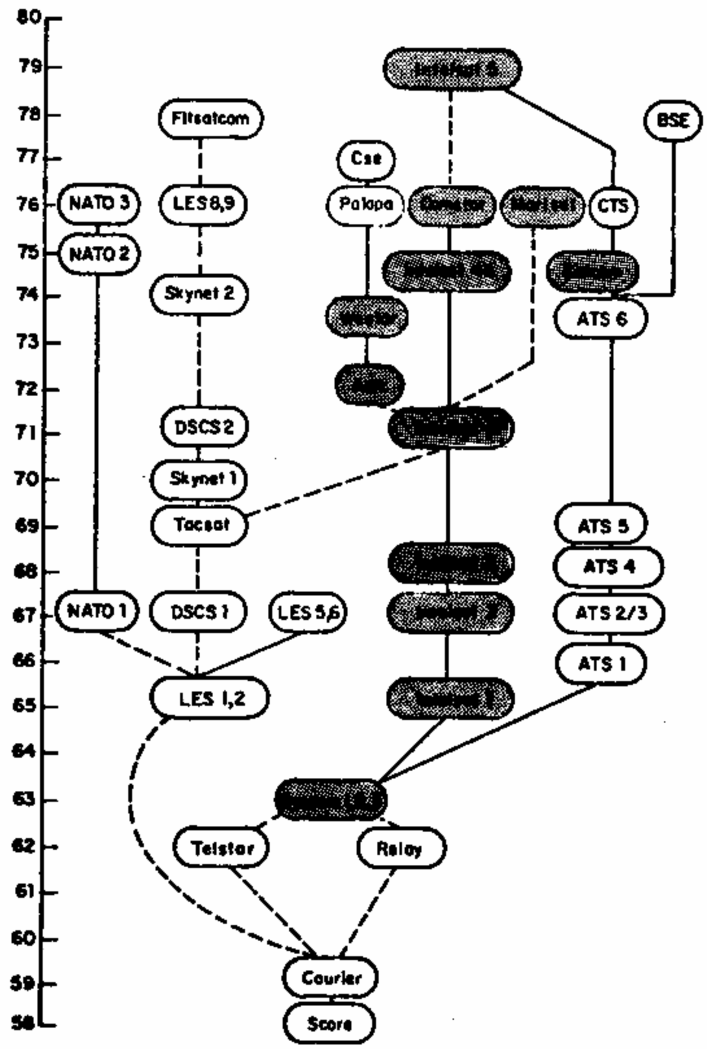
I will begin with the cocktail hour in Washington on Friday, September 12, 1975. There were a few people who knew at that time that just a few hours before the Eritrean Liberation Front had attacked and succeeded in very thoroughly destroying the Navy transmitter site at Asmara, a major Defense Communications System station. In the process they kidnapped a U.S. soldier and a sailor plus a couple of local national employees. The Asmara station was a very important link between the Mediterranean and the Indian Ocean, providing communications to ships and aircraft in that area. The loss of the high frequency radio left only a military satellite station connecting Asmara to the Defense Communication System via the Atlantic military satellite.

About 3:52 am Saturday morning I was awakened and told that the Atlantic satellite had "spun up" and was no longer useable. Many of today's military communications satellites use the spinning gyroscopic principle to maintain the correct attitude in space. However, the antenna must remain pointed at the earth and is therefore "despun" from the rest of the spacecraft. In this case the antenna bearings froze and the antenna began to spin causing a complete loss of communications. The net result was that Asmara was out of communications with the United States except for an open wire commercial telephone line to the Embassy in Addis Abbaba, then relayed by high frequency radio into Diplomatic Telecommunication System stations. There was, needless to say, some concern that Saturday morning.

Using this situation to set the stage, let's go back a year earlier to find out what kind of a posture we were in with respect to military satellite communications.

The Satellite Situation in 1974 and Early 1975

Earlier in 1974, we were very much concerned about the Pacific Defense Communications Satellite System (DSCS) spacecraft. It was experiencing a large number of gain state changes. The satellite is so constructed that it has several stepping levels that one can command into the satellite to put more or less power into various antenna beams available on the satellite. Geomagnetic disturbances can cause a build-up of several thousands of electron volts on the surface of the satellite and that invariably has to go somewhere. Whenever it did discharge, it caused the gain state settings in the satellite to change from as much as -12 db to +6 db and totally disrupted everything. This problem had cost us about 152 hours of outage during the preceding year and put another footnote in the physics textbooks as we began to understand it. At the beginning,



U.S.-Developed Communications Satellites Family Tree

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it took us from 1 1/2 to 5 hours to reconfigure the Pacific Basin Satellite Communication System.

Our Atlantic satellite seemingly was free of these kinds of problems. It had been a very successful satellite. So, I "gave" the Pacific satellite to Admiral Haynes, DCA's Deputy Director for Operations. It became known as Haynes' satellite. Since the Atlantic satellite was so successful, I kept it for myself. That was Paschall's satellite. That was not one of the better decisions I've made, as I found out later.

When the Atlantic satellite failed in September 1975, it had been serving all of the NATO earth terminals in Europe for over a year because the NATO IIB satellite was approaching the end of its design life. NATO IIB had shown a widely varying helix current, an early indication of impending failure of the travelling wave tube (TWT, a key amplifying element in satellites). Thus, the NATO IIB satellite was unused and with an expected early failure date. Despite its defects, critical needs in the Pacific caused the U.S. to borrow it from NATO pending the scheduled May 1975 launch of the next two DSCS satellites. The NATO IIB, incidentally, was a very useful satellite to us. It gave us a double-hop satellite link which provided 50 kilobit secure voice connectivity in a conference mode that was critical to the Phnom Penh evacuation, the Saigon evacuation and the Mayaguez operation. The key command and control link for all three operations was a dual-hop satellite-provided wideband secure conference involving Washington, Hawaii, and Thailand, which was then extended by narrowband secure voice to force elements. We expected that NATO IIB would fail sometime but, if it didn't, we planned to return it to NATO in June 1975 after we launched the next two DSCS satellites. The May 1975 launch, however, was a failure.

Parenthetically, we learned a lesson from that failure. The third stage guidance system failed. It uses a carousel-type inertial system which is the same one, incidentally, which is used in all 747s. Of course, they have two or three of these in a 747, and we only had one of them in the TITAN IIIC launch vehicle. What happened to us on that particular launch failure was that a supply clerk in the company that manufactured the inertial guidance systems put some airline-qualified parts in a supply bin with space-qualified parts, and had not made an appropriate entry on the stock record. We were able by telemetry to track the specific part that failed in the Titan III C. I'll say more about that when I talk more about lessons learned. In any case, those two new satellites did not reach orbital altitude, and after a couple of days of frantic activity trying to do something about it, they both ended up in the ocean.

So, in May 1975, I began to suffer some pain, but it wasn't acute. Remember, we still had an old Lincoln Laboratories experimental satellite (LES-6) doing a magnificent job, well beyond its design life, serving certain Navy ships in the Atlantic. The Atlantic DSCS satellite was performing very well, and NATO IIB was still perking along fine over the Pacific despite the questionable TWT amplifier. Moreover, we still had four of the initial defense communications satellites in a drifting sub-synchronous orbit (which continued to operate only because of the failure of their internal clocks to turn them off at the end of seven years). Depending upon their location and that of the earth stations, one or two circuits could be provided for perhaps 50% of the time. We rarely used them--more often cursed them as a source of sporadic interference to our DSCS satellites. The Pacific bird, at the same time, seemingly had settled down, or at least we had learned how to reconfigure things in about forty minutes instead of several hours.

The Atlantic Satellite Failure - September 1975

Early in September 1975 we began to see the upper bearing temperature of the despun antenna platform of the Atlantic satellite rise and the higher it rose, the more nervous we got. Several actions were taken to try to correct the problem. It looked something like the old Intelsat III series of failures, but nothing we did seemed to bring the temperature down. It was on Thursday, the 11th of September 1975 that I notified my primary users that we could no longer guarantee the Atlantic satellite and that they ought to begin their contingency restoral planning. I don't think much was done on Friday because on Saturday, when the satellite quit, everybody was in a state of shock.

Restoral Actions

Now what DCA did on an emergency basis that Saturday morning was to first lease 20 Autovon trucks from the International Carriers. Autovon is the Department of Defense worldwide private dial telephone network. We started ordering those circuits at about 8:30 Saturday morning (the 13th of September) and all 20 of them had come up by mid-afternoon on Sunday the 14th. It was really a great performance on the part of the International Carriers and their foreign correspondents in England and in Germany to bring those circuits up in that short period of time.

Remember that our most critical problem in September 1975 was Asmara, where a U.S. military installation had been attacked and military personnel taken prisoner. We had no direct way of communicating to Asmara, but we did have a Memorandum of Understanding (MOU) with Her Majesty's Government in the UK. The MOU provided for certain sharing of satellite assets in the event of failure of either the British military satellite (SKYNET II) or any of the U.S. DSCS satellites. It took a very simple telephone call from my operations center that Saturday morning to the British Embassy in downtown Washington who in turn placed a quick call to London. Within 30 minutes we had their authorization to make whatever use of SKYNET was required in order to restore service to Asmara. We worked through their satellite control facility at Oakhanger in Great Britain to do this.

Although we had the Memorandum of Understanding, and we had a restoral plan, we had never practiced it. All we were trying to restore were three circuits over SKYNET II, which was a relatively low powered satellite. When we brought Asmara up trying to connect them to Landstuhl, Germany, using Oakhanger as the coordinator, we realized that neither of the two American earth stations had ever been on that satellite before. Also, there was no way to communicate coordination orders or instructions except for that open wire line down to Addis Abbaba, hence relayed by the Diplomatic Telecommunication Service H-F link into Greece and then extended up to Germany by the Defense Communications System. It was really a remarkable achievement on the part of the Navy at Asmara, the Army at Landstuhl and the State Department communications people to coordinate that circuit restoral action.

When we succeeded, we overloaded the SKYNET II satellite and knocked all the UK subscribers right off their own system. The British were extraordinarily polite about that; their cooperation was just unbelievable. In any case, we soon ascertained that we didn't have the limiting filters that were required at Asmara to operate three circuits over SKYNET, so we pulled those out of the satellite earth station in Italy and airlifted them to Asmara. By Tuesday, September 16, 1975, we had our three circuits up. Without those limiters we were only able to keep up one circuit, but that one circuit was worth its weight in gold to us.

Later, we leased some 50 kilobit circuits to reestablish some wideband secure voice circuits and leased another half-dozen special purpose circuits as well. We were able to provide some limited service via the four initial defense communications satellites: about 40 or 50 percent service availability to a tracking station in the Seychelles Islands in the Indian Ocean. We also had some HF radio to the Seychelles and some HF to the Azores. All we could provide for the Diplomatic Telecommunication System was high frequency radio. The satellite connectivity to them was just lost entirely.

There were also a number of special wideband services that we were totally unable to restore. They came out of peculiar locations and were in the several megabit range in one direction and in the kilobit range in the other direction. They served the intelligence community where overseas processing facilities had essentially ceased. Instead, one remotes the data back via communications and processes it in the United States. Since the people were gone, the loss of that wideband communications caused the intelligence community some very great problems. We began looking for alternatives in that case and didn't find any that wouldn't cost us an arm and a leg and were very time consuming to achieve.

We had also disconnected NATO on September 13 when the Atlantic

Satellite failed. So what we had to do then was to move NATO IIB from its Pacific Location back to the Atlantic. NATO came back up on NATO IIB, and the service we were using NATO IIB for in the Eastern Pacific was partially restored by leasing some circuits from the International Carriers.

All this took place in a period of about ten days. Most of the actions--the immediatd restoral actions--were done over that weekend of the 13th and 14th of September 1975. This was a rather remarkable accomplishment on the part of all the participants involved to effect that major restoral.

We gained control of the Atlantic satellite on the 7th of October 1975. We have continued to have partial spinups that interrupted service, and from the 7th of October to the end of 1975, we had about 78% service availability from the satellite. Some things that we didn't want interrupted we kept protected with leases. We still have a number of those leased circuits to Europe. We brought all the others, except NATO, back up on the DSCS Atlantic satellite. NATO remains on the NATO IIB satellite which, although the helix current has now gone beyond the limits of telemetry, still continues to work just fine, confounding all of the experts.

Current Experience with the Atlantic DSCS Satellite

Our 1976 experience has been that we had a major series of spinup problems in the middle of January. The restoral plan has changed in that now we are able to restore certain State Department services via the NATO IIB. Also, we are able to supply some limited service via NATO IIB to the Azores. But one must manually control the satellite rather than rely on the automatic features which are not as smart as humans at preventing spinup.

Let me say a word about the failure mechanism itself. It appears that we have intermittent lubrication starvation on the upper bearing. Now this is a problem that faced the Intelsat III series of satellites as well, and emerging from that was a lubrication process used by all spinning satellites. We have never had a bearing failure until this Atlantic satellite. But in any case, what appears to happen is that you have friction transients. The sensors on the satellite provide reference signals in a feedback control loop which then varies the bias voltage on the motor that maintains the antenna pointing. We think the friction transients that occur every once in a while are so large that they overflow the sensor registers. When that happens, the satellite removes power to protect itself.

What we have today is a man who sits at the satellite control facility, and when he sees the satellite start to spin up, pushes a button and manually assumes control, over-riding the power off command. Last night (April 13, 1976) we put a software fix into the ground environment that worked at least until I left the office. We'll do that automatically instead of a man having to do it. In any case, since the first of March 1976, we have had almost 99% availability, although yesterday we had some 17 spinups, and it looked like it was worsening. The net result of all of this is that we continue to get a lot of use and service out of the Atlantic DSCS satellite but are anxiously awaiting the launch of the NATO IIIA satellite scheduled for about nine days hence. Again, we have a Memorandum of Understanding with NATO which will allow us to use about half of that satellite's power because of slippage in their earth terminal program. The net result is that I'll feel much more comfortable when, after a couple of months of on-orbit testing, we have NATO IIA as a primary route and can use the unreliable Atlantic DSCS II satellite as a backup or spare.

Lessons Learned

We learned a lot of lessons from these experiences that I want to relate to you. The first and most valuable lesson is one that we've all learned as operating communicators at one time or another, I'm sure. I'm referring to the value of restoral planning and execution. We had a lot of restoral plans. We had a Memorandum of Understanding. We had the framework to meet this kind of a contingency. We hadn't exercised them often enough. So not only restoral planning, but periodic exercises and execution of restoral plans is vital. We pay much more attention to that now than we did in the past.

The second lesson was brought home to me forcefully by the members of my Scientific Advisory Group who said, "Lee, it's just too hard to maintain over a period of years the degree of fanaticism required to achieve perfection". But that is what you have to do for space vehicles. Maintaining fanaticism about achieving perfection is hard to do but necessary. Fanaticism has to extend through all levels for this rather hostile environment. Hostile only in the sense that when it quits you can't get at it to fix it.

Diagnostics are important and that's the third lesson. Adequate, in fact, abundant telemetry is extraordinarily useful in these kinds of situations. Associated with that, never say die! I've given up on that Atlantic satellite myself at least twice but the satellite control facility on the West Coast operated by the Air Force and the DCA staff have just flat refused to give up. Over and over again, what looked like a totally hopeless situation has been retrieved. So with total unwillingness to give up, you can make things work. Finally it will quit, I am sure, but we will have gotten every nickel's worth out of it as well as having learned an awful lot.

There are some places even Intelsat can't go. And we found them very rapidly. I can't say where they are but the fact remains that you cannot always lease commercially to replace a failed military capability. We could get Intelsat space segment capacity but could not put earth stations where we wanted them. It is not possible to lease in all cases.

Moreover, we found that domestic satellites as well as NATO satellites have peculiar antenna patterns. Domestic satellites are designed to look at Alaska or the 48 States or Hawaii or Puerto Rico. They don't look at Southern Africa at all and they don't look at South America at all. NATO satellites look at the Atlantic basin. Thus trying to borrow or use someone else's satellite, or rent a domestic satellite, causes considerable problem because of the antenna coverage. You will see that many of my lessons tend to reinforce the need for a military satellite communications capability and I will conclude that way.

A policy that we have had in DCA for many years has been frequently challenged. Challenged, for example, by International Common Carriers who have maintained that the military satellite ought to be used only for unique and vital requirements, and then they want to help you define unique and vital. Our policy has been to try to split the service in trans-oceanic areas: one third military satellite, one third leased commercial satellite service, and one third leased undersea cable circuits. The value of that policy was demonstrated over that weekend in Sept., 1975 when, though we lost the military satellite, we only lost a third of our Atlantic transoceanic capability. It might have been noticeable during the week, but over that weekend, Autovon, for example, didn't even know that anything had happened. Our automatic digital data network (AUTODIN) experienced no difficulties whatsoever. So it revalidated in our minds the value of that one-third, one-third, one-third ratio, and we intend to continue that.

On-orbit spares are worth their weight in gold. They cost about that, too, but they are really worth their weight in gold when you have a failure like this. We now have program guidance that allows us two on-orbit spares with four operational satellites. Prior to the Atlantic satellite failure, although we had sought such guidance, we had been unsuccessful in getting it simply from a budget constraint standpoint.

Moreover, one satellite launch failure in four isn't a bad planning factor. That happens to be COMSAT's experience--theirs is 22%, I think. That's what we've experienced in the military communications satellite. Though I was asked by Congress recently how come TITANS failed only one time in ten but in communications satellites they failed one time in four--what are they doing, giving you the hand-me-downs? The answer, of course, was no. It is simply the luck of the draw.

We learned clearly what the importance of military satellites is during this drill. We found that with some special users, there's no other way to satisfy their needs; they had become very heavily dependent upon that military capability. The intelligence community wideband requirements, one such example; the Diplomatic Telecommunications Service, another such example; and when we lost that satellite and they lost communications there was great pain at very high levels. Command and control users need the special capabilities of military satellites; the anti-jamming capability, secure command and telemetry links, and some of those kinds of things. People became uncomfortable when we took key command and control circuits and leased them instead of providing them via the more secure military communications satellite.

I mentioned the importance of military satellite communications to general purpose users by the one-third, one-third, one-third ratio example. But the most important thing and the most urgent need for a military satellite communication capability is in the contingency situation. For example, the Saigon withdrawal. The Air Force had built a cable a number of years ago that connected Saigon to Thailand by way of a cable landing point at Vung Tau. As we watched the North Vietnamese come down the coastline headed towards Vung Tau, it was clear that Saigon was going to be cut off from communications except by the less reliable high frequency radio. So we deployed a small earth station into Saigon about three weeks before the evacuation, about a week before the cable head was lost. That TSC-54 earth station and one Diplomatic Telecommunication Service earth station at the Embassy were the two links out of Saigon that made possible the command and control of that withdrawal operation. We had to destroy that TSC-54 which broke my heart, as we didn't have many of those little contingency assets. In those kinds of contingencies, a military satellite gets to be very, very important.

Finally, there are, as I indicated, some things that you just can't afford. The wideband user is a case in point. Several megabits in one direction, a few kilobits in the other direction to a location pretty much by itself, doesn't really enthuse a commercial vendor of communications services, so he literally has to charge you for the whole thing and it gets very expensive. In addition, there are some places you just can't go with commercial services, but you can get there with the military earth station. Those are the kinds of reasons then, that make a military communications satellite essential, even though for many years there has been a debate about the need for a military communications satellite. "Why don't you get it from Intelsat, or why don't you lease it from someone else?" "They seem to do it cheaper and quicker than you." We find much of that to be false. A satellite that Intelsat buys costs 10 to 15 percent less than one we buy if you are talking the production versions. The difference is that we have certain added military features on our satellites. There is not that much difference in cost. They suffer about the same kinds of cost overruns--they suffer about the same kinds of schedule delays, and they suffer about the same kinds of failure rates.

The one final thing I guess I would say is that there have been some benefits that emerged from this whole experience. The lessons learned, I've mentioned to you already, but the overriding benefit is that there is a clear understanding and acceptance at the highest levels in the Department of Defense that an essentially 100 percent available space segment is a mandatory requirement. In fact, we are before the Congress now with a request to buy six more of the DSCS II satellites, as well as with the developmental effort to make the major change to the next (DSCS III) generation. That is supported at all levels within the DOD. We are debating the issue with Congress about 4 or 6 satellites, but there is a clear dedication now on the part of DOD to planning and programming conservatively for satellite acquisition for the DCS. That's a major gain.

We found out how important satellite capability is to us. As we place more emphasis on improving national command and control systems, there will be even more and greater dependence on the Defense Communications Satellite System as well as the other military communications satellite programs. So there is not a major policy pronouncement in my text today. We had an exciting year. It's not as grim and gloomy as you sometimes read. It certainly has been an educational experience.