Telecommunications Alternatives for Federal Users

Market Trends and Decisionmaking Criteria

Leland L. Johnson, Marvin A. Sirbu, Bridger M. Mitchell
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Leland L. Johnson, Marvin A. Sirbu, Bridger M. Mitchell

December 1985

Prepared for the National Science Foundation
Decisionmaking in telecommunications procurement has become more
difficult in recent years because of rapid technological advances,
changing agency needs, and increasingly competitive markets for voice
and data transmission and related equipment. The purpose of this report
is to identify the kinds of basic information that federal agencies
should collect, and the ways in which they should use it, to improve
their procurement decisions. The study is not intended as a complete
and comprehensive guide; rather, it provides a general framework for
assessing options and for choosing among them. In their decisions,
federal agencies would, of course, consider the special circumstances
they face and other factors beyond the scope of the present work.

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Contract PRA-8400689, Task 2, at the request of the Office of Management
and Budget. It is addressed primarily to federal telecommunications
managers and to budget and planning officials who oversee proposed
telecommunications and other procurements. It should also be useful to
those who face similar problems in the private sector.
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Of course, we remain responsible for any errors of fact or interpretation.
CONTENTS

PREFACE ................................................................. iii
ACKNOWLEDGMENTS ..................................................... v
FIGURES ................................................................. ix
TABLES ................................................................. xi
EXECUTIVE SUMMARY ................................................ xiii
   Identification and Assessment of Options .................. xiv
   Evaluation of Agency Needs ................................ xxii
   Evaluation Criteria for Options .............................. xxiii
   A Decisionmaking Framework ................................. xxiv
   A Checklist for Decisionmaking .............................. xxviii
   Limitations of This Study .................................... xxxiii

Section

I. INTRODUCTION ...................................................... 1
   The Federal Telecommunications System .................... 1
   Purpose of This Study ........................................ 3
   Organization of This Study .................................. 4

II. TELECOMMUNICATIONS SERVICES AND ORGANIZATIONAL ALTERNATIVES
    FOR SUPPLYING THEM ........................................... 8
   Voice Capabilities ............................................ 9
   Data Services .................................................. 12
   Systems Management Services .............................. 14
   Organizational Arrangements for Service Supply ........ 17

III. PBX VERSUS CENTREX ............................................ 24
   Technological Advances .................................... 26
   Voice Capabilities .......................................... 29
   Data Capabilities .......................................... 34
   System Services ............................................. 37
   Federal and State Regulation of Centrex .................. 42

IV. ALTERNATIVE TELECOMMUNICATIONS NETWORKS ............. 49
   Private Tie-Line Networks ................................ 50
   Private Electronic Tandem Networks ...................... 50
   Software Controlled Public Networks ..................... 60
V. THE SPECIAL PROBLEMS OF DATA COMMUNICATIONS ........................................ 71
   Levels of Integration ................................................. 72
   Criteria for Network Selection .................................... 75
   Implications for Federal Users ..................................... 77

VI. TECHNICAL STANDARDS ............................................. 78
   The Evolving Process of Standards Setting ....................... 79
   ISDN Standards ...................................................... 81
   Open Systems Interconnection ..................................... 98
   Conclusions .......................................................... 105

VII. DECISIONMAKING AND GOVERNMENT REGULATORY POLICY ...................... 107
   Access Charges ....................................................... 108
   Bulk Offerings ...................................................... 111
   Private Line Services .............................................. 114
   The Computer II Decision and the Modified Final Judgment ... 117
   Competition in Long-Distance Markets ........................... 119
   Implications for Decisionmakers ................................... 122

VIII. ASSESSING AND SATISFYING AGENCY NEEDS .................................. 124
   Establishing a Telecommunications Plan ............................ 124
   The Nature of Needs and Their Quantification .................... 125
   Evaluation Criteria .................................................. 133
   An Evaluation Matrix of Options ................................... 138

IX. CAPITAL BUDGETING AND DECISIONMAKING .................................... 141
   Principal Elements of Present Value Calculations ............... 143
   An Illustrative Example ............................................. 144
   The Discount Rate ................................................... 149
   Inflation .............................................................. 151
   Estimates of Acquisition Lifetime and Replacement ........... 152
   Project Interdependence ............................................ 165
   Capital Rationing and Institutional Constraints ................ 167

X. CAPITAL BUDGETING AND UNCERTAINTY ..................................... 170
   Initial Investment ................................................... 171
   Annual Cost ......................................................... 174
   Benefits .............................................................. 176
   Using Partial Information about Benefits to Assess Options .... 178
   Assigning Priorities for Sensitivity Analysis ................... 188
   Contingency Planning and Risks .................................... 188
   Guidelines for Decisionmaking ...................................... 190

BIBLIOGRAPHY .......................................................... 193
FIGURES

3.1. Cost per line behavior of PABXs ........................................ 30
3.2. An illustrative Centrex system ......................................... 36
4.1. Illustrative tie-line network ........................................... 51
4.2. An electronic tandem network with dual purpose switching ... 52
4.3. An electronic tandem network with specialized tandem switching ........................................... 54
4.4. Software defined network on-network architecture ............... 65
6.1. Integrated services digital network .................................... 83
6.2. ISDN access line reference points .................................... 96
6.3. Open systems interconnection layered model ....................... 100
6.4. OSI layers and protocols .............................................. 101
9.1. Present values at various discount rates ........................... 150
9.2. Benefits and costs of Option A ....................................... 155
9.3. Net benefits of Option A .............................................. 155
9.4. Net benefits (continuous) of Option A ............................... 156
9.5. Analysis of Options A and B ......................................... 158
# TABLES

2.1. Convenience Features ............................................. 11
2.2. Attendant Services .................................................. 11
2.3. Data Communications Service Requirements ...................... 13
6.1. Distribution of PBX Revenue ........................................ 90
8.1. User Control over Transmission and Switching Costs .......... 132
8.2. Evaluation Matrix for Specific Options .......................... 139
9.2. Revised Cost Comparisons Between Existing and Proposed Systems ................................................................. 148
9.3. Interrelations Between Acquisitions A and B .................... 165
10.1. Present Values for Acquisitions with Alternative Lifetimes and Initial Investment Costs ......................................... 171
10.2. Selecting Among Options ............................................ 179
10.3. Alternative Undominated Decisions When Benefits Can Be Ranked .................................................................................. 182
10.4. Probabilities and Expected Net Present Values of Selecting Individual Options ......................................................... 184
10.5. Decisions Compared on the Basis of Incremental and Relative Benefits ................................................................. 186
EXECUTIVE SUMMARY

Radical changes in telecommunications markets, marked by growing competition in local and long-distance transmission and in terminal equipment, stand in stark contrast to those of an earlier world. Telecommunications managers are faced with an array of decisions that previously would have been made within the Bell system. Consequently, both private and public organizations are scrambling for information about how to make sensible choices, while upgrading their internal telecommunications management skills.

In response to these needs, the goal of this study is to show what kinds of information government agencies should collect, and how they should use it, to improve decisionmaking. Consideration of specific internal decisionmaking procedures of federal agencies and their oversight organizations is outside the scope of the study. Rather, the intent is to treat topics relevant to a wide range of institutional settings. More specifically, the study has four major objectives:

- To identify and assess options for meeting voice and data needs, taking into account technical, economic, and regulatory constraints.
- To show how federal agencies can evaluate their needs in light of the options for supplying them.
- To establish criteria for evaluating the relative merits of options in light of these needs.
- To construct a decisionmaking framework for choosing among options, taking into account uncertainties about costs, performance, and benefits.

This summary treats the highlights of each objective and offers a checklist for decisionmaking and a description of the limitations of the study.
IDENTIFICATION AND ASSESSMENT OF OPTIONS

Agencies can choose from a wide range of network architectures in satisfying their diverse voice and data needs. For example, they can own their own transmission links by procuring a private line network; they can contract for transmission links by leasing lines; or they can simply buy transmission services by using the public switched network. They can own their own switches such as by purchasing a PBX; or they can contract for switching by using Centrex service; or they can buy switching service, through a public switched system. Moreover, these elements can be combined in various ways--such as owning transmission links but buying switching service--to further expand relevant options.

In addition to these combinations, agencies can select a number of ways to supply and support them: use of full-service common carriers, specialized carriers, resellers, transmission condominiums, equipment manufacturers (supplying turnkey and other assistance in addition to equipment sales), facilities managers, and in-house management.

Assessment of all possible combinations of options would be quite beyond the scope of this study. Instead, it addresses three key areas: the relative merits of PBX vs. Centrex procurements, alternative telecommunications networks, and the special problems posed by data communications. Relevant to all three are two other topics: the role of technical standards and regulatory issues at the federal and state level.

The most important distinguishing characteristic of the various options is the degree to which the agency takes responsibility for the acquisition and operation of its telecommunications system. Therefore, the agency's ability to meet whatever management requirements are imposed by particular options should weigh heavily in procurement decisions.

A decision to buy facilities--as opposed to obtaining the communications services from others--does not necessarily mean that the agency must manage the network with its own personnel. Because alternative providers of network services are available, options relating to use of these services should be considered in conjunction with assessment of agency telecommunications needs and its management
capabilities. However, the agency cannot delegate all responsibility for telecommunications to third parties, especially as telecommunications and information technology become more essential to fulfilling an agency's missions. Agencies should anticipate increasing the quantity and quality of their telecommunications staff in the present environment if only to provide the expertise needed to make intelligent choices among the available alternatives.

**PBX vs. Centrex**

Many federal and other users face a choice between PBX and Centrex facilities. We conclude that, currently, a PBX offers advantages over Centrex in (a) the range of convenience features and ancillary services, (b) the variety and level of integration of data-switching features, (c) the convenience of moves and changes, and other aspects of service provisioning, and (d) the support for network management and the control of usage costs. Indeed the PBX's contributions to controlling total communications costs account for much of its cost/benefit advantage. For example, the cost of a telephone line to a desk, whether provided by Centrex or PBX, is typically less than 75 cents per day. But an individual might easily spend 10 times that amount in toll calls. Thus, even a small percentage reduction in the cost of toll calls can overshadow any difference in the basic price.

At the same time, Centrex continues to be attractive for very large installations, particularly those spread among several locations within a metropolitan area. It is also well suited for small offices where the cost of a PBX with advanced features cannot be justified for only a few lines. Reliability and maintenance may be better for Centrex, particularly outside major cities.

Efforts are under way to upgrade Centrex performance, and many advances will be marketed during the next few years. The replacement of analog central offices with digital ones will permit Centrex to match most of the features of an advanced PBX and even provide others, based on common channel signalling, that PBX vendors may be unable to offer during the same time period. The introduction of common channel signalling between central offices--sometimes referred to as local area signalling services (LASS)--makes possible provision of "citywide
Centrex" where buildings serviced by multiple central office switches can nevertheless appear to the user as a single Centrex facility. Thus, federal agencies with a high concentration of offices in the same general area may find Centrex superior to PBX alternatives.

The introduction of LASS allows the local telephone company to provide enhanced services for regular local calls as well as intrafacility calls. For example, caller number identification can be provided for calls originating outside the company (but within the local area). For agencies that deal extensively with the public, the ability to identify all incoming calls may be a valuable service.

For all these reasons, in evaluating PBX and Centrex federal users should explore carefully with the local exchange carrier its plans for upgrading Centrex services at the relevant central offices.

Moreover, federal users faced with choices between Centrex and PBX systems should keep abreast of issues before federal and state regulatory bodies and should evaluate how their resolution could affect cost and benefit calculations. Centrex has been handicapped in providing many enhanced services because of the Federal Communications Commission's Computer II decision in 1980. However, the FCC has recently ruled in ways more favorable to Centrex, and the outcome of its current Computer III inquiry may further loosen regulatory constraints. At the state level, three issues are salient:

- Whether state regulatory bodies will take further action to permit local telephone companies to reduce rates for Centrex offerings to offset the effects of access charges imposed by the FCC on Centrex access lines.
- Whether state regulatory bodies will permit rate reductions or rate restructuring for Centrex, aside from the effects of access charges.
- The effects of flexible pricing, detariffing, or outright deregulation of Centrex being considered or already implemented in some states.
Alternative Telecommunications Networks

In addition to choices between PBX and Centrex local switching, users face numerous options with respect to network configuration and ownership. Wise choices among network alternatives are vital because they affect (a) the cost and quality of transmission available to the user, (b) the kinds of premises switching that the user will need, (c) the operations and management burden the user must assume, and (d) the level of control that the agency can exercise over network usage and service level—a consideration of key importance in controlling overall network usage costs.

For example, the relative merits of PBX and Centrex procurements depend on the technical characteristics of the network into which they are linked. Especially, whether Centrex becomes competitive with PBX depends on the availability of common channel signalling in the network and on the rapidity with which integrated services digital network (ISDN) standards are developed and adopted.

The most notable network choices available today to large users are either a private electronic tandem network (ETN) or a virtual private network. Much of the motivation for choosing an ETN lies in the increased control over quality of service in the user's hands, and a simplified numbering scheme for intra-organizational calling. An ETN also allows the user to take advantage of user-owned transmission facilities or of low cost offerings from specialized carriers.

But ETNs are not without problems. Especially, network administration and maintenance of the switching equipment is the responsibility of the user, who must either train or hire skilled telecommunications personnel or purchase facility management services from the switching supplier or third parties.

As a competitive response to ETNs, interexchange carriers have begun to offer "virtual" networks that give multilocation companies the illusion of operating a private network with customized services, but which in fact use the same circuit and switches as the standard public network. In contrast to an ETN where network management is in the user's hands, the virtual network leaves to the carrier almost complete responsibility for network maintenance, operation, and optimization--
an important advantage for users with limited in-house expertise. Moreover, overall reliability is likely to be higher with a virtual network because it can draw upon the massive redundancy of the carrier's switched network.

Whereas an ETN uses leased lines for on-network traffic and separate WATS or direct distance dialing lines for off-network calls, the same access lines can be used for all traffic in a virtual network. Thus, with more efficient line use, fewer access lines are needed. Notably for some government users, locations that are too small to justify leased lines for connection into an ETN can easily join a carrier-provided virtual network.

The introduction of virtual networking has been made possible through use of a common channel signalling (CCS) network that provides a separate data path for conveying complex signalling information between network switches. Before the introduction of CCS, signalling in the carriers' networks, as in an ETN, was accomplished with tone signalling preceding the voice signal through the circuit. With CCS, signalling information is sent over a packet network separate from voice circuits.

It is too early to generalize about the relative costs of ETN and virtual networks. Virtual network pricing consists of usage charges that vary with distance and time of day, whereas ETN pricing is based on capacity charges for switches and leased lines. How they compare depends heavily on traffic patterns. Users may eventually find a hybrid system attractive, using leased lines on high volume routes and virtual networking elsewhere.

Several key points emerge about long-run trends in network pricing: (1) Per-mile private line costs will decline more with distance in the future than they do today, reflecting more accurately underlying costs, (2) the WATS/direct distance dialing differential will remain limited because of the ease with which bulk discounted services can be resold, (3) WATS rates will likely decline in real terms as a consequence of competition and technological advance, (4) the relationship between future private line and WATS prices is uncertain in the face of future new filings by competitive carriers and the response of regulators.
The Special Problems of Data Communications

Data communication poses special problems because, unlike voice traffic, it is not a single, homogeneous service. Data traffic covers services ranging all the way from interactive terminal use to bulk file transfers. The quantities of data to be transmitted, and acceptable delay times, may differ by several orders of magnitude among different applications. Consequently, the variety of technology and approaches to providing data communications is much greater than for voice.

Responding to the diversity of data needs, large users typically operate several separate data networks alongside a single voice network. For future procurements, however, federal agencies should consider the advantages and disadvantages of integrating data networks at one of several possible levels: (a) physical level integration, (b) network level integration, and (c) host level integration. Users must also choose among privately operated and managed networks, third party management, and use of public networks, to reflect the appropriate level of integration and ownership arrangements. Major criteria for making choices include manageability, reliability, geographical coverage, staffing requirements, security, and protocol selection.

Technical Standards

To ensure that the wide variety of data terminals can communicate with each other, federal users may benefit by specifying the ISO standards that have been developed for the middle and lower protocol levels (e.g., Transport Protocol between hosts, X.25 for packet networks, IEEE 802 standards for local area networks). These simplify the problem of translating between incompatible systems by assuring the ability to move data from one system to another in a standard way.

Another choice facing federal users is the specification of technical standards being developed for ISDN. If all manufacturers and carriers provided ISDN-compatible services, the benefits to federal users would include reduced translation costs, more competition among suppliers, and more widespread service.
A key question is how fast ISDN standards are likely to be developed and embodied in new equipment and services. The rate of ISDN penetration will depend on how strongly potential users value all of its features. We do not yet know how fast user needs will pull the development of ISDN. But for two reasons, we conclude that this process will move quickly. First, the local exchange carriers favor rapid refinement of ISDN standards and marketing of ISDN-compatible equipment so that they can (a) compete more effectively with PBX suppliers and with private networks, and (b) take advantage of common channel signalling. Second, central office equipment manufacturers have little choice but to support ISDN capabilities being demanded by the local exchange carriers. Accordingly, major North American and European switch manufacturers are all developing ISDN-compatible equipment. ISDN compatibility may be offered also by PBX manufacturers. But they may move more slowly because, desiring to expand sales of ancillary equipment such as terminals, PBX vendors have an incentive to adopt proprietary standards.

Four specific problem areas of ISDN merit close attention by telecommunications managers: (a) access lines, (b) channel specification, (c) boundaries between carrier-controlled and customer-controlled equipment, and (d) links between a PBX and a host computer. Federal users should seriously consider equipment and services capable of meeting a full CCITT specification of 2B+D for access lines. Despite concerns that have been raised in some quarters about this specification, we conclude that it will become the dominant standard for several reasons: (a) The two largest vendors of PBXs and central office switching equipment have committed themselves to support the 2B+D specification, (b) AT&T and four other integrated circuit manufacturers have announced they would be building chips to support 2B+D, and (c) the Europeans will be implementing the full 2B+D specification, and early American users of ISDN will be large multinational corporations that will emphasize compatibility between equipment in their European and U.S. offices.
Regulatory Issues

Besides confronting numerous technical issues, federal users should also stay abreast of federal and state regulatory activities. If an agency knows, for example, that no regulatory proceedings relevant to its choices are under way or are likely to be initiated in the foreseeable future, it may have some assurance that during the next year or so, at least, information on tariffs and service offerings will likely remain valid. Otherwise an agency may make a decision only to see substantial changes in tariffs and service offerings based on regulatory proceedings that, had it been aware of, would have encouraged it to postpone its procurement decision or to make another choice.

In addition to procurements related to Centrex offerings, important areas for regulatory scrutiny include

- Access charges imposed on end users and carriers, which affect the rates charged for both public and private services.
- Rates for bulk discounted services where, for example, the problem of establishing "just and reasonable" rates led to the demise of Telpak and has posed uncertainties for WATS users.
- Rates for private line services, which have also been subject to much controversy in the face of competitive pressures that have grown steadily since the 1960s.
- The outcome of the FCC's Computer III inquiry dealing with separation requirements between basic and enhanced services, which affects not only choices between PBX and Centrex but the availability of other services as well.
- The future application of the Modified Final Judgment arising out of the AT&T divestiture, which may affect the terms and conditions of offerings by the Bell operating companies.
- The degree of future competition in long-distance markets permitted by federal and state regulators.
EVALUATION OF AGENCY NEEDS

When selecting from the multitude of supply options, the agency must, of course, carefully assess its needs. This should be done within a telecommunications plan established by the agency to provide a framework within which individual investments are included to meet these needs. The assessment of needs within the telecommunications plan can be pursued from two different perspectives: the traditional "requirements" approach and the "strategic planning" approach. The traditional approach considers requirements for communications and, say, for office space in much the same way. Each provides essential resources needed by the agency's staff. Telecommunications requirements can be related to staff size, function, location, and other related measures of the agency's organization; and changes in these needs can be developed in terms of past trends in telecommunications use and expected changes in agency size and activities. This approach works best when both the agency's own activities and the telecommunications environment are changing slowly.

In line with the requirements approach, the agency should assemble key statistics summarizing both current-year and recent patterns of its telecommunications use and costs, the extent of capacity use, and indicators of service quality. Unfortunately, the problem of gathering adequate data is severe. Many telecommunications managers simply do not have the necessary records in a clean form. Some are buried in other accounts; others are in the hands of outside organizations; yet others are lost in the overhead rate. Improved data collection is a key management need that must be addressed if procurement choices are to be better informed.

In addition to using the requirements approach, at least some needs for telecommunications services can be developed from a strategic perspective that reexamines the agency's mission. Many government organizations, for example, provide a variety of information services directly to the public or to other agencies as a central component of their overall mission. New technologies and changing costs of telecommunications services provide the opportunity to assess how an agency can best provide these services in the future. For this
approach, longer-term strategic planning can be used to relate the agency's objectives to alternative technologies for delivering its services.

In general, agencies should use both strategic planning and traditional requirements approaches on which to base an evaluation of their telecommunications needs.

EVALUATION CRITERIA FOR OPTIONS

On the basis of data and other information as discussed above, the following are suitable criteria for assessing the costs and benefits of the major options that are screened out of the fuller range of possibilities.

- Cost, including initial investment, subsequent investments, and recurring operating and maintenance expenses.
- Performance, including reliability, responsiveness, upgradeability and security.
- Organizational impact, including staffing requirements, ease of use, and user support.
- Systems management capability, including switch operation and management, operational management, provisioning and administration.
- Risk to the agency.

The organizational criteria are especially noteworthy. While the problem of obtaining in-house skills for management and other functions varies among agencies, it is, in general, one of the most serious problems to be considered. Options are available to retain at least some of the benefits of in-house expertise, given the limits of the government's ability to staff highly paid positions. Examples include managing some segments of the communications system while purchasing others (managing intrabuilding and campus communications while purchasing long-distance service) or using third party managers (buying bulk long distance and using outside managers to develop value added services).
A DECISIONMAKING FRAMEWORK

How should one put together all of the information discussed above in the way that most effectively contributes to a good decision? The answer is to use the "present value" approach drawn from the principles of capital budgeting. Under this approach, future costs and benefits of the option in question are both discounted back to the present to estimate its net present value—that is, the discounted value of benefits minus the discounted value of costs. Although controversy surrounds the question of which discount rate is appropriate, agencies generally should use the 10 percent real discount rate specified by OMB to encourage consistency in decisionmaking by federal agencies. This rate is roughly equal to the estimate of the average rate of return on private investment, before taxes and after inflation.

Using these calculations, options should be selected whose net present values are positive or, in the case of options that are competitive with each other or "mutually exclusive," the option with the higher net present value should be selected.

The present value approach is advantageous for five reasons:

- It permits comparisons under a common set of ground rules of options having widely varying time profiles of investment and recurring costs.
- It is applicable not only to options that are mutually exclusive but also to options that are complementary or only partially competitive with others.
- It can be used to compare alternative means (e.g., lease vs. purchase) of procuring a given telecommunications system, thus contributing to a sound procurement strategy as well as to a good "basic" system choice.
- Its applicability to side-by-side evaluation of options outside as well as within the telecommunications field makes it useful for overall agency budget planning and analysis.
- Use of present value formulas and the calculations themselves are surprisingly simple. The real difficulty is obtaining appropriate information on costs and benefits.
Coping with Uncertainty

How then should one cope with uncertainty about costs and benefits and the risks that some options may not turn out as well as expected? Uncertainty with respect to costs, performance, and benefits can be reduced by

- **Drawing heavily from the experience of others with the same or comparable services.** Contacts with outside telecommunications managers, such as those who are members of the International Communications Association, and those who recently purchased the same equipment or service from the same vendor, would be primary sources of valuable information. Moreover, the agency should require the vendor to supply names of recent purchasers before making a final decision.

- **Using fixed price contracts and competitive bidding.** Since the seller can be presumed to be more knowledgeable about the product than the buyer, the cost to the seller of bearing risk is less than that to the buyer. Thus, the additional costs to the buyer for the "insurance" offered by a fixed price contract is likely to be money well spent. However, the procurement should not necessarily go to the lowest bidder. In addition to cost, assessment of the vendor's track record and future prospects is important. Many telecommunications firms may be gone in a few years; some have better long-run prospects than others; yet others may have a record of being more responsive to an agency's day-to-day needs than their competitors.

- **Doing sensitivity analysis.** While this is a standard prescription for dealing with uncertainty, difficulties arise because the combinations of comparing benefits, costs, and other factors could quickly generate dozens of present value estimates that might obfuscate more than they clarify. To avoid information overload, one must selectively identify key factors for detailed analysis as discussed in this study.
Doing risk assessment and contingency planning. Agencies should carefully take into account the varying levels of risk among options—for example, the risks of going to "fourth generation" PBXs where some of their advantages have yet to be demonstrated in the marketplace and where they require proprietary protocols. Any option seriously considered for procurement based on a favorable present value calculation should be examined with respect to fallback alternatives if the option is not available as soon as expected or if its performance turns out to be deficient. For these reasons, the agency might be justified in selecting a less risky option with a lower net present value.

In present value calculations it is important, needless to say, to consider all costs associated with prospective acquisitions. Unfortunately, it is all too easy to neglect or underestimate the costs of design, transition and startup, user support, system management, space requirements, and building upgrades required for new equipment. Frequently, such costs are embedded in the monthly rental prices local telephone companies charge for their existing services. When considering options as a substitute for existing telephone services, agencies should account explicitly in their cost estimates for these embedded elements.

Similarly, the benefits side should reflect cost savings to the agency, the value of improved performance to the provision of existing and new agency services and, more generally, the expected contribution of the option to the agency's program outputs. Moreover, for both benefit and cost estimates, options that increase or decrease total telecommunications usage should take into account the impact on salaries. Staffing costs and benefits are often missed because the government has long-distance accounts but no salary-while-on-the-phone account. Yet, the costs of personnel using telecommunications equipment can far exceed the cost of the equipment itself. A toll call on the current Federal Telecommunications System costs about 25 cents to 30 cents a minute. But, assuming a 100 percent overhead rate, a government worker earning $30,000 per year would cost about 50 cents a minute.
Limitations on Funding

A fundamental problem in capital budgeting is that agencies may simply not have the funding required to adopt all options that have a positive net present value—a situation that requires "capital rationing." In these cases the agency must rank the options and choose those that are the most important. A straightforward way to do this is to divide the net present value by the investment cost requirement in the current period where capital must be rationed. The agency then ranks the options by the descending value of this ratio and selects those options down to the point where the agency's procurement budget is exhausted. This procedure is aimed at assuring that the greatest value is obtained for each dollar invested. (Again, some otherwise acceptable options may be rejected on the grounds of excessive risk.)

The ranking of options and the conditions of capital rationing may, however, be complicated especially by the difficulty or impossibility of assigning dollar values to the benefits side of the equation. Uncertainty with respect to benefits can be handled with present value analysis (constrained by capital rationing) by three methods, listed in their declining order of preference.

- Rank the options in accordance with the dollar benefits (positive or negative) that each option has in relationship to each other option if incremental, but not total dollar, benefits of each option are known (e.g., Option C provides $10 million more benefits per year than B).
- Rank the options in accordance with their relative benefits (e.g., Option C is 50 percent better than Option B).
- Rank the options in accordance with a judgment about the benefits of each, if no information whatsoever is available about the dollar amount of the difference in benefits (e.g., Option C is better than Option B).

By ranking benefits, in accordance with the degree to which benefits can be quantified, one may be able to make final choices close to those that would have been made if full information had been available about total dollar benefits of each option.
A CHECKLIST FOR DECISIONMAKING

The following is a checklist of key items that decisionmakers should keep in mind in identifying options and making selections, based on analyses and conclusions throughout the study. The list is organized in accordance with the major themes of the study: (a) network architecture and management, (b) choices between PBX and Centrex systems, (c) choices relating to network design and operation, (d) the special problems posed by data communications, (e) standards and protocol issues, (f) regulatory issues, and (g) agency needs assessment and capital budgeting. The discussions of material relating to items in the checklist are referenced by the page numbers in parentheses.

Of course, not all items are of equal importance to all agencies. Indeed, to prevent information overload, one must be selective in deciding which questions to ask. Although the most relevant questions depend on the nature of the particular procurements being considered, in all cases the basic decisionmaking framework we have developed is applicable. Hence, the items below relating to assessing agency needs and capital budgeting should be taken into account in all contemplated procurements.

In general, then, the agency should select whatever technical and regulatory items are relevant to its particular procurement actions and, using responses to these items as inputs, pursue a rigorous analysis of agency needs and capital budgeting.

Network Architecture and Management
1. Assess agency capabilities to manage its switching and transmission facilities and services (pp. 8-9, 14-17).

2. Determine the degree of network management the agency is willing to apply (pp. 136-137).

3. Take into account the end user's perspective, as well as the telecommunications manager's perspective, by bringing end users into the planning and operations process (pp. 16-17).
4. Review the range of telecommunications options and, in light of the above, select a subset for detailed review (pp. 138-140).

PBX vs. Centrex

1. Determine whether proposed PBX or Centrex can provide the necessary tandem switching, routing, and network management support, consistent with the overall network architecture plan (pp. 27-42).

2. Check future plans of the local telephone company before choosing between Centrex and PBX systems (pp. 28, 33-34).
   
   A. If relevant central offices are not yet digital, determine if and when conversion is to take place (p. 28).
   B. If offices are digital, determine whether and when they can be upgraded to support ISDN services (pp. 84-89).
   C. If the agency's offices are scattered within a metropolitan area, determine if and when common channel signalling will be introduced to permit local areas signalling services and citywide Centrex (pp. 33-34).

3. Take into account federal and state activities that affect Centrex services offered in geographical areas relevant to the choices in question, by evaluating

   A. Existing and prospective FCC decisions with respect to
      (1) services that are permitted on Centrex (pp. 42-43),
      (2) the coordination of switching and customer premises equipment offerings (p. 43).

   B. Existing and prospective court decisions relating to the Modified Final Judgment that affect restrictions imposed on the Bell operating companies, and their ability to offer advanced Centrex services (pp. 118-119).

   C. Existing and prospective state regulatory decisions regarding
      (1) repricing to offset federally imposed access charges (pp. 44-45).
(2) rate reductions and restructuring (pp. 45-46),
(3) flexible pricing, detariffing and deregulations (pp. 46-47).

Network Design and Operation

1. In a contemplated procurement of an ETN include

   A. Detailed cost analysis of software development and procurement (pp. 50-56).
   B. Assessment of management requirements imposed on the prospective user and the ability of the user to satisfy those requirements (pp. 59-60).
   C. Assessment of problems of acquiring all PBXs from the same manufacturer to satisfy requirements for a common protocol (p. 53).

2. In a contemplated procurement of an "interim" Digital Access and Cross-Connect System, determine when the relevant telephone central offices are likely to be converted to digital (pp. 61-62).

3. In a contemplated procurement of a virtual private network

   A. Determine if and when data transmission will be provided on an equivalent basis with voice transmission (pp. 67-68).
   B. Include the cost and additional management requirements, for a separate data network, if data are an important part of the users' needs (pp. 67-68).
   C. Take into account the loss of integrated accounting if virtual networks are procured separately from interexchange carriers and from local exchange carriers (p. 66).
   D. Take into account the differences in system services between a virtual network and an ETN (pp. 67-68).
   E. Weigh the dangers of being unduly dependent on, or being locked into, a single vendor (pp. 69).
Data Communications
1. Assess merits of alternative levels of integration in light of agency needs and management capabilities (pp. 72-75).

Standards and Protocols
1. Insist on the CCITT specification of 2B+D for equipment and services, if this specification can be met at reasonable cost (pp. 82, 92-94).

2. Assess possible gains to the user from specifying ISO standards for the lower protocol layers (p. 106).

3. Take into account the long-run gains to government and other users from specifying ISO protocols, even if ISO-compatible software is currently not the lowest cost way to meet a particular network need (p. 106).

Regulatory Issues
1. Take into account prospective FCC, state, and court decisions (to the extent that they can be foreseen) about

   A. Access charges (pp. 108-110).
   B. WATS and other switched-service bulk offerings (pp. 111-114).
   C. Private line offerings (pp. 114-117).
   D. Outcome of the Computer III inquiry (pp. 117-118).
   E. Line-of-business restrictions imposed by the Modified Final Judgment (pp. 118-119).
   F. Changes in regulatory policy with respect to AT&T Communications (pp. 120-122).

Agency Needs Assessment and Capital Budgeting
1. Develop a telecommunications plan (pp. 124-125).
2. Use both the requirements and strategic planning approaches to assessing needs (pp. 125-131).

3. Obtain adequate, detailed usage data to support estimates of future requirements. In establishing evaluation criteria for options, include considerations of

   A. Cost (p. 133).
   B. Performance (pp. 134-135).
   C. Organizational requirements (pp. 136-137).
   D. Systems management (pp. 14-17).
   E. Risk (pp. 137-138).

4. Estimate benefits of the options in question by using the above evaluation criteria (pp. 138-140).

5. Estimate costs by including all investment, operating, and maintenance costs with the appropriate discount rate (usually the 10 percent real rate prescribed by OMB) (pp. 143-150).

6. Estimate benefits by the same procedure if they can be quantified in dollar terms (pp. 143-144).

7. Use constant real dollars in all comparisons (pp. 151-152).

8. In estimating the operational lifetime of a prospective acquisition

   A. Compare net present values of alternatives that involve both immediate and postponed investments (pp. 153-162).
   B. For prospective acquisitions having an operational lifetime of less than about 10 years, include the net present value of its replacement in the analysis that compares this option with others (p. 162).
9. Use present value analysis to account for interdependencies among options (pp. 165-167).

10. When faced with capital rationing use the "modified" present value of net benefits and rank options accordingly (p. 168).

11. Reduce uncertainty about cost and performance by

   A. Using fixed price contracts and competitive bidding (p. 172).
   B. Drawing as fully as possible from the experience of other users (pp. 172-173).
   C. Assessing the track record and future prospects of potential vendors (p. 172).
   D. Designing contingency plans to reduce risk (pp. 188-189).

12. If overall benefits of an option cannot be satisfactorily estimated in dollar terms, rank options in accordance with

   A. A judgment about which ones are better than others, where no information is available about the amount of difference (pp. 181-184).
   B. The estimated dollar differences in benefits among options, if this information can be obtained (pp. 184-186).
   C. The estimated percentage or relative differences in benefits among options, if this information can be obtained (pp. 186-187).

LIMITATIONS OF THIS STUDY

Finally, we must emphasize that this study constitutes only one input into the decisionmaking process for federal telecommunications procurements that best serve the national interest. More investigation is needed, especially analysis of the "externalities" that arise from alternative procurement strategies. These externalities, analysis of which is outside the scope of this study, include most notably
The effects of an agency's decisions on the availability and cost of services to other agencies in light of possible economies of scale in procurement and operation.

Whether an agency's decisions, reflecting only costs and benefits to itself, affect federal telecommunication capabilities for emergency preparedness or attainment of other national objectives.

Other considerations that, given time and budget constraints, are outside the scope of this study include

- The impact of federal procurement policies and regulations, including OMB and GSA directives.
- Budget restrictions in addition to those we treat under capital rationing.
- The opportunities afforded by shared use of existing and planned major government telecommunications networks, including the FTS 2000, Washington Interagency Telecommunications System, and the Aggregated Switch Procurement.
- The process of approvals, procurement, and implementation once agencies have evaluated and selected options.

Within the limited scope of our study, nevertheless, the basic kinds of information we identify and the decisionmaking framework drawn from capital budgeting are highly relevant to agencies within whatever specific circumstances they face—as illustrated by several examples: Officials of one federal executive department report to us that, in response to National Security Decision Directive 145, their department has issued department-wide directives to (a) define sensitive information requiring protection outside the realm of national security, (b) mandate authentication of funds transfers and electronic movements of value to and from the department, and (c) require specific time frames for establishing system safeguards. Such directives will have a major impact on the future telecommunications systems and services used by the department. Although this situation poses additional constraints
on decisionmaking, the areas we address—Centrex vs. PBX procurements, alternative networks, technical standards, state and federal regulatory issues, and others—remain key ingredients in a sound assessment of alternatives.

As another example, agencies obviously should consider the possibilities of pooling their purchases to achieve economies of scale. Thus, a specific option that has a high estimated net present value may be feasible only if procurement is coordinated among a number of agencies. In this case, too, the need remains to discount future benefits and costs and to consider other factors within our recommended decisionmaking framework. Indeed, the framework helps to quantify the advantages of agency coordination and, thus, encourages interagency cooperation when those advantages are shown to be large.

As yet another example, one option may show a lower net present value than others but be superior in contributing to emergency preparedness. In this case, the government would be justified in selecting this option if it judges that its emergency preparedness advantage more than offsets the merits of others. Thus, our framework encourages agencies to confront tradeoffs that might otherwise be neglected.

Again, much study is needed to guide decisionmaking in the tumultuous arena of telecommunications. We contribute here only a part—but one that we hope will improve the quality of procurement practices and provide a basis for further research and analysis.
I. INTRODUCTION

In earlier decades, the management of telecommunications services by private sector and government users was straightforward. The Bell system functioned like an enormous black box in which users inserted money at one end and got basically good service out the other. The Bell system itself designed, built, and managed networks and developed the kinds of terminal equipment that would best meet the needs of users--as Bell saw those needs. Relatively few options were offered, which simplified the problem of making choices. Moreover, the existence of a single dominant firm in the industry virtually eliminated the problem of justifying sole-source selections.

Radically changing telecommunications markets, marked by growing competition in local and long-distance transmission and in terminal equipment, stand in stark contrast to those of an earlier world. Telecommunications managers are faced with an array of decisions that previously would have been made within the Bell system. Consequently, both private and public organizations are scrambling for information about how to make sensible choices, while upgrading their internal telecommunications management skills.

THE FEDERAL TELECOMMUNICATIONS SYSTEM

These changes have very much affected the FTS, by far the nation's largest private network. The FTS is about equal in size to the total of the next 17 largest private systems. About 15 percent of its traffic consists of data transmission, making it the largest data network in the federal government.\(^1\) Service on the system was started in 1963 in response to the need for a highly reliable, centralized system--highlighted by the network overloading problems that arose in the public network during the Cuban Missile Crisis in 1961 and at the time of President Kennedy's assassination.\(^2\)

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\(^2\)See, for example, J. Wilke, "The Biggest PBX Purchase of All Time?," Data Communications, September 1984, pp. 45-50.
Demand has grown rapidly since the inception of the FTS, evidenced by the doubling of traffic volume during the 1970s. The volume of data also has grown rapidly from the time the FTS was established, to a level now about equal to the total data traffic volume on all other civilian federal data systems combined. GSA expects data usage to continue growing at about 10 to 20 percent annually, with voice traffic projected to level off toward the end of the decade, so that data may overtake total voice traffic in the 1990s.³

With the emergence of competitive alternatives in the mid-1970s, the FTS has undergone a continuous replacement of facilities, and AT&T's share of revenues has fallen to about 88 percent. Nevertheless, because of changing agency needs, rapid technological advances, and many other factors, the existing FTS is generally judged to be inadequate, with many of its facilities no longer embodying state-of-the-art technology. As just one example, only 17 percent of GSA-managed systems are current generation PBXs working under stored program control, whereas 39 percent are electromechanical, and 44 percent are Centrex systems. According to GSA, the remaining 83 percent of the systems can be characterized as "mainly obsolete technology, limited in services and features, limited in ability for management to control costs, and limited in management information provided."⁴ Because of these and other considerations, GSA further concludes that

We can no longer rely upon the FTS to provide an implicit structure for telecommunications, nor upon the old Bell system practices to assure manageability and connectivity. Agencies can no longer rely upon GSA as the main provider of services. We can no longer expect that the FTS can in some way grow to serve all agencies' needs.⁵

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³GSA, op. cit., p. 6.
⁴Ibid., p. 111.
⁵Ibid., Vol. 1, p. 8.
In response, a new Government Telecommunications System (GTS) is being planned. According to GSA, the GTS could consist of any one of the following:

- A single, multipurpose network incorporating all applications and serving everyone.
- An incoherent assortment of isolated noncommunicating systems—most dedicated to single functions or serving single organizations.
- A more or less coherent system of communicating networks.  

GSA has decided that the third alternative—the middle ground—is the most promising in creating GTS. GSA believes that choosing the third approach will avoid the severe management problems associated with a single, multipurpose network and the lack of connectivity of isolated noncommunicating systems.

Consequently, we can expect agencies to exercise different levels of autonomy in their telecommunications procurement decisions in the future from those they have in the past. At the same time, the competitive multivendor telecommunications world will require that these agencies, and agencies with responsibility for oversight, have much more information about the available alternatives, along with effective decisionmaking criteria, if the resulting choices are to best serve the public interest.

PURPOSE OF THIS STUDY

Our purpose is to delineate the kinds of information that federal civilian agencies should collect and the decisionmaking criteria that they should establish to make sound choices when procuring telecommunications facilities and services. More specifically, this study has four major tasks:

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*Ibid. p. 9.*
To identify and assess options that are available for meeting voice and data needs, taking into account technical, institutional, and regulatory constraints.

To show how agencies can evaluate their needs for telecommunications services, in light of the available options for supplying them.

To establish criteria for evaluating the relative merits of options in light of these needs.

To construct a decisionmaking framework for choosing among options, taking into account uncertainties about costs and benefits.

One word of caution: In the quest for better decisions, it is all too easy to add on and on to checklists and questionnaires so that important points are not overlooked. But doing so raises another danger. The number of questions will be so large, the difficulty of answering many of them will be so great, and the problems of evaluating answers will be so formidable that the whole decisionmaking process bogs down. Consequently, two factors are of key importance.

- To be highly selective in posing questions.
- To be able to evaluate the answers.

Agencies will need to decide for themselves, given the specific circumstances they face, the priorities required to avoid "information overload" in their procurement decisions. We seek to help this process by establishing general principles for judging the relative importance of the many questions that could be posed. We also address processes useful in obtaining answers and in evaluating them.

ORGANIZATION OF THIS STUDY

This manuscript is divided into three parts. The first, consisting of Sec. II, discusses voice and data services available today or expected within the next few years and describes the various kinds of organizations--such as "full service" common carriers--that supply them.
The purpose is to provide useful background for the remainder of the study.

The second part, consisting of Secs. III through VII, concentrates on the wide range of technical, institutional, and regulatory considerations that affect the range of available services. More specifically, Sec. III addresses the relative merits of procuring PBX and Centrex equipment. Centrexes and PBXs are switching equipment that links users to the telephone network. A Centrex is a portion of the switch in the local telephone company's office dedicated to serving the switching needs of the Centrex subscriber. A PBX, in contrast, is a switch on the user's premises, connected by access lines to the local telephone company office (and perhaps directly to other telecommunications carriers as well). Discussion of these two alternatives is important because many government buildings are served by Centrexes or PBXs that are candidates for replacement.

Section IV describes alternative telecommunications networks. Consideration of network architecture is vital because it affects (a) the cost and quality of transmission available to the user, (b) the kinds of switching that the user will need, (c) the operations and management burden the user must assume, and (d) the level of control over network usage and service level that the manager can exercise.

Section V addresses the special problems associated with data communications. Unlike voice traffic, which represents a single, well-defined commodity, data traffic ranges all the way from interactive terminal use to bulk file transfers. Consequently, the variety of technologies and approaches to providing data service is much greater than for voice.

Section VI focuses on technical standards. It treats the development and potential benefits of implementing (a) Integrated Services Digital Network (ISDN) standards, designed to permit the transmission and receipt of data as easily as voice is transmitted domestically and internationally today, and (b) Open System Interconnection (OSI) standards designed to enable computers from different manufacturers to operate compatibly with each other.
Section VII focuses on federal and state regulatory issues that affect telecommunications choices available to federal (and other) users, going beyond Centrex and PBX options treated in Sec. III. These issues involve (a) access charges imposed on end users and carriers, (b) rates for bulk discounted services such as WATS, (c) rates for private line services, (d) constraints imposed on carriers by the FCC's Computer II decision and by the Modified Final Judgment arising out of the AT&T divestiture, and (e) the future regulation of long-distance carriers, in light of increasing competition in long-distance transmission markets.

The final portion of the study, consisting of Secs. VIII, IX, and X, addressed primarily to budget and planning officials rather than to telecommunications managers, takes the preceding into account to show

- How the agency should assess its needs, including the kinds of usage data it should collect.
- What criteria it should use to select options for satisfying these needs.
- How the agency should compare the costs and benefits of these options under a common set of ground rules.
- What criteria it should use to rank options and to make final choices.

To pursue these tasks we have drawn heavily from surveys of the published literature and materials from regulatory proceedings. In addition, we conducted interviews with a dozen large private firms, mostly in financial services and other information-intensive industries, to obtain a better understanding of the basis on which they choose among telecommunications alternatives—a process relevant to federal agencies facing similar situations. Nearly all of these interviews were conducted by Professor Sirbu and graduate students at the Massachusetts Institute of Technology.

Finally, we must emphasize that this study constitutes only one input into the decisionmaking process for federal telecommunications procurements that best serve the national interest. Topics outside the scope of this study include
• Possible economies of scale in procurement and operation arising from interagency coordination.
• The effects of alternative procurement strategies on emergency preparedness.
• The impact on procurement practices of federal procurement regulations, including OMB and GSA policy and regulatory issuances.
• The variety of possible budget restrictions in addition to those we treat under the principles of capital budgeting in Sec. IX.
• The opportunities afforded by shared use of existing and planned major government telecommunications networks.
• The process of approvals, procurements, and implementations once agencies have evaluated and selected options.

As discussed in the Executive Summary, each agency must consider whatever unique circumstances it faces and other factors beyond the scope of this study.
II. TELECOMMUNICATIONS SERVICES AND ORGANIZATIONAL ALTERNATIVES FOR SUPPLYING THEM

A telecommunications system can be designed for a wide range of capabilities and services—from carrying simple voice calls to supporting complex network management functions. The most important distinguishing characteristic of the various service options is the extent to which the agency takes responsibility for the acquisition and operation of its telecommunications system.

The typical organization's use of telecommunications is similar to its use of computers 20 years ago. At that time, few companies owned computers. Those that needed computing bought it from service bureaus. If they did buy computers, they relied on the vendor for software. Only gradually did corporations bring computers and software development in-house and take greater control over their management and use. Similar behavior is occurring with respect to telecommunications.

An increasing number of firms, especially in the information-handling and computer sectors, have concluded that they can no longer entrust the control and operation of such a key factor of production to third parties. These companies, when faced with a choice of buying service or buying facilities and configuring their own customized services, are opting for the latter. This behavior appears to be as much strategic as tactical. These firms want to begin to develop in-house skills in telecommunications to position themselves for competing in an information society. Even some long-time manufacturing organizations, such as General Motors, seem to have concluded that control of telecommunications is vital to coordinating its vast enterprises.¹

Many other firms, of course, have not seen such a strategic need, and continue to rely on the carriers. Moreover, the carriers, responding to customer demands for increased control, are striving for

¹GM is planning to spend $270 million over the next 10 years for a new telecommunications network. J. Mulqueen, "GM's $5B Purchase of Hughes Could Bolster Push into Telecom," Communications Week, June 10, 1985, p. 4.
greater flexibility in offering customizable services over shared public facilities.

Taking control of telecommunications often means a radical increase in the number and sophistication of telecommunications staff. The ability of the agency to attract and manage such staff is a crucial factor in evaluating alternatives. This issue is discussed further in Sec. VIII.

To make wise choices, telecommunications users should consider carefully the kinds of services available today and in the near future, and the characteristics of firms that supply them. In response to these needs, this section addresses three areas:

- **Voice capabilities**, including consideration of geographical coverage, convenience voice features, and ancillary voice services, offered by advanced telecommunications systems.
- **Data capabilities**, with emphasis on the problem of meeting diverse user needs, and discussion of the distinction between circuit switching and packet switching.
- **System management**, which is a critical factor in controlling when and where service is delivered, accounting for service usage, and planning for future telecommunications requirements.

**VOICE CAPABILITIES**

Voice communication currently accounts for 85 percent of federal telecommunications use and, as noted in Sec. I, is likely to remain the dominant component at least until the end of the decade. Today, the capability to complete voice calls is almost the definition of a telecommunications system. But simple provision of voice service is too broad a concept. To evaluate alternatives, one must examine options with respect to geographical coverage, convenience features, and ancillary services.
Geographical Coverage

With respect to the geographical coverage, one must consider four dimensions: intrafacility, interfacility, local, and toll.

These distinctions are important because the appliability of particular technologies and the nature of regulatory constraints imposed on service suppliers depend on geography. Frequently, specific system alternatives are relevant for only one category of calls. For example, the development of "virtual" private networks (such as AT&T's Software Defined Network), discussed in Sec. IV, currently is of interest only for providing toll service. Moreover, in states where competition within local access and transport areas (LATAs) is not permitted, as discussed in Sec. VII, the variety of services may be relatively limited.

Convenience Features

Modern telecommunications systems do more than just transport voice calls. Typically they provide at the user's handset numerous "convenience features" that facilitate the placing and receipt of calls. Table 2.1 lists some of the services offered by advanced communications systems. The number and diversity of these features is increasing rapidly. Since many require only minor changes in software, their number is limited only by the imagination of designers and the needs of the market.

For example, AT&T claims to offer more than 150 special features with its Dimension 75 and 85 PBXs.\footnote{AT&T, "What Makes Us Think We Can Speak For Everybody?," Communications Week, May 27, 1985 (Advertisement).} AT&T Technologies has recently developed a special service definition programming language to facilitate the addition of new services to Centrex by local operating companies.\footnote{E. M. Mazur et al., "New Voice and Data Features for Centrex," Telephony, Vol. 208, No. 24, June 17, 1985, pp. 66 ff.} Although the benefits provided by each of these services may appear small, cumulatively they can significantly enhance communication efficiency and cost effectiveness.
Table 2.1

CONVENIENCE FEATURES

| Call forwarding--all calls | Executive call interrupt          |
| Call forwarding--busy line | Flexible ringing assignment       |
| Call forwarding--do not answer | Hot line                        |
| Call forwarding--secretary override | Last number redial |
| Call hold | Music on hold                     |
| Calling number display | Night connection                  |
| Call pickup | Paging access                     |
| Call queeuing | Paging transfer                   |
| Call transfer | Periodic time indication tone     |
| Call waiting | Remote access to system           |
| Data line security | Speed dialing--system            |
| Direct inward dialing | Speed dialing--group              |
| Direct outward dialing | Speed dialing--station           |
| Distinctive ringing | Station hunting                   |
| Do not disturb | Three way calling                |

Source: Vendor literature.

Ancillary Services

In addition to services provided at the handset, other services can typically be provided from a central point to all users. These include attendant services, message desk services, and directory services. Table 2.2 lists some generic attendant services.

Table 2.2

ATTENDANT SERVICES

| Attendant call control | Night service             |
| Attendant console queueing | Power failure transfer   |
| Attendant camp-on | Attendant ID of incoming calls |
| Attendant override | Busy verification         |
| Call queueing

Source: Vendor literature, and Bell Communications Research, Industry ISDN Seminar, February 5-6, 1985.
Attendant and message desk features can significantly reduce the high costs of operators and receptionists or improve the responsiveness of agencies serving the public. Some systems, for example, employ a display on the telephone to automatically show the names and telephone numbers of persons who call. Such automatic services reduce the likelihood of messages being lost. Also included in this category are voice mail services that store and retrieve voice messages much as electronic mail handles text messages. Of course, agencies must assess their needs before deciding which ancillary or convenience services to include in a systems procurement.

It is worth emphasizing that a government worker with a salary of $30,000 per year, assuming a 100 percent overhead rate, costs nearly 50 cents per minute—a figure in excess of the typical per minute cost of a toll call. A system that saves a caller's time by providing the appropriate services can be very cost-effective. This point is often overlooked in evaluations of needs and benefits because agencies have a long-distance account but no salary-while-on-the-phone account.

DATA SERVICES
Problems of Meeting Diverse Needs

Unlike a voice call, which has fairly standardized characteristics with respect to required bandwidth, average holding time, and acceptable quality, data communications requirements span a much broader range of service characteristics that depend on specific applications, illustrated in Table 2.3. For example, interactive terminal support must cope with bursty data, with no more than modest speeds required, whereas image data transfer is not bursty but requires much higher transmission speeds.

This diversity complicates comparisons of alternative methods of supplying data communications service. A PBX and Centrex both provide about the same voice carriage and thus must be compared on other criteria such as price or reliability. But the two may offer quite dissimilar data capabilities. Therefore, one must compare not only price but the marginal benefit to be obtained if one system offers, say, a higher intrinsic bit rate than the other.
Table 2.3

DATA COMMUNICATIONS SERVICE REQUIREMENTS

<table>
<thead>
<tr>
<th>Bidirectional transmission</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freedom from error</td>
<td>Priority service</td>
</tr>
<tr>
<td>Efficiency despite burstiness</td>
<td>Insensitivity to distance</td>
</tr>
<tr>
<td>High connectivity</td>
<td>Short transit delay</td>
</tr>
<tr>
<td>High peak information rate</td>
<td>Uniform transit delay</td>
</tr>
<tr>
<td>Security</td>
<td>Broadcast capability</td>
</tr>
<tr>
<td>Authentication</td>
<td>Station mobility</td>
</tr>
</tbody>
</table>


In today's environment, characterized by a lack of data communications protocol standards and a mix of analog and digital facilities, a telecommunications system has many components whose primary purpose is to provide stopgap solutions to satisfy the wide range of data needs. Thus, many PBXs offer protocol conversion between asynchronous terminals and IBM 3270 type terminals or support for modem pooling.

In Sec. VI, where we treat in more detail the problems of providing data communications, we will focus on two major telecommunications architectures: circuit switched and packet switched. It is useful to briefly discuss them here.

Circuit Switched and Packet Switched Services

In a circuit switched data communications system, a clear physical channel from origin to destination is established. Today's telecommunications network employs primarily analog channels optimized for voice traffic. Circuit switched data service is provided with modems that convert the data to analog signals limited to voice band frequencies. Consequently, data rates on the switched network are limited to 9600 bps or less.

A circuit switched data network would carry signals in digital format from end to end. (A major motivation for carriers to build an ISDN, discussed in Sec. V, is to provide ubiquitous circuit switched
digital service at speeds up to 64 kbps.) "Third generation" PBXs, discussed in Sec. III, support circuit switched data within the facility served by the PBX. Having circuit switched data is also possible between PBXs if they are linked by digital transmission channels.

In a packet switched network, user data are broken up into individually addressed packets of about 1000 bits. Packets from many users are interleaved on high-speed transmission lines that interconnect packet switches. By sharing the transmission line among many users, packet switching provides efficient carriage of bursty data such as that required in an interactive terminal session. In addition, packet network protocols generally provide for error detection and correction, thus providing a more reliable data communications service than does a circuit switched channel. At the same time, packet switching can introduce delays that are troublesome for certain applications. Moreover, the addressing overhead makes packet switching less efficient where bulk data transfer is required. Finally, the top speed of today's packet networks is 56 kbps, making them too slow for video and some graphics applications.

In Sec. VI we will consider the merits of user-managed versus carrier-provided packet switching services, where these desirable and undesirable characteristics will be important to keep in mind.

SYSTEMS MANAGEMENT SERVICES

A communications system must not only carry user information from one station to another, it must also be managed as a system. A properly configured communications system can greatly improve the ability of an agency to (a) provide service, (b) control when and where service is delivered, (c) account for service usage, and (d) plan for future needs.

In evaluating system alternatives, it is all too easy for an organization to focus on the price/performance for carrying voice or data, while neglecting the importance—and cost—of managing the system. Fortunately, many of the organizations we interviewed did list system management facilities as a major criterion in selecting or changing their telecommunications system. These facilities can significantly affect the overall cost of agency communications affording closer control of usage and easier configuration of service.
System management services, to a greater extent than information carriage, are provided by a complex of hardware, software, purchased services, and organizational procedures. Indeed, to evaluate alternatives, the merit of organizational procedures needed to complement purchased materials and services is a critical factor, as will be emphasized in our later discussions.

In the evaluation of alternatives, three major components of systems management services are relevant—operational management, service provisioning, and administrative management—to which we now turn.

**Operational Management**

Of course, hardware, software, and operating procedures must work together to insure the continued smooth operation of a network. These procedures include diagnostic services, problem determination facilities, and system status and monitoring capabilities.

The complexity of problem determination in a multivendor environment should not be underestimated. Even where agencies rely on a carrier for both switching (e.g., Centrex) and circuits (e.g., leased lines) the fact that these must be supplied by separate entities (e.g., local exchange carriers and interexchange carriers, respectively) can lead to finger pointing when problems occur. Thus the agency may need to develop test systems and procedures in addition to those used by the carriers themselves.

In addition to assisting recovery from system failure, support for continuous network optimization and control can lead to lower costs and higher-quality service. Thus, operations management includes facilities for automatic route selection and least-cost routing, load balancing, and performance monitoring. In this respect, it is worth recalling that the original motivation for creating the GSA's FTS network was the desire to control the allocation of capacity in an emergency.

For some systems, responsibility for operational management lies with the carrier or some other entity. In evaluating such systems, one must judge the likely quality of operational management service provided by such an entity, in addition to its specific functional capabilities.
Service Provisioning

Service provisioning includes such functions as adding users, deleting users, altering the purposes to which specific equipment or transmission channels are put, or otherwise reconfiguring the network. These functions are obviously important for responding to personnel turnover or changing user needs.

In the public network, where services are provided by the carrier, service provisioning requires that the user communicate the appropriate instructions to the carrier. The user must then verify that the instructions have been carried out. In some newer systems discussed in later sections of this report, the agency can control service provisioning through a terminal on the telecommunications manager's desk.

Software-controlled provisioning can significantly improve the timeliness of service modifications, while reducing costs. This advantage is nontrivial. According to our interview with one firm that has 5000 employees, phone assignment changes have exceeded 5500 per year at an annual cost greater than $100 per employee. In another organization we interviewed, a plan to redesign office space led to a need to change 10,000 phone assignments at one location within a short period. Support for moves and changes was cited by all of our interviewees as a key decision variable in comparing system alternatives.

Service provisioning also includes control over the assignment and configuration of convenience features, discussed above, and class of service features that allow system management to vary the range and quality of service available to individual stations or users. For example, particular stations may be restricted to making only intrafacility calls or only local calls, or calling may be controlled during certain hours. For long distance, different grades of service may be offered to different users.4

4 Grade of service is a complex of many variables but a major component is the delay to complete a call during the peak hour. For example, calls for some users can be blocked until a tie line is available, whereas for other users a call can be routed over higher cost direct distance dialing (DDD) lines rather than forcing the caller to wait.
Examples of other provisioning functions are assignment of (a) message desk responsibility, (b) call overflow numbers or hunt groups, and (c) other tasks required to specify fully how various system features are to perform for specific individuals or groups of users.

We must emphasize that the diverse service capabilities illustrated in Tables 2.1 and 2.2 will not be effectively used unless service provisioning is both easy and flexible. Perhaps even more important, control over grade of service can have a major impact on usage costs and capacity requirements.

For these reasons, the needs, habits, and attitudes of end users must be taken into account both in planning and routine operation of the system. In other words, telecommunications should be managed from a user's perspective as well as from the perspective of the telecommunications manager. A traditional management tension is between the supplier of services—the responsibility of telecommunications managers—and the needs of end users. Resolving that tension in telecommunications is one of the major challenges of government as well as other organizations.

Administrative Management

This last category of system management includes the provision of call detail reporting, transmission and switch usage reporting, cost analysis, and information for analyzing trends and predicting future needs. Systems vary with respect to both the kinds of administrative data made available to the system manager and the flexibility of the reporting format for showing these data.

ORGANIZATIONAL ARRANGEMENTS FOR SERVICE SUPPLY

Twenty years ago the only way to obtain telecommunications service was from the monopoly carrier, typically by the call. Today, many organizational arrangements exist for supplying telecommunications services and network support—from buying service by the call to buying switching and transmission equipment and operating one's own network.
Some organizational alternatives offer relatively low prices but with the penalty of service rigidity; others offer just the opposite. Especially important, these alternatives vary with respect to the control—and the burden of responsibility—placed in the user's hands. The value of increased control must be carefully weighed against this burden and the capabilities of the agency to assume it.

Major alternative organizational arrangements we will discuss briefly include full service common carriers, specialized carriers, resellers, transmission condominiums, equipment manufacturers, facilities managers, and management by users themselves.

Full Service Common Carriers

To describe full service carriers, it is useful to consider first AT&T's divestiture of its Bell operating companies (BOCs). Under the Modified Final Judgment (MFJ) governing the terms of the divestiture, AT&T Communications (AT&T-C) is the regulated portion of AT&T supplying domestic and international long-distance services. Under the terms of the FCC's Computer II decision (discussed in Secs. III and VII) it is permitted to sell only basic services, which are regulated. AT&T Information Systems (AT&T-IS) markets "enhanced" services, which are unregulated. The 21 divested BOCs provide service only within LATAs. Only AT&T-C, and other carriers if permitted by state regulators, carry intrastate traffic between LATAs.

Entities such as AT&T-C, MCI, and GTE-Sprint provide a full range of service options and offer to act as end-to-end service contractors for services they do not provide directly (e.g., local access). For large users such as the federal government, these interexchange carriers may even undertake to provide local access from customer facilities to their point of presence in each LATA, thereby bypassing the local exchange carrier's network.

The local exchange carriers (LECs) also offer full service in the sense that they provide a wide range of services within their assigned LATAs. However, because of the restrictions imposed by the MFJ, the

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5Some 164 LATAs were created nationwide, with 38 states having more than one LATA.
BOCs cannot act as contractors to provide inter-LATA services. Moreover, they may provide customer premises equipment only through a fully separated subsidiary.

Full service carriers emphasize service by the call, where they assume complete responsibility for such functions as operational management of the network and service provisioning. Using redundant facilities within their networks, they provide a high level of network availability.

In addition to per-call offerings, a full service carrier may dedicate a fraction of its plant to the use of a particular customer--such as a portion of a switch in its central office for Centrex, or a particular leased transmission line. Whereas in the past these offerings literally involved the dedication of specific physical equipment to the user, we are seeing the introduction of "dedicated" services that are no more than pricing options. Thus, "private line" service may be offered over varying physical facilities as it suits the convenience of the carrier for operational or maintenance reasons--much as with switched circuits--but with charges accruing per month rather than per call. Users value private line options, whether or not they involve dedicated physical facilities, because of the pricing and management control advantages they offer along with economies of scale in centralized network management and maintenance.

**Specialized Carriers**

These carriers provide a variety of facilities that are "specialized" because of:

- The use of technologies with specific characteristics.
- Regional selectivity.
- Provision solely of transmission or of limited switching.

Typical in this group are satellite carriers such as Western Union or American Satellite, whose service is based primarily on dedicated satellite circuits that the user must configure with switching facilities and other inputs to form a complete network. Unless terrestrial circuit extensions are included, network coverage is limited to those locations where the user installs earth stations.
Generally, these carriers provide a high level of transmission line availability through redundant equipment and centralized network management. Service may be tariffed by capacity, or usage, or both. However, to take advantage of specialized carrier offerings, the user must be prepared to undertake directly, or to contract for, integration of these limited services with added network equipment, depending on its communications requirements.

Also in this group are the public packet network operators (e.g., Telenet) that provide a range of both basic and enhanced data communications services. These offerings may be relatively complete in their provision of both transmission and switching but are limited to serving only data traffic that is best carried on packet networks. Service may be tariffed by the packet or by overall capacity.

Resellers

Some carriers, known as resellers, do not own their own transmission facilities. Taking advantage of regional variations in the tariffs of full or specialized carriers, or of bulk discounts such as WATS tariffs, they buy service from a variety of carriers and resell it in smaller units to end users. Resellers may add switching or multiplexing to purchased transmission to offer a more complete service.

Resellers can provide an attractive option for small users who do not have sufficient volume to make use of bulk offerings. For large users, such as federal agencies, resellers are unlikely to be the optimal choice. Moreover, as the full service carriers realign prices to reflect costs, the arbitrage opportunities for resellers will narrow. Consequently, resellers who do not control their own transmission facilities, through ownership or long-term leases, will probably disappear.

Transmission Condominiums

To avoid the regulatory obligations of common carriers and to shift some of the financial risk to users, a new group of companies has emerged. They offer users the right to own a "share" of a transmission system or component—ranging from a transponder on a satellite to a pair of optical fibers in a cross-country network.
Such offerings are attractive on at least two counts:

1. They reduce cost uncertainty, because ownership locks in a fixed cost over the life of the investment. Of course, if the price of competitive offerings drops, the customer sees the value of his investment decline; conversely if competitive prices rise.

2. They lower net costs to private sector customers because of the investment tax credit. Or course, this advantage is irrelevant to government agencies, since any savings from a tax credit are offset by a reduction in tax revenues.

Services provided by condominium operators sometimes include a degree of network management. However, because the user has rights to a particular unit of transmission, the maintenance of spare facilities for cutover in the event of failure may rest with the user, rather than with the network supplier. Also, in contrast to carrier-provided channels, condominium channels are generally sold in large bulk units, leaving the responsibility for subdividing or multiplexing to the individual user.

**Equipment Manufacturers**

Those who decide to buy and build their own network can, of course, acquire the equipment from numerous manufacturers. Seeking to increase sales, some manufacturers provide various levels of turnkey assistance to the customer to configure a comprehensive communications system. For example, Northern Telecom, in addition to selling backbone switches to General Motors for its corporate network, is acting as overall system design contractor. Large manufacturers also provide a range of management services, including remote testing and diagnosis of their equipment, skilled support staff to assist in such areas as service provisioning and assignment of grade of service, and even maintenance engineers located on the customer's premises.
Facilities Managers

A good example of a facilities manager in the computer business is Electronic Data Systems (EDS). The user buys equipment, thereby reducing cost uncertainty and accruing any tax advantages, while hiring the facilities manager to run the computer center. The facilities manager's tasks may range from simply maintaining the equipment to performing extensive programming and operations support.

The independent facilities manager, unaffiliated with any equipment manufacturer, can also provide unbiased assistance in equipment selection. Since the regional Bell operating companies are barred from engaging in manufacture yet possess a wealth of expertise in system management, all of them (as well as some independent telephone companies) have set up unregulated subsidiaries to provide facilities management services.

Of course, the quality and range of services available from facilities managers vary considerably. Among other things, this arrangement allows the user more options of service quality, either higher or lower than standard carrier service. ⁶

Given the complexity of options available to end users, and the economic advantages that some enjoy in buying their own systems, facilities management companies are likely to enjoy a growing market.

User Management

The final option, of course, is for the user to take full responsibility for the operation of his network. This task may include everything from network design to maintenance and day-to-day operations management. Such responsibility can be organized on a divisional basis or on an organization-wide basis. In the federal context, the GSA could act as a "private carrier," owning and operating an extensive network that it retails to the individual agencies. Or the agencies can

⁶However, the carriers are becoming more flexible as well. Thus AT&T's new private line tariff allows the user the choice of buying "access coordination"—a guarantee of the quality of the interconnection—in conjunction with an access line from the customer's premises to the AT&T point of presence. See B. L. Marks and E. L. Diamond, "Centrex Countdown," On Communications, June 1985, pp. 47-52.
themselves acquire and operate telecommunications facilities, as DoD and the Federal Aviation Administration have done for years.

Because alternative providers of network services are available, a decision to buy facilities, as opposed to obtaining communications services from outsiders, is not necessarily tied to a decision to manage a network with agency personnel. The primary factors that determine whether user management is appropriate for a given agency include: availability and cost of qualified personnel, the scale at which operation of a private network makes economic sense, the availability and characteristics of other equipment required to make best use of the network, and the need for capabilities that cannot be purchased from others.
III. PBX VERSUS CENTREX

The single most important choice an agency must make at any end-user location is between a PBX and a Centrex. This choice epitomizes the central question for telecommunications decisionmakers: Should the agency acquire—whether by lease or purchase—capital equipment to provide a service free or should it buy the service directly from a carrier? While both provide the principal function of linking individual desks—whether for voice or data—in an agency's office, they often differ substantially in the way they contribute to system and overall network management. Because the total usage costs that flow through the PBX or Centrex office often far outweigh the costs of basic access, the ability of the switch to manage these costs is crucial. Thus, the choice between a PBX and Centrex must be made as part of an overall system choice.

To treat the relative merits of these two alternatives, we divide the discussion into the following topics:

• Recent technological advances that affect the capabilities of PBX and Centrex equipment.
• Voice capabilities of each, including a discussion of convenience features, ancillary services, and differences in capabilities for intra-LATA calling.
• Data capabilities, including a discussion of ongoing efforts by Centrex suppliers to upgrade their data offerings.
• System services that, as emphasized in Sec. II, are critically important to controlling telecommunications costs.
• Federal and state regulatory constraints that affect the ability of Centrex suppliers to compete with PBX vendors.

Our treatment of these five topics leads to the following principal conclusions:
1. Currently, a PBX offers significant advantages over Centrex in (a) the range of convenience features and ancillary services, (b) the variety and level of integration of data switching features, (c) the convenience of moves and changes, and other aspects of service provisioning, and (d) the support for network management and the control of usage costs. Indeed, the PBX's contributions to controlling total communications costs account for much of its cost/benefit advantage. The cost of a telephone line to a desk, whether provided by Centrex or PBX, is typically less than 75 cents per day. But in some government offices an individual might easily spend 10 times that amount in toll calls. Thus, even a small percentage reduction in the cost of toll calls can overshadow any difference in the basic price.

2. Centrex continues to have advantages for very large installations, particularly those spread among several locations within a metropolitan area. It is also well suited for small offices where the cost for a PBX with advanced features cannot be justified for only a few lines, e.g., in the range of 200 to 400 lines. Reliability and service may be better for Centrex, particularly outside major cities. By contracting maintenance to the PBX vendor, however, staffing requirements can be as low or even lower than for Centrex. A nagging question, however, is whether the reliability of PBX vendor service is generally as good as that provided for Centrex, which shares facilities located on telephone company premises.

3. Because of intense competition from advanced PBXs, Centrex performance is being upgraded, and many advances will be marketed during the next few years. The replacement of analog central offices with digital ones will permit Centrex to match most of the features of an advanced PBX and even provide others based on common channel signalling that PBX vendors may be unable to offer during the same time period. Provision of some of these enhanced features by Centrex has been precluded or subjected to doubt because of the FCC's decision in its Computer II inquiry to require physical separation between basic and enhanced services. However, recent decisions by the FCC have reduced these constraints, and the outcome of its ongoing Computer III inquiry may move further in that direction.
4. The repricing of Centrex approved by some states, along with flexible pricing, detariffing, and even outright deregulation of Centrex, approved or being considered by others, will further enhance Centrex's appeal.

TECHNOLOGICAL ADVANCES

The market for Centrex was declining before the AT&T divestiture, evidenced by a fall in the number of BOC Centrex access lines from about 7.9 million to 7.4 million during the two-year period 1980-1982.\(^1\) With vertical integration of BOCs, AT&T, and Western Electric, the Bell system saw its advantage in emphasizing the PBX market, illustrated by promotion of its Dimension series.

Incentives have changed because of the divestiture of the BOCs from AT&T and Western Electric. Under terms of the Modified Final Judgment in the divestiture, the BOCs are permitted to sell, but not to manufacture, customer premises equipment (CPE). Moreover, the FCC's decision after the Computer II inquiry requires that sales of CPE (including PBXs) be made only through a fully separated subsidiary.\(^2\) Thus, the BOCs are seeking to enhance their Centrex service offerings. The results of these efforts are illustrated by the gain of about 180,000 lines in 1983, and 300,000 lines in 1984.\(^3\) Moreover, for the BOCs and independent telephone companies together, the market for Centrex is projected to grow steadily from about 8.3 million lines in 1984 to 9.4 million in 1988--an average annual growth rate of 4 percent. In comparison, the PBX market is projected to grow slightly more--from

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\(^1\)North American Telecommunications Association, *Sourcebook*, Washington, D.C., 1985, p. 74. Two types of Centrex are offered. By far the most important is Centrex-CO, where switching equipment is located in the telephone central office. In contrast, Centrex-CU, involving switching equipment on customer premises connected by trunks to the central office, operates much like a PBX system. Unless otherwise specified, all references to Centrex in this study are confined to Centrex-CO systems.


\(^3\)NATA, op. cit., p. 74.
21 million lines in 1984 to 25 million in 1988, an increase of 4.5 percent.  

The technology of both central office switches and of PBXs has changed dramatically from that available in the early 1960s when Centrex was introduced. A PBX consists of a switching matrix, a controlling mechanism, station side access (lines connecting telephones, terminals, etc., to the PBX), and trunk side access (one or more connections to the public network or other PBXs). Before the 1970s, PBXs were analog electromechanical devices used strictly for voice service. The introduction in the public network of electronic switching and stored program control in the late 1960s was soon applied to PBXs. Unlike their electromechanical predecessors, "second generation" electronic stored program control switches can provide an ever-expanding array of software-based features, such as least-cost routing. A few of these second generation switches convert the analog speech signal to digital form inside the switch matrix.

So-called "third generation" PBXs handle all traffic in digital form and are designed to handle both voice and data with equal ease. PBXs in this category include the AT&T System 75/85, the Northern Telecom SL-100, the NEC NEAX 2400, and the Mitel SX-2000. Such PBXs are attractive because they can

- Distribute intelligence into switch modules remotely located from the main switch, a useful feature in campus or office park situations.
- Easily interconnect with digital transmission lines in private networks.
- Be upgraded by adding modules to provide computation-intensive advanced features.

Finally, some PBXs are referred to as "fourth generation," since they are designed to support high-speed local area networks (LAN). These include the Northern Telecom Meridian, the CXC Rose, and the Ztel PBX.  


*The value of integrating LANs and PBXs is uncertain at the present*
In the past, Centrex has had an advantage in that central office switches are usually designed to be upgraded in place, thus assuring that new features can be continuously added. In contrast, PBXs have had to be replaced in their entirety when they became outdated by new technology. Since the late 1970s, however, we have seen a reversal. Although the vast majority of central office switch installations remain analog, several PBX manufacturers have begun to offer products using 100 percent digital switching that can be upgraded by replacing modular circuit cards. In contrast, certain Centrex improvements cannot be realized until an existing analog central office switch is totally replaced by newer digital equipment.

According to our interviews with companies that had recently converted from Centrex to PBX, or who are contemplating doing so, their decisions were tied to the disparity between the capabilities of a new PBX and the capabilities available from the particular central office that provided them with Centrex service. In response to competitive pressures, the replacement of central office equipment may accelerate. Nevertheless, according to one projection only 26 percent of the nation's central offices will be converted to digital by 1987. In many areas, it is the demand of Centrex users that will drive this conversion.

In evaluating PBX and Centrex, federal users will need to explore carefully with the local exchange carrier its plans for upgrading the relevant central offices. Users should also examine carefully the modularity of competing PBX designs and their potential for continuous upgrading through replacement of low-cost circuit boards.

Because PBXs and Centrex compete in the same market, vendors have a strong incentive to offer the customer comparable services. The same hardware (e.g., AT&T 5ESS) is being sold both to carriers as a switch

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The situation is further complicated by the fact that many of these PBXs use nonstandard LAN technologies (see the discussion of standards, Sec. VI).

Del Myers, "Telecommunications Carriers to Spend $23.634 Billion in 1985," Telephony, January 14, 1985, p. 46. However, one would expect central office replacement to proceed most rapidly in high traffic areas. Hence, the level of conversion relevant to government needs may be much higher than 26 percent.
from which to provide Centrex and to end users as a PBX. Differences between the two must rest then not on technology but on the differences in the institutional structure of provision. Institutional differences exist in pricing, service, and constraints imposed by regulation.

The costs of a PBX per line vary considerably from vendor to vendor. The more modular switch architectures show a relatively constant cost per line with increasing switch size. Figure 3.1 shows wide variations in costs of maintenance, power, and space among vendors and switch sizes. Note that the sum of maintenance, power, and space costs for the smaller systems can be a significant fraction of monthly equipment amortization. Centrex costs are flatter but vary widely among state regulatory jurisdictions, as discussed below.

We now turn to comparisons between PBX and Centrex by considering how well each supports voice, data, and system services.

**VOICE CAPABILITIES**

The essential function of both the PBX and Centrex is to provide intrafacility voice call support. Of course, they also provide the first step in both local and long-distance calling. Whatever the advanced data or management features offered in addition, the system must provide sufficient, reliable voice service, both initially and as agency needs evolve over the life of the system.

When Centrex was first introduced, it provided features such as direct inward dialing, unavailable in a PBX. But today, PBX offerings provide more convenience features and ancillary services than are available from all but the newest Centrex systems. These differences partially result from the digital architecture of the newer PBXs in comparison with analog-based Centrex products. Third generation digital PBX products provide both a digitized voice channel and a digital signalling channel at every handset and some provide a digital data channel as well. Using proprietary electronic handsets designed to work with the PBX vendor's signalling protocols, a modern PBX can provide the full range of features listed in Table 2.1. The use of common channel signalling (discussed in Sec. IV) permits use of handsets that can display a caller's number, light a lamp if there is voice mail waiting, or provide access to multiple line appearances over one set of wires.
Fig. 3.1—Cost per line behavior of PABXs
Often, proprietary phones have a simple user interface with a dedicated button on the handset for such services as call transfer or camp on busy.

In contrast, the typical analog central office used for Centrex is limited to in-band signals generated by a tone phone. Messages or caller identity cannot be signalled to the handset. Having multiple numbers accessible from a phone requires multiple pairs of wire. Access to special services, such as call forwarding, may require dialing a difficult-to-remember sequence such as *72, instead of pressing a labeled button.7

The introduction of digital central offices with ISDN standard interfaces incorporating common channel signalling, beginning in 1987, will significantly improve Centrex's ability to compete in providing advanced convenience features.8 Until then, Centrex's offerings will lag PBX's with respect to voice features. The advantages of insisting on ISDN standards in PBXs is discussed in Sec. VI.

Because the FCC's Computer II decision has required that the BOCs provide CPE only through a separate subsidiary, they have not been able to coordinate developments in both CPE and switching, except through the publication of standards. They are also hampered in responding to requests for bids that specify single vendor responsibility for both. However, the situation could change soon, depending on whether the FCC decides to modify or abandon these restrictions as a result of its current "Computer III" inquiry discussed in Sec. VII.

7Recently, however, handsets especially designed to provide "one button" convenience with Centrex have appeared; pressing the "call forward" button causes the handset to generate the tone sequence for "*72." R. M. Carlson, "Centrex: A Long Time Winner That Still Looks Good," Telephony, October 8, 1984, p. 43.

8See Sec. V for a discussion of the factors affecting the availability of ISDN.
Ancillary Features

With respect to ancillary services, such as voice mail, message
desk, or advanced attendant features, PBXs also have an edge. If a user
has specified that unanswered calls to his number are to be forwarded to
the message desk, the feature forwards both the user's number and the
call. With the proper database, the user's number can be translated
into the user's name for display on an attendant's console. This allows
the attendant to answer with a personalized "Miss Jones's phone."9 This
is a common feature in a PBX but is not yet available from Centrex.
However, message desk capabilities are being developed for Centrex and
could even be retrofitted into older central office equipment.10

Regulatory actions also intrude. The FCC has ruled that voice mail
is an enhanced service and has declined thus far to permit the BOCs to
offer it with Centrex. Moreover, the limitations on joint marketing of
CPE and Centrex service noted earlier complicate offerings that Centrex
is permitted to provide. However, the situation could change after the
FCC's current Computer III inquiry.11

Intra-LATA Calling

Centrex has been attractive for large organizations, particularly
those with multiple office buildings in an area served by a single
central office. Where an organization's facilities are spread among
many buildings that are close together, Centrex can provide integrated
service among all the buildings from the same central office. To
provide similar capability from a PBX would require obtaining a
franchise to run massive amounts of wire from the PBX under city
streets. Moreover, because Centrex is central office based, rapidly
growing organizations have found it attractive because it is
continuously expandable.

9 Mazur et al., op. cit.
10 Ibid.
The situation has changed somewhat with the introduction of the Northern Telecom SL-100, and the use of AT&T's #5ESS as a PBX. Both are modular switches, which permit remote switching modules in a distant building to be controlled via a fiber link to a central control unit. Capable of handling up to 30,000 or 100,000 stations, respectively, these PBXs simplify the problem of providing integrated switching for multiple buildings by reducing the wiring problem to that of stringing a single fiber optic cable or using leased T1 circuits between modules.\footnote{A T1 channel refers to a transmission facility consisting of two twisted wire pairs carrying 24 channels encoded at 64 kbps, for a total bit rate of 1.544 Mbps including framing bits. Colloquially, "T1" has come to refer to any 1.544 Mbps transmission channel, whether on fiber, microwave, or twisted pair.}

For example, Digital Equipment Corporation is currently replacing its headquarters Centrex, plus other older PBXs, with four multimodule SL-100s linked by 80 miles of fiber optic cable to serve some 40,000 employees scattered over dozens of buildings in Massachusetts and Southern New Hampshire. According to our interviews with officials at that corporation, only the SL-100 and the #5ESS have the capacity and modular design to meet their needs. Savings of nearly $1 million per month are expected on a $36 million investment in the total project.

Centrex may markedly benefit from the introduction of common channel signalling. Before its introduction, signalling in the carriers' networks was accomplished with tone signalling preceding the voice signal through the circuit, as discussed in more detail in Sec. IV. In contrast, a common channel signalling network provides a separate data path for conveying complex signalling information between network signals. The introduction of such signalling between central offices—sometimes referred to as Local Area Signalling Services (LASS)—makes possible provision of so-called "citywide Centrex" where buildings serviced by multiple central office switches can nevertheless appear to the user as a single Centrex facility. Indeed, LATA-wide Centrex would be feasible with this technology. Thus, federal agencies with a high concentration of office buildings in the same general area, may find Centrex superior to the above PBX alternatives.
The introduction of LASS also allows the local telephone company to provide enhanced services for regular local calls as well as intrafacility calls. For example, caller number identification can be provided for calls originating outside the company (but within the LATA). For agencies that deal extensively with the public, the ability to identify all incoming calls may be a valuable service. LASS-based services are currently being offered on an experimental basis in Orlando, Florida. Most BOCs expect common channel signalling to become widely available beginning in 1987.

DATA CAPABILITIES

Current generation PBXs can provide switched digital services at data rates up to 56 kbps. Recently announced products, such as Northern Telecom's Meridian, specify data rates above 2 Mbps. Other equipment, such as Northern Telecom's Displayphone or Rolm's Cedar and Juniper, provide integrated voice data terminals that run over PBX lines. These switched data services are used in conjunction with modem pooling, protocol converters, and T1 tie lines. Some PBXs provide direct interfaces to local area networks such as Ethernet.\footnote{Indeed, we had several reports from users who attempted to use the same PBX for both voice and data and found that the longer holding times for data severely overloaded the switch. Buyers who intend to use their PBX for data should be careful to specify nonblocking switch designs that can support the data load.} A survey of 400 users by the Market Information Center Inc. revealed that only 12 percent used a PBX to switch data; 26 percent planned to do so in the future, and 60 percent had no future plans to use a PBX for switching data.\footnote{"The Data Network," \textit{Communications Week}, October 14, 1985, p. 33.} Where data traffic is extensive, it is still cheaper today to use a dedicated data switch for data and to limit the PBX to voice traffic.

However, on third generation nonblocking switches--and when most users have full-function electronic telephones--adding data capability at each desk involves relatively little additional cost. Using the PBX also makes sense today where transmission links off site are being shared by switched voice and data calls. As semiconductor manufacturers
gear up to supply very large-scale integration for ISDN beginning in 1988, PBX manufacturers will be able to use the same chips to lower the cost of voice/data integration.

Centrex currently does not provide strong support for data. However, local telephone companies are seeking to enhance the ability of the current generation of central office equipment to do so. Pacific Bell's Public Switched Data Service (PSDS) provides switched 56 kbps service through alternative voice data lines.\textsuperscript{15} Local Area Data Transport technology currently offered by Bell South multiplexes packet data at speeds up to 4.8 kbps on standard analog voice lines; speeds up to 9.6 kbps are feasible with this technology. The data are then separated out at the central office and routed to the carrier's packet network service. Atlantic Bell is offering low speed (up to 19.2 kbps) asynchronous data switching capability to customers using AT&T's Datakit virtual circuit switch technology. The carrier provides the data switch at the central office, connected by standard wire pairs to the customer. The range of possibilities for handling data with Centrex is illustrated in Fig. 3.2.

While these offerings allow Centrex to meet at least the basic requirements for data users, generally they are not likely to be as cost effective in the long run as an integrated digital switch. Additional costs arise, in part because these Centrex offerings require craft work at both the user's site and at the carrier's office to allocate specific wire pairs to the service, or to install integrated voice data multiplexers.

The newer digital central offices can, of course, switch data as readily as can a digital PBX. Indeed, when ISDN software becomes available within the next few years, Centrex offered by these offices will be a highly competitive alternative to a PBX.


Note: Centrex offers customers a variety of data transmission features, including simultaneous voice and data at up to 9.6 kbps, alternative voice and data at up to 56 kbps, multiplexed data on T-carrier lines at up to 1.5 Mbps and access to packet switching networks with X.25 protocols.

Fig. 3.2—An illustrative Centrex system
SYSTEM SERVICES

In Sec. II we stressed the importance of system services in making a complete evaluation of a telecommunications system, for it is in this area that the differences between PBXs and Centrex are most pronounced. We shall consider (a) switch operations and maintenance, (b) operational management, (c) service provisioning, and (d) administrative management.

Switch Operation and Maintenance

The salient selling point of Centrex has been that the carrier took complete responsibility for hardware and software operations and maintenance.\textsuperscript{16} Proper operation and maintenance of a PBX require not only skilled staff, but extensive investment in floor space equipped with air conditioning and backup power. For example, one firm we interviewed estimated space preparation and air conditioning costs at $2.5 million, for an installation of four PBXs with a total of 40,000 lines. Central office switches are uniformly equipped with battery and generator backup, whereas several of the PBX installations we reviewed were not. As one telecommunications manager put it, "If the lights go out, we're going to send our staff home anyway, so what difference does it make if the PBX doesn't work?" Although such an attitude may produce savings on space preparation costs, it may be inappropriate for many government operations.

Although our interviewees regarded Centrex as more resistant than PBXs to major failures, they agreed that attention to minor problems with Centrex is more costly and time consuming. As one manager put it, "The carrier charges $60 per hour, fully loaded, and the PBX vendor $30 per hour; my own maintenance staff costs me only $22 per hour."

Moreover, several firms complained that only one standard of service was available from the telephone company, even if the firm had been willing to pay for a higher standard or wished to save money by accepting a lower one. With a PBX, the user can more easily contract for the precise level of service response time desired.

\textsuperscript{16}The larger PBXs, such as the SC-100, approach telephone company central offices in their complexity and require skilled technicians to manage. And like central offices, several can be managed from a remote network operations center.
Operational Management

As noted earlier, the cost of a telephone line to a desk, whether provided by Centrex or PBX, is typically less than 75 cents per day. But in some government offices an individual might easily make 10 times that amount in toll calls. Thus, even a small percentage reduction in the cost of toll calls can overshadow any difference in the basic price. Today, a major advantage of PBX over Centrex is superior performance in controlling overall network usage costs by facilitating the use of T1 transmission systems and managing the organization’s network.

As a result of recent tariff changes, T1 circuits capable of carrying 24 channels of voice or 56 kbps data cost no more than a dozen separately purchased voice channels for distances under 100 miles.\textsuperscript{17} For example, approximately half of the savings from Digital Equipment Corporation’s conversion to SL-100s will come from reduced leased line charges afforded by conversion to T1. Thus, where volume justifies it, conversion to T1 is attractive—all the more so because individual 56 kbps channels can be readily reassigned between voice and data uses.\textsuperscript{18} Thus, acquiring a digital PBX may be a prerequisite to the use of cost-effective digital transmission with T1 lines.

Similarly, if a user wishes to build a private fiber or microwave transmission system, a special trunk side access line to the Centrex switch is required. This can take weeks for the carrier to provide. In contrast, the user is in complete control with a PBX and can make the connection within hours.

The PBX also has advantages in network management. At the present time

- PBXs generally provide better facilities than Centrex for Least Cost Routing (LCR) and Automatic Route Selection (ARS), because of better algorithms for calculating the least-cost route

\textsuperscript{17}E. E. Mier, "Long Overdue, T1 Takes Off—But Where Is It Heading?" \textit{Data Communications}, Vol. 14, No. 7, June 1985, pp. 120-140.

\textsuperscript{18}However, this advantage is reduced if the T1 line must be demultiplexed and converted into analog signals to match analog Centrex or PBX switches.
(e.g., variable by time of day) or the ability to handle more alternative routing options. Surveys of both PBX and Centrex users list LCR as their highest priority requirement.\textsuperscript{19} 
\begin{itemize}
  \item PBXs generally provide greater flexibility in assigning grades of service, or making a lower grade of service more tolerable through call-back queueing.\textsuperscript{20} Such features can result in more efficient use of leased lines and can thus reduce the number required.
  \item PBXs can be equipped with tandem routing software for use in a multinode network, as discussed in Sec. IV. This feature permits the agency to use transmission-only offerings at relatively low cost.
  \item PBX vendors have been able to move more quickly to adapt their networking software to such requirements as Equal Access and 10XXX dialing codes for access to alternative long-distance carriers as another way to reduce network usage costs.
\end{itemize}

Local telephone companies have responded by introducing comparable capabilities for Centrex. For example, Mountain Bell's Centrex 300 offering, for sites with fewer than 300 stations, includes features such as Automatic Route Selection-Deluxe (ARS-D); Facilities Restriction Levels (FRL); Deluxe Queueing; Facilities Administration and Control; Traffic Data to Customer (Pollable); and Automatic Overflow to DDD.\textsuperscript{21}

However, because the requirements for software are more complex in a central office than is the case for a PBX, PBX vendors may be able to move more quickly with new services. Moreover, local telephone companies may be reluctant to provide software that makes it easier for the user to bypass their local transmission facilities. For these reasons, PBXs will probably retain an advantage over Centrex with respect to software-controlled services during the foreseeable future.

\textsuperscript{20}With call-back queueing, if a low-cost tie line is not available, the caller can hang up and the PBX will "call back" to the caller when the tie line is free.
\textsuperscript{21}North American Telephone Association, Petition for Declaratory Ruling, before the FCC, November 7, 1983, p. 18.
Service Provisioning

Another frequently mentioned item on surveys of PBX and Centrex users' requirements is improvements in handling telephone moves and changes. Support for moves and changes was noted by all of our interviewees as a key decision variable in comparing system alternatives.

Most of our interviewees contract with PBX vendors to implement moves and changes via an on-premises terminal attached to the PBX. One firm reported that by switching to a PBX, with software-controlled provisioning, the average time to implement a move was reduced from 15 to three days. Complaints about carrier delays in implementing service changes with Centrex were frequently voiced among our interviewees.

Recently, several of the BOCs have filed tariffs for services that allow customers to enter Centrex moves and changes from an on-premises terminal. For example, New Jersey Bell Telephone Company has filed a tariff for Centrex Customer Change Features (CCCF). Using this feature, a Centrex subscriber can use a terminal on his premises, which is connected to the Centrex switch, to transmit requests for station moves or changes in service level, such as adding call forwarding or station restriction, without placing formal orders with the telephone company. It has taken longer to provide such a capability for Centrex because the software required on a central office switch is more complex than similar software on a PBX. Because Centrex may serve multiple entities from the same central office, CCCF software must provide ironclad protection against one organization's making changes in the lines assigned to another. Since a PBX serves only one entity, the software does not need the same level of protection. The difference is similar to the relative simplicity of personal computer software, compared to a multiuser minicomputer.

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22 Marks and Diamond, op. cit.
23 North American Telephone Association, Petition for Declaratory Ruling, before the FCC, November 7, 1983, p. 17. To take full advantage of CCCF, Centrex users may find it desirable to reduce the number of key systems behind the switch, as these limit the ability to reassign phone numbers and the like.
Flexibility in providing outgoing call screening is another major benefit of PBX purchase. For example, one company was able to program its PBX to limit toll calls to working hours, thus preventing abuse during nights and weekends. The move was expected to save up to 10 percent on toll usage. Current Centrex offerings do not provide equivalent levels of flexibility, e.g., toll restriction by time of day.

In the area of service provisioning, we conclude that state-of-the-art PBXs are generally superior to Centrex but that the gap will be narrowed as services such as CCCF are introduced.

Administrative Management

Another feature valued by Centrex and PBX users is call accounting and Station Message Detail Reporting. Accurate information on calling patterns is needed to predict future switching and transmission requirements, to detect areas of excessive calling or abuse, and to aid in charging costs to individual departments, users, or project accounts.

All modern PBXs provide the capability of logging all calls, including local and tie line calls. Either through attached processors, or through service bureaus run by the PBX vendor, these logs can be processed to produce a variety of reports on phone usage, trunk usage, and calling patterns. The newest PBXs maintain the records on line in a database that allows usage reports to be produced on demand. Call detail reports can be distributed to department heads to be reviewed for signs of abuse, thus leading to significant reductions in usage charges.

In contrast, Centrex generally has provided call detail only for toll calls. Even where local calls are usage-priced, the Centrex user has no way of tracking usage and therefore costs. The variety of report formats has also been limited. AT&T has recently developed an advanced communications software package (ACP) that runs on a computer attached to the central office switch and can provide support for real-time access to call detail records from a terminal on the customer's premises. However, the FCC concluded that such services violate the

25 Mazur et al., June 1985, op. cit.
terms of its Computer II decision, and the question remains about the
treatment of such services after the FCC concludes its Computer III
inquiry.

Because of the importance of regulatory policy to decisions about
procurement of PBX and Centrex, we now turn to a discussion of
regulatory issues surrounding the provision of enhanced services on
Centrex.

FEDERAL AND STATE REGULATION OF CENTREX
Enhanced versus Basic Services

Agencies should monitor closely recent and prospective FCC
decisions that affect the relative merits of prospective Centrex and PBX
procurements. Most notably, the requirements for physical separation
between basic and enhanced services have handicapped Centrex's ability
to compete with PBX equipment and have generated seemingly endless
controversy because of ambiguities in the distinction between basic and
enhanced service.

In accordance with the FCC's Computer II decision, AT&T and the
divested BOCs may offer "enhanced" services, as distinguished from
"basic" services, only through a fully separated unregulated subsidiary.
Basic services involve use of a "transmission pipeline" to move
information between two or more points.\(^\text{26}\) Enhanced services, in
contrast,

employ computer processing applications that act on the
format, content, code, protocol or similar aspects of the
subscriber's transmitted information; provide the subscriber
additional, different, or restructured information; or involve
subscriber interaction with stored information.\(^\text{27}\)

Responding to these difficulties, the FCC ruled in May 1985 that
"most Centrex features, such as automatic route selection, customer-
originated changes in the features received, and a number of other
commonly offered features, may be offered by carriers under tariff as
part of a basic transmission service offering."\(^\text{28}\) The notable

\(^{26}\text{FCC, Reconsideration Decision, 84 FCC 2d at 53-54.}\)
\(^{27}\text{FCC, Final Decision, 77 FCC 2d at 498.}\)
\(^{28}\text{FCC, "FCC Finds Most Centrex Features To Be Basic Telephone
Services" (News Release), Report No. CC-9, May 9, 1985, p. 1.}\)
exceptions, according to the FCC's ruling, are (a) customer-dialed account recording, which is an enhanced rather than a basic service "because it allows customers to use the central office processor to store their own account numbers, which are used to track the customers' business uses of their telephones," and (b) "the use of the electronic switch for storage and retrieval of a customer's business information, where that information is not used in the provision or management of the customer's telephone service." Customer-dialed account recording has been offered with Centrex in some locations for more than five years. Under this ruling, however, these two services may not be provided under tariff; and, in the absence of a waiver, companies subject to structural separation may not provide them within the network.29 However, this situation could be affected by the outcome of the Computer III inquiry.30

As a substitute for structural separation of basic and enhanced services, the FCC has proposed in its Computer III inquiry to use "market power as the distinguishing characteristic for treatment of some or all products, and...to rely on accounting controls to identify the costs of separate categories."31 Agencies should follow closely the decisions (and reconsiderations of decisions) that are likely to extend well into 1986 if not beyond, to evaluate the effects on prospective Centrex and PBX procurements.

The Pricing of Centrex Services

In addition to issues at the federal level, the pricing of Centrex poses three particularly important issues among state regulators.

• Whether state regulatory bodies take further action permitting local telephone companies to reduce rates for Centrex offerings to offset the effects of access charges imposed by the FCC on Centrex access lines.

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29Ibid., p. 2.
31Ibid., at 33585.
• Whether state regulatory bodies permit rate reductions or rate
restructurings for Centrex, aside from the effects of access
charges.

• The effects of flexible pricing, detariffing, or outright
deregulation of Centrex, which are being considered or are
already implemented in some states.

Repricing To Offset the Effects of Access Charges. Because
Centrex requires more access lines than does a PBX for a given number of
customer telephones, its economics are more seriously affected by the
FCC's decision to impose monthly flat charges on access lines.\(^{32}\) Under
the decision, the monthly Customer Access Line Charge (CALC) for 1984 is
set at $2.00 monthly for Centrex lines installed or ordered on or before
July 27, 1983, with possible future increases depending on subsequent
FCC decisions.\(^ {33}\) Installations on or after that date are charged a CALC
equal to that of other business multilines, which varies according to
the cost characteristics of each telephone company in each state, with a
cap set at $6.\(^ {34}\)

Responding to the imposition of access charges, BOCs have been
seeking to adjust their intrastate tariffs so that Centrex customers
remain essentially unaffected by the FCC's action. The BOCs argue that
Centrex previously was making a substantial "contribution" to cover
telephone company costs, thereby helping to reduce the prices of the
company's other services. If so, other customers benefit from the
offering of Centrex. With repricing, the contribution, they argue,
although reduced, will still be positive.\(^ {35}\) Without repricing, on the

\(^ {32}\) FCC, MTS and WATS Market Structure, *Memorandum Opinion Order,*
Phase I, C.C. Docket 78-72, released August 22, 1983.

\(^ {33}\) FCC, Federal-State Joint Board, *Recommended Decision and Order,*
CC Docket Nos. 78-72, 80-286, November 23, 1984, pp. 6 and 11. In July
1985 the Joint Board recommended an increase in the monthly rate to
$3.00 effective June 1, 1986. *Telecommunications Reports,* July 15,

\(^ {34}\) The computation of federal and user access is described in 47 CFR
sec. 69.104(d), 69.202.

\(^ {35}\) Typically, Centrex CALCs are reduced by imposing a CALC that
reflects only the "equivalent" number of access lines required in PBX
trunks.
other hand, the BOCs maintain that many customers will desert Centrex so that not only will the entire contribution be lost but the BOCs will be left with costly "stranded" investment in idle lines and equipment. If so, users of other services will face even higher rates.

Vendors and manufacturers of PBXs argue that attempts by BOCs to reprice raise severe dangers of cross-subsidization. They allege that BOCs are cutting the price of Centrex below cost and compensating by raising prices in their "captive" markets, consisting primarily of residential and small business users.\(^{36}\) They also claim that BOCs' arguments about stranded investment are exaggerated. Frequently, lines idled by moves out of Centrex can be shifted to other services, especially since many Centrex users are in metropolitan areas where growth of other BOC offerings continues to be strong.\(^{37}\)

As an outcome of these conflicting arguments, by mid-1984 Southwestern Bell had won CALC offsets in three of the five states within its territory, and Northwestern Bell has succeeded in offsetting CALC rates in all five of its states.

Rate Reductions and Restructuring. In addition to the effects of access charges, Centrex rates are being reduced and restructured as a consequence of competitive pressures that are forcing rates to track underlying costs more closely. For example, Illinois Bell, the third largest provider of Centrex in the nation, is restructuring rates not only to offset CALCs but also to make per-line charges distance-sensitive. Under a three-band system, customers in the Chicago Loop and near Loop areas are accorded the lowest rates. Also, the more lines the user orders, the lower the per-line charge.\(^{38}\) The California Public Utilities Commission has also permitted Pacific Telephone to reprice its services because of the PUC's findings, in part that

\(^{36}\)See, for example, J. W. Wilson, Testimony and Exhibits, before the Indiana Public Service Commission, Cause No. 37558, November 1984.

\(^{37}\)In the Washington, D.C., area 52 percent of all business lines terminate on Centrex facilities.

Pacific's average cost of providing a Centrex line is significantly lower than its average cost of providing other business lines....Pacific's projections of idled plant and assignment of associated cost to Centrex service are generally reasonable....The viability of Pacific's Centrex service is threatened; substantial numbers of Centrex customers are abandoning or actively considering abandoning the service.\textsuperscript{39}

Such repricing and restructuring of Centrex rates is particularly important for federal agencies and other users to monitor because the process is likely to continue for many years to come. In contrast, the adjustment of Centrex rates to mitigate the effects of access charges has already been approved in many states and, unless these decisions are reversed, fewer changes in access charges are likely in the future.

**Flexible Pricing, Deteriffing, and Deregulation of Centrex.** A controversy surrounding Centron service (an upgraded version of Centrex service) introduced in 1983 by Mountain Bell and Northwestern Bell illustrates a key issue: the degree to which abolition of the separate subsidiary requirement would more easily permit the BOCs to adopt flexible pricing, or detariff Centrex, or operate it entirely as a deregulated service. Three pricing issues are paramount:

*Flexible pricing.* This is a regulated service offered pursuant to a tariff structure that includes full descriptions of services and conditions, but does not specify any rates or contain a requirement that the service be offered only at "above cost." Flexible pricing is the most common state regulatory treatment of Centron service within the service territories of Mountain Bell and Northwestern Bell.\textsuperscript{40}

*Detariffing.* Here the service offering is removed from tariff but remains in the intrastate rate base. It is overseen by regulators and is subject to complaint and audit. Mountain Bell and Northwestern Bell


currently offer the service without fully tariffed rates in at least seven states. According to NATA, "In some of the states, rates and charges for the detariffed service are not filed at all; in others a copy of each customer's individual Centron contract is filed at the time it takes effect."\(^1\) The result, according to NATA, is that the companies "are offering the same Centron services to different customers at different rates."\(^2\) By commingling Centron services with other regulated services the companies allegedly "are able to shift costs without detection between unregulated and regulated accounts, to the detriment of the ratepaying public."\(^3\)

**Deregulation.** Here the service in question is removed from tariff, from the rate base, and from most aspects of state regulation. For example, Iowa has deregulated Centron.\(^4\) Even in the most extreme case--deregulation--Mountain Bell and Northwestern Bell assert that "the Iowa situation represents an example of state action which is completely permissible under federal law."\(^5\) If the FCC decides that deregulated Centron need not be offered by a separate subsidiary, but rather that accounting controls are adequate as it has proposed in the Computer III inquiry, Centron may become even more competitive with PBX systems, with other states following Iowa's lead.

**Implications for Federal Users**

In light of the above market trends and controversies, a critical element of informal federal decisionmaking involves the monitoring of current and prospective federal and state regulatory proceedings.

\(^1\)North American Telecommunications Association, *Complaint*, Before the FCC, Docket E-85-1, October 1, 1984, p. 3.
\(^2\)Ibid.
\(^3\)Ibid., p. 13.
\(^4\)T. Race, "Iowa is 1st State To Deregulate BOCs' Centrex Offerings," *Communications Week*, June 10, 1985, p. 1.
\(^5\)Mountain Bell and Northwestern Bell, *Answer to Complaint*, op. cit., p. 5.
More specifically, federal agencies contemplating Centrex or PBX replacement or acquisitions should query their state regulatory agencies and the FCC about the following:

- Whether Centrex has recently been repriced in accordance with regulatory decisions, whether a regulatory decision is pending, or whether a relevant proceeding is likely to start soon. For example, the agency should seek to avoid acquiring a PBX only to find shortly thereafter that Centrex rates have fallen, or are likely to fall soon, and where on the basis of the repricing the agency would have been better off with another choice.

- Whether Centrex services are based on flexible pricing, detariffed offerings, or deregulated services, and whether proceedings are under way, or likely to take place in the foreseeable future, that would affect the terms under which these services would continue to be offered.

Of course, staying abreast of regulatory activities will not provide complete protection against uncertainty about current and prospective prices and services. But it will help. If an agency knows, for example, that no regulatory proceedings relevant to its choices are under way or are likely to be launched in the foreseeable future, it may have some assurance that during the next year or two, at least, information on tariffs and service offerings will likely remain valid. The situation to be avoided is one where the agency makes a decision only to see substantial changes in tariffs and service offerings based on regulatory proceedings that, had it been aware of, would have caused it either to postpone its procurement decision or to make another choice.

In addition to the above regulatory issues that relate to the relative merits of PBX and Centrex offerings, we will address other issues of regulatory policy affecting telecommunications users in Sec. VII.
IV. ALTERNATIVE TELECOMMUNICATIONS NETWORKS

In addition to issues about the relative merits of switching options discussed above, wise choices among network alternatives are vital because they affect

- **The cost and quality of transmission available to the user.** A wider choice of carriers and services is available if the user is buying only transmission rather than a complete switched service.
- **The kinds of premises switching that the user will need.** Operating a dedicated network requires switches capable of handling complex routing and network operations functions.
- **The operations and management burden the user must assume.** Network management requires skilled personnel not easy to find.
- **The level of control over network usage and service level that the manager can exercise.** Control over network usage and service levels is critical to cost control. Differences between dedicated and public switched networks in the control provided to the network manager can significantly affect total usage costs.

Moreover, as emphasized in the preceding section, the relative merits of PBX and Centrex procurements depend on the technical characteristics of the network into which they are linked. Especially, the extent to which Centrex becomes competitive with PBX depends on the availability of common channel signalling in the network and on the rapidity with which ISDN standards are developed and adopted, as discussed in Sec. VI. In this section we treat in detail the characteristics of networks, including the role played by common channel signalling.

To illustrate available choices we shall examine three network architectures. The first two--private tie-line networks and private electronic tandem networks--use dedicated or leased transmission
facilities. The third—"intelligent" networks—uses the public switched network in ways that give the customer many of the advantages of a private network.

PRIVATE TIE-LINE NETWORKS

In the past, pricing of private line service, unlike message toll service, has not been required to cover a portion of local loop (nontraffic-sensitive) costs. Therefore, users have had incentive to route their long-distance traffic over dedicated (private network) rather than switched (public network) lines. The network of a multilocation user, therefore, has often consisted of simple PBX switches interconnected by private lines, known as tie-lines, as shown in Fig. 4.1.

Several problems are associated with this approach. First, to call from, say, E to F as shown in Fig. 4.1, one must dial tie-line codes 75 + 20 + 25 + extension or 75 + 21 + 71 + 25 + extension. Because the end user himself must determine the routing information needed to place a call between such locations, no assurance exists that calls are completed over the lowest-cost links. Second, dialing patterns are complex and varied, depending on particular geographical locations. Third, accounting data are difficult to obtain, since each switch creates a connection only to the subsequent switch. Thus, at no point in the network are the origination and destination numbers recorded. Finally, transmission quality varies, since some calls are routed through several switches. Hence, overall system services are limited by the independent, uncoordinated nature of the individual PBXs.

For these reasons, use of tie-line networks is declining in favor of newer alternatives to which we now turn.

PRIVATE ELECTRONIC TANDEM NETWORKS

An electronic tandem network (ETN) consists of a coordinated set of PBXs or other switches, linked by privately owned or leased transmission facilities, to provide switched services as an alternative to using DDD on the public network. Electronic tandem networks employ either dual-purpose switches or specialized tandem switches.
Dual-Purpose Switching

The latest generation of PBXs makes possible a far more sophisticated private network, as shown in Fig. 4.2. With increased computer capacity built into the switch or available through an attached processor, the network can provide higher-quality service and better control over usage than is possible with tie-line networks.

More specifically, each switch is equipped with a database, allowing it to translate user numbers into a sequence of dialing instructions that carry the call across the network. This configuration allows use of a standard numbering scheme for all locations on the network. Typically a user will dial a "network selector" code, e.g., 6, to indicate an on-network call. Then a standard "location code"--
Fig. 4.2—An electronic tandem network with dual purpose switching

similar to an exchange code—indicates the branch office. Finally, the extension number indicates the particular station desired. Once warned by the network selector number that this call is to a branch office, each switch in the ETN translates the location code into the proper outgoing trunk line. At the same time, LCR software calculates the least-expensive choice of trunk facilities for the particular call.

Moreover, encoding the service grade or other information into additional tone signals sent down the line ensures that the proper grade of service is provided at each switch along the path. In this way, all relevant data about the call and the caller’s eligibility to access network features are carried from node to node through the network. For example, by carrying along information about the route already
traversed, the network can ensure that no call is subject to two satellite hops in one connection.

Because the PBX performs both the routing functions of a tandem switch and the local switching functions commonly associated with a PBX, the ETN shown in Fig. 4.2 illustrates the use of dual-purpose switching.

Two other points are worth noting. First, because private line tariffs have risen relative to those for WATS and DDD, users are beginning to use switched WATS circuits to link their ETN nodes. This approach is sometimes referred to as PBX-based virtual networking. The benefits from uniform numbering and similar services frequently justify using sophisticated ETN switches and software on top of public switched service.

Second, an ETN requires that the PBXs at all of the locations use similar software and communicate using a standard protocol. Currently, no single standard exists. Thus, configuring an ETN in this fashion generally requires that all PBXs be from the same manufacturer.

**Specialized Tandem Switching**

An alternative approach uses a smaller number of switches dedicated to the routing function as shown in Fig. 4.3. Here the PBX needs to know only that all on-network calls are to be routed to the nearest tandem switch. The tandem then handles the least-cost routing and other chores.

Specialized tandem switches have both advantages and disadvantages. Generally, a PBX is designed to support a large number of lightly loaded lines. A tandem switch, in contrast, supports the interconnection of heavily loaded trunks. Thus, design of a tandem switch can be optimized for a much different call frequency, without compromising standard PBX functions. Moreover, by separating the tandem routing functions from the PBX functions, software problems are simplified. On the other hand, if the tandem switch is not from the same manufacturer as the PBX, the flexibility of the signalling protocol between the PBX and the tandem switch may be more limited than that afforded by the tight coupling in a

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Fig. 4.3—An electronic tandem network with specialized tandem switching

dual-purpose switch. Network management may also be more difficult. Finally, because many Centrex systems do not have the necessary software for configuring a state-of-the-art tandem network, specialized tandem switches allow use of Centrex where that is the preferred local switching choice.

Finally, tandem switches need not be purchased: AT&T, for example, leases capacity to users on its toll (tandem) switches as well as on its transmission lines, enabling users to configure private networks with only carrier-supplied facilities. This arrangement, referred to as a Customer Controlled Switching Arrangement (CCSA), is used in the FTS.
Control over Grade of Service

Besides simplified numbering, the principal advantages of an ETN are the control it provides over the network and the quality of service available to individual users. Whereas the public network provides only one grade of service, an ETN enables variations tailored to user needs. Although the public network generally has enough capacity so that less than 1 percent of calls cannot be completed in the busy hour, a private network can be designed to run at a less costly lower grade of service.

Because the carriers do not currently offer universal switched data services, a private network configured around digital switches and digital transmission lines provides the user with a higher-quality data service than can be procured from the carriers. Control over the transmission links also makes it easier to encrypt sensitive traffic link by link. Relying on the public switched network's in-band signalling, switched lines cannot be encrypted because doing so would obscure the signalling information. (By 1990, as common channel signalling becomes more widespread in the public network, it will be possible to encrypt the call without encrypting the signalling, as discussed in Sec. VI.)

Optimizing Network Configuration and Use

By using the intelligence available in both Centrex and PBX switching systems, the telecommunications manager can take advantage of the wide variety of dedicated and switched transmission alternatives. Tandem switching capabilities, automatic route selection, and least-cost routing allow the telecommunications manager to combine the various offerings and to use the computational powers of the switch to allocate traffic.

Given state-of-the-art switches and complete statistics on the traffic at all organization locations, and given complete information on the costs of all transmission or transmission-plus-switching alternatives, it is theoretically possible for any given organization to calculate the optimum configuration and use of facilities. Indeed, several companies provide sophisticated computer models for performing such calculations.
Not surprisingly, our interviews show that no company can optimize its network so completely, because of several obstacles. First, the least-cost routing, automatic route selection, and tandem switching required for optimization are often not in place at the necessary customer locations. Because switches—whether Centrex or PBXs—last a long time, an organization will inevitably have a variety of equipment of different vintages. As the organization replaces older PBX and Centrex installations with newer facilities, its ability to take advantage of new transmission options, particularly digital, is increased. Thus, one limit on the use of dedicated lines or other special facilities is the absence of appropriate switching capabilities. As organizations increase the percentage of locations with modern switching facilities, their use of dedicated transmission facilities increases.

Second, our interviews disclose that in many large decentralized organizations, no one in management is even aware of what the total communications costs of the firm are, or whether the network could be configured more efficiently. Individual divisions take responsibility for meeting their own communications needs, and no attempt is made to enforce, for example, a single switch architecture for a sophisticated ETN. Many organizations are far from capturing all of the economies possible from an optimized network. Studies by several BOCs of the potential for bypass in their service area show a large potential that is not yet being fully realized.²

Finally, the cost of reconfiguration poses a problem. If the firm were to attempt to optimize the network in the face of changing tariffs and changing levels of demand, the optimal configuration would fluctuate almost daily. Yet each change in the network involves costs in network reconfiguration and carrier service charges. Costs sunk in user-owned facilities are a source of further inertia.

Typical of the companies we have interviewed, one large petroleum company uses call statistics collected by its PBXs to recalculate optimal network configuration on a quarterly basis. These recalculation are based in part on discussions with divisional managers to ascertain whether projects are under way that will increase the demand for capacity over the next quarter. Based on this analysis, dedicated lines, FX lines, or WATS lines may be added or deleted.

The cost of reconfiguration is increased by each carrier's pricing strategy--designed to tie customers more closely to itself. Such devices as increased installation charges, order cancellation charges, lengthened contract periods, and volume discounts are being introduced to discourage switching between carriers. Perhaps the prime technique for capturing and holding traffic is the introduction of the "virtual" private network discussed below. Much of the value of a virtual network derives from the centralized control and accounting it offers. If a customer splits his traffic among many carriers, he loses this integrated management reporting. Bulk discounts associated with virtual networks may replace Telpak as a device to keep users from building their own transmission systems, while making it more difficult for a reseller to arbitrage.

**Price Trends Affecting Transmission Choices**

Before 1982, the rate structure for the various services generally led to a network configuration with a few major switches that aggregated large volumes of traffic. From these points traffic was then routed over Telpak private lines or WATS lines. Because both of these services were priced at substantial volume discounts, aggregating traffic to a few hubs resulted in cost savings.

However, current trends in network pricing and technology are encouraging a more distributed network structure. Increases in the cost of short-distance access lines reduce the cost of routing long distance point-to-point relative to routing via a hub. Moreover, smaller volume discounts in WATS and dedicated line tariffs have reduced the advantages of aggregating traffic at a hub. Finally, the availability of smaller PBXs with full routing capabilities obviates the need for a larger hub to do routing.
New tariffs have increased the cost of FX lines from an average flat rate of $45 per month to a usage-sensitive rate expected to average $177 per month.\textsuperscript{3} As equal access is phased in, as discussed in Sec. VII, these rates may further escalate. In contrast, leased lines terminating in a PBX that provides local exchange access are being boosted only $25 by the special service access line charge (also discussed in Sec. VII). This also leads to a preference for many smaller switches linked by dedicated lines, as opposed to larger tandem hubs feeding FX and WATS lines.

The increased availability of T1 circuits, which provide significant economies when compared to an equivalent number of analog voice circuits, creates an incentive to concentrate traffic between a few hubs. The newest digital PBXs are capable of being directly interconnected by T1 links carrying up to 24 channels of voice or 56 kbps of data.\textsuperscript{4} The use of T1 links provides significant equipment savings at each end compared to the use of individual voice or data channels. Moreover, with a T1 link, either data or voice traffic can be assigned to a channel at will, thus providing more flexibility for network resource management. T1 links generally travel over newer, more reliable, transmission facilities. These benefits have created a demand for T1 links that is being satisfied in part by the rapid growth of satellite, private microwave, and fiber optic installations.\textsuperscript{5}

We can summarize the trends in costs as they affect network configuration as follows:

\textsuperscript{3}V. J. Toth, "FX Services--On Course to Obsolescence," Business Communications Review, September-October 1984, pp. 27-29.
1. Rates for leased lines from the carriers are increasing relative to WATS and DDD tariffs, encouraging a shift in network configurations toward public switched links.

2. The cost of short-distance leased lines is increasing relative to that of long-distance leased lines. This trend discourages use of large tandem hubs.

3. The demise of Telpak has reduced the discount for having many lines from one location, also discouraging the use of hub designs. However, the economies provided by T1 lines work in the opposite direction.

4. Rate increases arising from equal access may make FX prohibitively expensive.

Operations Management

Although an ETN provides higher quality of system services than does the simple use of WATS or DDD lines, it also creates burdens for the user. Network administration and maintenance of the switching equipment is the responsibility of the user, who must either hire and train skilled telecommunications personnel or purchase facility management services from the switching supplier or third parties.

Because automatic routing systems typically can route calls to the public switched network as a fallback, fear of lower levels of availability in an ETN network is not a problem. More important are the extra costs incurred when dedicated lines are down. Because the fallback alternatives for data are often of inferior quality (e.g., dial backup versus conditioned lines), reliability of individual circuits is of more concern for data networks. An ETN manager must balance the desire to use large capacity single links (such as fiber optics) to exploit their economies of scale against the need for redundancy to enhance reliability.

Concerns about reliability vary among organizations. According to our interviews, the more important communications is to the organization, the more it seems willing to experiment with new transmission systems to remain on the leading edge. Many firms report

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McCauley, op. cit.
that reliability and availability are higher with private satellite and optical fiber services. Other firms prefer to leave maintenance of transmission facilities to the carriers, by using only carrier-supplied dedicated lines. Because long-distance leased lines require the involvement of two intra-LATA and one inter-LATA carrier, the pinpointing of problems can be a burden on the user.

Despite these problems, ETN networks are becoming increasingly popular because of the increased network control enjoyed by the telecommunications manager. And because, with sufficient traffic volumes, leased lines are less expensive than switched facilities, an ETN network can lead to substantial savings.

SOFTWARE CONTROLLED PUBLIC NETWORKS

A major motivation for users to set up a private network is to obtain services that are unavailable from common carriers, or greater control and flexibility over the system. This motivation is especially strong for large high-volume users able to achieve scale economies and also willing to devote considerable capital for equipment and personnel. Not surprisingly, these are the same customers that the interexchange carriers seek to hold to maintain a broad revenue base and to exploit their own scale economies. Because private and public services are highly substitutable, carriers need to keep rates low and to provide user controlled service offerings to discourage growth of privately owned networks.

Thus, the carriers are closely watching the usage patterns of large, multilocation businesses and are designing new services specifically directed to the needs of this group. These services are designed to make dedicated lines leased from the carrier more attractive than user-owned or specialized-carrier facilities. By sharing public network resources, the user realizes the economies of a larger network, benefits from its built-in redundancy, and avoids the burden of purchasing, maintaining, and administering privately owned equipment.

Carriers are striving to offer the flexibility of a private network with the advantages of the public network in two ways. First, with Customer Controlled Private Line Reconfiguration carriers are providing users with dedicated or leased lines on more favorable terms and
enabling users to change line assignments from terminals in their own offices. Second, with virtual networks, they are providing multilocation public networks to allow telecommunications managers to control the services provided to different user groups on the network. To the user, the system functions as a private network. However, it consists completely of the carrier's switched system except for the local access needed to reach the carrier's point of presence. We now turn to these alternatives.

Customer Controlled Private Line Reconfiguration

Historically, when a customer wanted a dedicated voice-grade line between two locations, the carrier would physically connect wires at the main distribution frame in the central office to link the incoming and outgoing circuits, bypassing the switch. This method has numerous drawbacks including: high labor content, difficulties in substituting alternative facilities in the event of a circuit failure, the need to convert incoming digital voice circuits to analog and back to effect a connection, and unsuitability for providing digital private line connections.

In the early 1980s, carriers began to install a new facility for making the linkage between circuits—a Digital Access and Cross-Connect System (DACS). A DACS is essentially a nonblocking digital switch that can take multiple T1 channels and cross-link individual 64 kbps circuits between them. To connect an incoming and outgoing link, an operator simply enters a request at a terminal that is connected to the DACS via a packet data network. An entire cross-country circuit can be set up by an operator sitting at one location and contacting successive DACS in each office along the route—virtually eliminating manual office labor.7

If a user wants a dedicated line from Boston to Chicago, for example, an operator in Cincinnati can set it up by sending instructions from his terminal to each DACS along the route. Each DACS can maintain a connection between the proper incoming line to the appropriate outgoing line until further instructions are sent. The private line

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could be redirected in the same manner, requiring as little as 15 minutes.

Beginning in 1985, some carriers began to take this facility one step further by making it possible for the customer himself to issue reconfiguration instructions to the DACS. Thus, a customer could reassign lines between various branches monthly, weekly, or even on a preset day-night schedule. This allows the user to set up a private line to one location during business hours and to a different location on evenings and weekends for such tasks as file transfers. Organizations can also add and drop sites as usage patterns change or as new and attractive services are offered. Moreover, the circuits from a customer's premise to the DACS need not all be used for leased line services. On demand, the DACS can route circuits to the telephone company central office switch where they can be used as standard access lines for switched voice traffic.

With a private network or hard-wired leased line through public facilities, line failure forces the user to switch to more expensive public facilities or, for high-speed data, to forgo service altogether. With DACS, however, lines are tested periodically and in case of failure a new line is automatically assigned. Thus, the customer approaches the same level of control over network configuration that he would have with privately owned facilities, while retaining the economies of scale and network redundancy advantages of carrier services.

DACS is essentially an interim technology for facilitating dedicated line provisioning in central offices serviced by analog switches. As these offices are converted to digital switches, the same functions now being provided on a DACS can be performed by the switch itself.

In summary, DACS represents an attempt to increase the overall flexibility of the public network, so that carriers can respond to the increasing diversity of customer requests. For the federal decisionmaker, it is but one example of how the capabilities for user control heretofore available only via privately owned and operated networks are increasingly available from public facilities.
Virtual Private Networks

As suggested earlier, much of the motivation for creating an ETN lies in the increased control over grade of service provided to the users, as well as the simplified numbering scheme for intra-organizational calling. Recognizing this demand, interexchange carriers have begun to offer virtual networks that give multilocation companies the illusion of operating a private network with customized services, but which in fact use the same circuits and switches as do standard public network offerings.

The introduction of these services has been made possible through the use of a common channel signalling (CCS) network that provides a separate data path for conveying complex signalling information between network switches. Before the introduction of CCS, signalling in the carriers' networks, as in an ETN, was accomplished with tone signalling preceding the voice signal through the circuit.

CCS was originally introduced into AT&T's network because of the efficiencies it provided in setting up ordinary long-distance calls. Instead of taking 10 or 20 seconds to establish a coast-to-coast call by propagating touch-tone signals through successive switches, a message sent via the CCS network can set up the call in only two seconds. Moreover, if the called number is busy, that fact can be communicated back to the calling central office via the CCS network before any trunks have been tied up by the call.

To provide virtual network services, the CCS network has been supplemented by the addition of network control points (NCPs)--computers and databases that can be programmed with detailed information on how a call is to be handled.

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9The use of a separate data channel for signalling between PBXs in an ETN has recently been introduced by AT&T-1S under the name of Distributed Communication Service (DCS). However, DCS is not as sophisticated as comparable carrier CCS facilities. See G. M. Anderson, "Transition to the AT&T-1S Integrated Private Network Architecture," IEEE Journal of Selected Areas in Communication, Vol. 5, July 1985, pp. 600-605.
In the virtual network, dedicated access trunks link the customer's premises with the local telephone company's switch, much as they might link to a specialized tandem switch, illustrated in Fig. 4.4. When an on-network call is dialed using only an abbreviated location number plus extension, the number is sent to the carrier's switch along the access line. At that point, the number is sent through the CCS to the NCP where the database is used to translate the abbreviated number into specific routing instructions to the physical destination. Any special requirements such as call screening or authorization codes are also specified in the NCP database.

For an on-network call, the dialed number is translated into the access line of the destination office. Off-network calls are routed to the carrier's switch in the proper LATA and delivered through the local carrier's facilities, much as an ordinary long-distance call.

The NCP can be programmed to provide such services as call screening, authorization codes, and varying grades of service to specific users. An organization's telecommunications manager can access the NCP using a terminal in his office to program service changes or revisions.

Whereas an ETN uses leased lines for on-network traffic and separate WATS or DDD lines to go off network, the same access lines can be used for both on-network and off-network traffic in a virtual network. Thus, with more efficient line use, fewer access lines are needed. Indeed, locations that are too small to justify leased lines for connection into an ETN can easily join a carrier-provided virtual network.

To do so, the customer needs no special equipment other than telephones or a simple PBX at various network locations. Except for local access, all transmission is done over the interexchange carrier's switched network. Information about the appropriate grade of service to assign to an incoming call can be based on the particular access line used to reach the carrier's switch. Thus, the PBX on the customer's premises must be programmed to select the appropriate access line corresponding to the grade of service assigned to the particular calling station.\(^{18}\)

\(^{18}\)However, where many different grades of service are involved, underutilization of some access lines can arise.
CPE—customer premises equipment
CO—central office
Action Point—switch
NCP—Network Control Point
SMS—Service Management System
CCIS—Common Channel Interoffice Signaling


Fig. 4.4—Software defined network on-network architecture
Alternatively, the PBX can be programmed to send special in-band grade of service signals to the virtual network switch, much as is done for an ETN. In a similar vein, United Telecom offers off-network to on-network calling in its virtual network; the user must input an authentication code that is used to determine what services are authorized for the particular user.

Several BOCs are contemplating virtual network service within their LATAs and will eventually offer switched access to the interexchange carriers' (IECs) virtual network offerings. Such offerings depend upon the BOCs implementing CCC, expected to become generally available by 1987. Northwestern Bell has already filed a proposed tariff for switched access to AT&T's Software Defined Network service. However, a key element of virtual networking is a single database maintained by the IEC that interprets and controls calls and provides unified accounting. With local virtual networks, some of the benefit of integrated accounting may be lost. The user would end up with split reports from each regional carrier. It is possible that the IECs will permit the local companies to access the IEC's databases to provide the appropriate control information, while maintaining centralized management of the database. Conversely, as with 800 number service, a virtual network operated by the local company could provide a means for lowest-cost routing among all IECs. Such routing must be specified by the customer, not the BOC, however, to stay within the limits of the Modified Final Judgment.

Until the advent of ISDN, which will bring common channel signalling all the way to the end user (discussed in Sec. V), only the carriers will be able to take advantage of services that require common channel signalling for efficient operation. For example, in an electronic tandem network, if a phone in Los Angeles is put on call forwarding to New York, and if the Los Angeles number is called from someone in Boston, the call will tie up a voice circuit all the way to Los Angeles and then back to New York. With common channel signalling, the fact that the phone is on call forward can be sent over the CCS network so that the call is actually routed directly from Boston to New York.
With respect to security, it is easier to introduce encryption or scrambling on the dedicated lines of an ETN than is true of the public switched network. As ISDN brings common channel signalling directly to the user site, however, it will be possible to encrypt the information channels on virtual networks, which use the public switched network, without interfering with signalling functions, as noted earlier.

While virtual network offerings do not yet support data service, one can expect them to do so as networks become increasingly digital. Certainly, this type of service is contemplated in emerging ISDN specifications. Other IECs can be expected to follow suit as more digital microwave and fiber are introduced into their long-distance networks. These are strictly circuit switched services, however. Packet switching would have to be handled separately.

**System Services.** It is in the area of operational management that the greatest differences arise between ETN and virtual networks. The virtual network leaves to the carrier almost complete responsibility for network maintenance, operation, and optimization. With the exception of the access lines (and they may eventually be standard switched lines through the local telephone company), no special lines need to be monitored. Thus, in comparison with an ETN, a virtual network should reduce the requirements for skilled network maintenance and operations staff. Moreover, overall reliability is likely to be higher with a virtual network because of the massive redundancy of the carriers' switched networks.

However, if the customer wants a separate data network, a virtual network may not eliminate the user's responsibility for operational network management. Moreover, the user may find that running a private tandem network to link multiple sites within the LATA and then running a

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11Today, dedicated access lines to an AT&T switch are needed for both that carrier's SDN and its Accunet 56 kbps switched digital service. If the customer leases a T1 line to provide access from his premises to the switch, the Customer Controlled Reconfiguration service could be used to reallocate the access lines as necessary between the two services--e.g., to SDN for voice traffic during the day and to Accunet 56 kbps service for bulk data traffic in the evening. The services are likely to be more closely integrated in the near future. J. Dix, "SDN Supplements Private-Line Nets," *Computerworld*, April 29, 1985, pp. 53 ff.
large bypass link through a local hub directly to the IEC's point of presence is the most economical means of obtaining access. This would require either establishing or contracting for a maintenance and operations group for the local bypass network.

With respect to service provisioning, the virtual network shows great strides over previous carrier offerings. By providing such capabilities as call screening, account control, and authorization codes, a virtual network provider can compete with an ETN in affording control over telecommunications usage. As emphasized earlier, better cost accounting and control has been a major factor in the establishment of dedicated networks.

A virtual network also simplifies service provisioning by centralizing the control data in one NCP (illustrated in Fig. 4.4), which can be accessed from a data terminal in the telecommunication manager's office. In the virtual network, the data are centralized and the database is queried by each node as needed. In contrast, in a tandem network the data are distributed and updates need to be made at multiple nodes. In general, the virtual network enables a level of responsiveness in provisioning that is not possible today when adding and subtracting WATS lines or leased lines.

Virtual networks eliminate the provisioning delays for inter-LATA circuits by relying on switched facilities. But they do not affect delays in provisioning for local access circuits or other intra-LATA facilities. Whether the user interface and flexibility of the provisioning systems in various virtual network and ETN products will be equivalent remains to be seen.

With respect to administrative management, the virtual network centralizes traffic recording and can provide an integrated picture of usage. The actual quality of the management reports produced remains to be seen. One can expect, however, that these administrative reports will be in a standardized format, and that it will be more difficult to demand custom report formats from a virtual network carrier than from a PBX vendor.

The virtual network provides an interesting option to the federal communications manager. While giving control over grade of service and accounting features previously available only from privately managed ETN
networks, it puts all of the responsibility for network operations and maintenance on the carrier. Moreover, by making more efficient use of trunks, it allows smaller offices to benefit from participation in the standardized system services of the organization's telecommunication network.

However, two cautionary notes are in order:

- The very fact that the agency does not need strong internal management skills to use a virtual private network may encourage excessive independence of the vendor to do what "best" serves the interests of the agency. Thus, some internal management skills are needed to monitor and assess the vendor's performance.

- The bundling of services in a virtual private network can unduly "lock in" the agency to the vendor, making it more difficult for the agency to negotiate with other vendors for services as substitutes for some of those included within the virtual private network.

**Relative Prices.** It is still too early to generalize about the relative costs of ETN and virtual networks. An ETN has higher entry costs because of its high up-front costs for intelligent switches and fixed costs for leased lines. Virtual network pricing is based on a usage charge that varies with distance and time of day, whereas ETN pricing is based on capacity charges for switches and leased lines. How they compare depends heavily on traffic patterns. Users may eventually find that a hybrid system is attractive, using leased lines on high volume routes and virtual networking elsewhere.\(^\text{12}\) Some of the advantages of centralized control would be lost, however.

Additional charges for each change to the network database made by the telecommunications manager may raise costs for firms with frequent organizational changes.

\(^{\text{12}}\)M. Canipe, "Users and Suppliers Trying To Preserve Functionality of Private-User Networks," *Communications News*, June 1985, pp. 78-79.
All of the companies we interviewed reported problems at the present time with bills they receive from carriers. The amounts at issue often amount to several percent of the total bill. The use of dedicated lines or bypass facilities is seen as a way to reduce the need to verify detailed calling records received from the carriers. Not just price, but price certainty is a major motivation for many users in configuring dedicated networks. Particularly where both transmission and PBXs have been purchased, the organization has established a fixed cost structure for the life of the investment. Virtual network costs may vary according to tariff policies set by the FCC or by the strategic interests of the carriers. Having ETN capability in all switches enables the organization to take advantage of low-cost "bare" transmission offered by emerging private carriers. On the other hand, virtual network prices may well fall if IECs enter this market.

**Summary.** Emerging virtual networks offer many of the managerial control features that were previously unobtainable except through dedicated networks. They are likely to be more reliable, with less skilled staff required for operational management. At the same time, they will not, for at least a few more years, provide as effective solutions to the problems of data communications. Moreover, if intelligent PBXs are necessary for intrafacility communications, management of a dedicated network--based on leased digital lines and making full use of CCR--may require only marginal additional switching capabilities and network management skills, depending on the size and scope of the network. At this juncture it is too early to tell how aggressively these services will be priced (or, in the case of AT&T, the latitude that regulators will allow).
V. THE SPECIAL PROBLEMS OF DATA COMMUNICATIONS

Data communications currently accounts for about 15 percent of all traffic in the FTS network. As office automation and distributed computing grow in the government, as in private organizations, the demand for data communications capability will surely rise.¹

Unlike voice traffic, which represents a single, well-defined commodity, data traffic covers services ranging from interactive terminal use to bulk file transfers. The quantities of data to be transmitted and acceptable delay times may differ by several orders of magnitude among different applications. Consequently, the variety of technologies and approaches to providing data communications is much greater than for voice. As evidence, most organizations operate a single integrated voice network connecting their major facilities; but they may operate a dozen or more separate data communications networks for specific applications. Indeed, the major issue for many corporations is not who will provide data network services but what level of integration among different network applications is most appropriate.

In response to these problems, this section addresses two areas:

- The advantages and disadvantages of integrating data networks, ranging from no integration (resulting in a diversity of wholly separate data networks within a single user organization) to a network that integrates all host computers and provides for sharing applications and data.

¹The 15 percent figure includes many analog lines carrying data from modems at 1200 bps or less. As networks begin to offer 56 kbps over a "voice" channel the traffic could probably be collapsed onto many fewer lines. We believe, however, that the availability of higher-speed links will lead users to upgrade their 1200 bps connections to 9600 bps or greater, thus counterbalancing this trend. Moreover, many systems will use rate adaptors, which tie up an entire 56 kbps circuit to send data at 9600 bps.
- 72 -

- The criteria for network selection, including manageability, reliability, geographical coverage, staffing requirements, and security.

LEVELS OF INTEGRATION

According to our interviews, many corporations face a situation similar to that of one financial institution we examined, which at one time had 23 separately operated and managed networks. These ranged from support for automatic teller machines to networks linking customer financial officers to computers at the bank that provide an up-to-the-minute picture of the customer's accounts. In considering how to best meet the organization's demand for data communications, those we contacted identified four different levels of network integration.

Zero Level Integration

One alternative is simply not to integrate organizational networks. The advantage is that individual applications running on specific brands of computers can use the type of communications network and network interface software that is most appropriate to the application. This leaves responsibility for network design and management with whatever data processing group uses the network. Such networks tend to be technologically simple and limited in scope. No need exists to force cooperation between different groups or to delay network implementation to coordinate with others.

The disadvantages are (a) lost economies of scale, (b) the greater cost of providing reliability in a small system where redundant links are lightly used, (c) the greater difficulties of interconnecting the networks to share data across the different applications, and (d) the dispersal of scarce network management personnel across many groups.

Physical Level Integration

Many organizations have put together extensive systems of communications trunks, either leased from carriers or incorporating private bypass transmission systems. These trunks are used mostly for voice communications. Physical integration implies sharing these
trunks, particularly large capacity T1 carriers, for both voice and data. Although individual networks may still be logically separate and use separate protocol architectures, they may share the capacity of a multiplexed physical link. For example, a T1 line between two points may carry traffic for 20 voice channels, while the remaining channels are each dedicated to four separate data network applications.

The advantage of this approach is that it allows the organization to reap the benefits of scale economies in transmission capacity. Although the extent of these economies from the carriers has declined following the discontinuation of Telpak offerings (discussed in Sec. VII), substantial economies remain from leasing T1 lines and from installing private transmission systems, such as microwave, cable, and optical fiber. In effect, the organization functions as a wholesaler of transmission capacity to its different data processing groups, much as the carriers do in zero level integration discussed above. The amount of required coordination is much less than if the applications themselves were more highly integrated.

The disadvantages of this approach are (a) management of applications networks is still dispersed among many groups, and (b) without protocol compatibility, the difficulties of interconnecting applications remain.

**Network Level Integration**

A few organizations have moved to integrate most data communications onto a single network. Here, a common physical and logical architecture links all data processing nodes. Terminals and computers for separate applications share the same physical and logical subnetwork for routing information between devices attached to the network. The network itself is composed of redundant transmission lines interconnecting specialized communications processors.

There are two approaches to creating an integrated network: packet networks employing the internationally standardized X.25 interface to computers and terminal devices; and proprietary networks, such as IBM's Systems Network Architecture or Digital Equipment Corporation's Decnet. In the former case, software to match specific computers to the network must be obtained from the computer vendor or from third parties for each
type of device. In the latter case, the network interfaces are part of
the overall computer communication system product sold by the vendor,
though products from other companies may emulate the necessary
interfaces.

Such an integrated network may be acquired from public packet
network service providers, may be installed and managed on a private
basis by a third party, or may be designed and managed by the
organization itself.

With sufficient traffic volume, this level of integration has
notable advantages: High-speed backbone trunks reduce unit costs and
transmission times; traffic can be spread over multiple links that, in
turn, improve overall reliability; and responsibility for network
operations and management is concentrated in one organization, thus
economizing on scarce personnel.

The principal disadvantages arise from the need to obtain
compatible software for every computer to be used on the network, and
from the loss of economies of specialization for particular forms of
data traffic.\footnote{For example, bulk data might be best sent via a circuit switched
data service, while a newswire might be best sent via a digital
satellite channel.} From an organizational point of view, sharper
demarcation between the applications computer and the network arises,
which can create difficulties in determining the source of problems.
Finally, the common subnetwork approach, while guaranteeing that any
terminal can reach any applications host, does not guarantee that the
hosts themselves can exchange data easily. This requires protocol
integration at higher levels.

Host Level Protocol Integration

For many organizations, what needs to be integrated is not simply
the network but the applications and data, e.g., the order entry system
with the purchasing system so that finished goods orders get translated
more rapidly into raw material requests. For application modules
running on separate computers to communicate with each other, they must
not only share the same network but they must have common host-to-host
protocols. Today, these common protocols are available only within a
single vendor's product line, or in multivendor environments by using, for example, the Defense Department's TCP/IP protocol suite. By 1990, host-to-host communications, using the emerging Open Systems Interconnection protocols being developed by the International Standards Organization, discussed in Sec. VI, will probably be supported by the majority of computer manufacturers, at least in conjunction with such basic applications as electronic mail and file transfer.

**CRITERIA FOR NETWORK SELECTION**

Our interviews with large organizations faced with network decisions similar to those facing government agencies produced a number of common criteria for evaluating choices among privately operated and managed networks, third party management, and use of public networks. In addition to cost, major criteria are: manageability, reliability, geographical coverage, staffing requirements, security, and protocols.

**Manageability**

Where organizations choose to manage their own network, the issue of control is often paramount. Typically the organization is in an environment where information management is a key issue in competitive markets, and it wants to be in a position to respond quickly and flexibly by developing new network-based services. The flexibility that comes from developing an in-house network management capability can be a major advantage. Even without the pressure for flexible response, firms may feel that operating the network gives them the ability to control their own destiny and to know where to trace responsibility when things go wrong.

Working through a third party gives high levels of control but with delays through a level of indirection. Public packet networks give users lower levels of control, for example with respect to management statistics or technical evolution.
Reliability

Reliability is measured by network availability, error rates, and mean time to repair. Some firms conclude that telecommunications carriers provide the highest levels of reliability. For others, operating their own network is seen as the less risky alternative. This difference in views is perhaps explained by the fact that the carriers offer a single level of reliability to all customers. The organization cannot tailor the reliability to its own requirements. If the available level is a good match to user needs, the carriers may be the better choice.

Geographical Coverage

For firms that need to reach numerous locations with relatively low interactive traffic volumes, public packet networks provide a more economical solution than one where the organization leases lightly used lines. One firm we interviewed has adopted an intermediate solution that combines public and private facilities. The firm had acquired from Telenet a packet switch compatible with the Telenet network. The switch provided high-volume interconnection of several buildings in its headquarters complex. In turn, it was linked directly to the Telenet public network that supported communications to its dispersed regional offices. Tymnet and AT&T can similarly configure a private network to interface with their public network.

Staffing Requirements

Building a private network requires development of a large internal technical and management group. These personnel are not easy to identify and recruit. Use of third party management and carrier networks is useful where staffing is a constraint. Having network management staff available is seen by some interviewees as aiding the eventual integration of applications above the network level, by calling attention to the issues and educating the organization. On the other hand, devoting scarce staff resources to network management at the bits and bytes level may detract from efforts to integrate applications—a goal likely to have higher payoff for the organization and one that cannot readily be delegated to an outside service organization.
Security

For a few interviewees, concerns about security and the absence of efficient protocols for providing security in public networks are reasons for opting for privately managed systems. In particular, if the switches are securely placed on the organization's premises, it is a simple matter to bulk encrypt the links between them. By contrast, if a public network is used, the packet headers must be in the clear so that addresses may be interpreted by the network operator. This requires more complex software to encrypt the data fields while leaving the headers readable. As new technical standards are developed, however, it may become easier to provide security over public networks. Before opting for a privately managed network for all traffic, users should consider whether it would be more economical to segregate the traffic needing very high levels of security and using public networks for the rest.

IMPLICATIONS FOR FEDERAL USERS

From the preceding, it is clear that federal agencies must take carefully into account the level of integration most appropriate to satisfying their needs. In doing so, they should consider the major criteria for data network selection reported in our interviews with large private organizations. Furthermore, a key factor involves specifications relating to technical standards, required if components are to communicate with each other. Because of the importance of this subject, we devote the following section to a detailed treatment.

VI. TECHNICAL STANDARDS

In previous sections we discussed a wide range of technical and institutional options. In this section, we address the role of technical standards in telecommunications procurement. Widespread adoption of particular standards is important to federal (and other) users because:

- They promote competition among suppliers, thus avoiding the dangers of being tied to a single supplier of proprietary technology.
- They eliminate the translation costs of interconnecting incompatible systems.

However, in an area that is changing as rapidly as computers and communications, use of standards often lags the best commercial practice. Thus, consideration of standards in prospective telecommunications procurements is a delicate process requiring:

- Analysis of standards and a specification of subsets and options that are pertinent to the user's particular application.
- Assessment of the completeness of standards and the availability of options that embody them.
- Comparison of the benefits of standardization versus the costs of shifting from nonstandard to standard architectures, or the costs that can result when the standards selected lag best commercial practices.\(^1\)

• Assurance that products advertised as conforming to specific standards actually do so, and operate compatibly with components stipulated by the user.

The benefits of standards—such as compatibility and competitive procurements—can also be realized to a large degree through use of "industry standards"—de facto standards that result from many vendors making products compatible with a market leader. For example, communication using IBM's Bisynch protocol is a way to achieve the benefits of standardization even though the protocol does not represent a formal standard. Indeed, formal standards frequently result from taking de facto standards and documenting them through the normal public standards writing procedures.

In this section we will examine development of standards relating to telephone networks and to computer communications. Our purpose is to provide guidance to federal decisionmakers about:

• The meaning of "standardization."
• The characteristics of telephony and computer communications standards as they have evolved over the last decade.
• The rapidity with which standards in these areas are likely to become available in both products and services, and the implications of scheduled availability for federal procurements.
• Selected specific issues currently being debated in standards committees, and the implications of the proposed alternatives for federal users.

THE EVOLVING PROCESS OF STANDARDS SETTING

Before the 1970s, standards development proceeded piecemeal with, for example, interface standards, signalling standards, and standards for specific services such as telegraph. During the second half of the decade, two separate efforts began to develop not just standards but architectural frameworks to guide future standardization. The first began within the International Consultative Committee for Telephone and
Telegraph (CCITT), the standards-making body of the International Telecommunications Union. The goal is to transform the world's telephone networks from a primarily analog, voice-oriented service, to an ISDN. Simultaneously, the International Standards Organization (ISO), spurred by the emergence of computer networking architectures such as IBM's SNA, began development of a reference model for Open Systems Interconnection (OSI) of computers.

These frameworks bear many of the characteristics of political ideologies: They are metaphors and rallying cries that, under close inspection, often turn out to mean very different things to different people. Moving from ideology to rigorously defined and widely accepted standards involves tough bargaining and political compromise among numerous actors, each concerned with his own needs and interests. Only when the standard has been voted and the fine print analyzed can the real meaning of the slogans be determined. Standards, like legislation, often embody conflicting—even mutually incompatible—goals. The implementors of the standard play a major role in determining the ultimate meaning of the standards after they are written. Indeed, some standards are unimplementable or incomplete, as voted, so that users must complement them with more detailed specifications, much in the same way that executive agencies must issue regulations to flesh out a piece of legislation. And because they are incomplete, the existence of a standard on paper may precede workable products by several years.

Given these characteristics, federal users must be wary of claims that a vendor "supports" some particular standard. Because of differences in the options or subsets supported, two products each claimed to be "compatible" with the standard may not interwork. Federal agencies must be prepared to specify the particular options or subsets most appropriate to their needs and to demand some evidence that a proposed product conforms to the standard and supports the chosen procurement options.

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We now turn to a more detailed examination of these two major architectural frameworks: ISDN and OSI.

**ISDN STANDARDS**

In the words of the chairman of the study group that developed the major standards for ISDN during the 1980-1984 CCITT study period,

An ISDN is a network in general, evolving from a telephony integrated digital network that provides end-to-end digital connectivity to support a wide range of services, including voice and non-voice services, to which users have access by a limited set of standard multipurpose user-network interfaces.¹

Three elements are embodied in this concept of the ISDN.

- Communications channels are digital end-to-end.
- A signalling channel is associated with each information channel, which can be used both for signalling to the network and for end-to-end signalling between customer terminals.
- Bit streams are interleaved through a standard interface for user access to accommodate a broad scope of services.

As noted in Secs. III and IV, the nation's telecommunications infrastructure is gradually evolving from a primarily analog network, geared to voice traffic, to a primarily digital network, capable of carrying either voice or data with equal facility. The ISDN standards are designed to permit interconnectivity of digital networks as easily as analog voice networks are interconnected today.

The evolution toward an ISDN follows naturally from three considerations related to the gradual introduction of digital transmission paths and digital switches into the telephone network. First, today a voice telephone call may well be digitized as it enters the local central office and remain in digital form as it is switched and transmitted across the country. By bringing the point of

digitization back to the user's handset or terminal, it is possible to imagine transmitting voice or data calls in digital form with equal ease. Thus, end-to-end digital connectivity is the first major element of the ISDN.

Second, the vast majority of today's telephone network uses in-band signalling—e.g., touch tones or rotary pulses—when a user signals the network for call set-up or other services. As noted with respect to advanced networking services in Sec. IV, common channel signaling is necessary for advanced services such as calling number identification or software defined network capabilities. Heretofore, common channel signalling has been used only within the network. In the ISDN, common channel signalling extends all the way to the user's terminal. ISDN standards attempt to define, therefore, the syntax for common channel signalling (CCITT Signaling System #7) and standards for messages associated with specific service options. This signalling capability is to be available for both user-network signalling and user-to-user signalling. The process of defining messages to be sent over this signalling system must be seen as essentially unending, with new messages being standardized as new service capabilities are defined and marketed.

Third, today's subscriber would most likely use separate access lines to link his premises to a packet switching network or to a circuit switched voice network. The need for dedicated lines for these separate purposes leads to high costs and inefficiencies in access line usage. One goal for ISDN, therefore, is to permit a single access line for multiplexed digital access to various types of networks. The typical interface at a user station (referred to as "basic access") will be two clear 64 kbps information channels and a 16 kbps signalling channel that can also be used for low-speed packet data. The 64 kbps channels are referred to as "B" type channels, and the signalling channel as "D" type, or "2B+D" for basic access. So-called "primary rate access" is an access line running at 1.544 Mbps, consisting of 23 B channels plus one D channel, at 64 kbps each.

Figure 6.1 illustrates how a standard interface will link the customer with the local carrier serving office and on to various interexchange carrier facilities. ISDN is a specification for how the
public network will provide switched digital services and advanced voice features. However, as we have discussed previously, users are increasingly creating their own networks by acquiring little more than transmission capacity from the carriers and using their own switching systems. Thus, a major related question is the extent to which private networks will mirror the standards of the public network, for example by providing ISDN-like interfaces between a user's workstation and PBX.\footnote{In Europe the definition of ISDN is enlarged to encompass many services that the United States defines as "enhanced"—e.g., videotext and electronic telephone directory. In contrast, we use ISDN in a more narrow sense as described above.}

![Diagram of integrated services digital network](image)


Fig. 6.1—Integrated services digital network
Adoption of ISDN Standards and Roles of Major Players

If ISDN standards were well defined, and all manufacturers and carriers provided ISDN-compatible services, the choice for federal users would be clear. Conformance to the standards would lead to reduced translation costs, more competition among suppliers, and more widespread service. However, if products conforming to common standards were a long way off, users needing end-to-end digital connectivity or enhanced services requiring common channel signalling would be tempted to acquire private dedicated networks now.

A leading question, therefore, for federal users is how fast ISDN standards are likely to be developed and embodied in new equipment and services. We believe that ISDN standards will underpin the dominant architecture of the world's telecommunication networks in the 1990s. United States and foreign carriers and equipment manufacturers have invested literally thousands of man-years in developing this architecture and the associated standards. A principal characteristic of this architecture is that it provides a low-cost solution for the continued expansion of voice services, while reducing dramatically the incremental cost of adding data capabilities. Even if the demand for data services were not growing rapidly, many ISDN standards would be adopted simply for the enhancements they provide to existing voice services and to network management--e.g., through common channel signalling and standardized access to both switched and dedicated channel services.

Consequently, we believe that ISDN compatible equipment and services will be introduced very rapidly in the United States beginning in 1987, although the process will not be complete for more than a decade. Our view is based on an assessment of the strategic importance of ISDN to various carriers and manufacturers, whose situations we now discuss.

Local Exchange Carriers. For at least three reasons, the LECs have much to gain from the rapid refinement of ISDN standards and the deployment of ISDN-compatible equipment. They would be able to compete more effectively with PBX suppliers and with private networks, and they would to be able to offer new products and services with CCS.
With respect to the first--competition between Centrex and PBXs--the ability to switch data calls as well as voice has been a major selling point for the PBX. Numerous PBX vendors provide a capability of switching data at speeds up to 56 kbps, useful for connecting data terminals to host computers. However, if the LEC's central office and the local access line are configured to support ISDN, Centrex could similarly provide intrafacility circuit switched digital service.

Moreover, it is not even necessary that ISDN capability extend beyond a single switch for the LEC to find Centrex-ISDN a potentially valuable offering. Indeed, introduction of ISDN is likely to begin with isolated central offices configured to provide Centrex-ISDN services to a single customer, with only gradual expansion to intra-LATA and then inter-LATA connectivity. By 1984, only 5 percent of local offices in the United States were digital and thus even potentially capable of being upgraded to provide ISDN service. But this number is estimated to grow to 24 percent by 1990.⁶

The second reason for LEC interest in ISDN standards is that their use would reduce the cost of providing special services, such as packet network access or dedicated channels, by providing a common access line for all services. Today's users must have special leased lines manually installed for data services, whereas in an ISDN one would simply dial a data call. Such cost reductions would permit LECs to compete more effectively with private network alternatives.

The third reason for LEC interest lies in the ability to support CCS within the network and ultimately all the way to the user. The LECs have numerous reasons to push for the accelerated introduction of CCS, the most important being the lucrative 800 number business. Currently, translation of 800 numbers into the actual physical line address can be accomplished only through the facilities of AT&T's common channel interoffice signalling (CCIS) network.⁷ Thus, a subscriber wishing to purchase 800 service must buy it from AT&T, even for intra-LATA calls.

⁷Dorros, op. cit.
If the LEC had its own CCS system and translation databases, it could route 800 calls to any of the long-distance carriers that compete with AT&T. These carriers would pay LECs handsomely to be able to compete for 800 number service. Moreover, the LECs could retain intralATA 800 toll service. But implementation of CCS is a prerequisite to serving the 800 number market.

Once implemented, of course, CCS provides the infrastructure for offering a wide range of additional services, including mechanized calling card service; advanced custom calling features such as camp on busy, distinctive ringing, or selective call rejection; and Citywide Centrex.

Moreover, CCS results in more efficient trunk use by delaying trunk seizure until after it has been determined that the called line is free. This alone can provide the economic justification for installing CCS.

In short, the LECs are strongly motivated to adopt CCS. Not surprisingly, several have already announced commitments to provide CCS by 1987. By selecting Signalling System #7 as the basis for providing CCS, the LECs are preparing themselves for eventual evolution to ISDN compatibility.

The BOCs and the Bell Communications Research Corporation (BellCore) have taken the lead in the United States in developing ISDN standards. The Chairman of ANSI Committee T1D1, charged with developing the U.S. position on ISDN standards, is with BellCore. In a recent seminar for the industry, BellCore presented a proposed time scale for the development of procurement specifications for use by the BOCs for ISDN-compatible equipment. Final specifications for most elements are scheduled for release by early 1986. Demonstrations or trials of ISDN service have been scheduled during 1986 by operating companies of both U.S. West and Bell South.

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Of course, the rate of deployment of ISDN-equipped central offices will depend heavily on marketplace demand. Many of the most urgently desired services promised by ISDN could be offered without going all the way to full ISDN compatibility. CCS-based services can be offered in conjunction with analog-stored program control switches. Flexible line assignments to data or voice services can be achieved by the use of a T1 connection from the customer's premises to a DACS equipped for customer configuration control. Support for switched data at speeds up to 19.2 kbps can be offered as an add-on to an analog Centrex using AT&T Datakit technology.\footnote{J. Weber, "Bell Atlantic Boasts: 1st with Centrex Data," \textit{MIS Week}, May 8, 1985, pp. 1 ff.} A large measure of the required functionality can be achieved without supporting ISDN basic or primary rate access.

The rate of deployment will also depend upon the speed with which the costs of full ISDN-capable systems fall and the rate at which customers demand full 64 kbps transparent B channels and full D channel capabilities. The commitment to ISDN by the BOCs will lead to investments in cost-reducing technology, which will in turn make ISDN-compatible equipment less costly than nonstandard alternatives.

The demand for 64 kbps service promised by ISDN also hinges on the future development of customer terminals, a subject to which we now turn.

\textbf{Central Office Equipment Manufacturers.} Equipment manufacturers are less disposed to support ISDN standards than are the LECs. Let us consider, first, central office equipment manufacturers.

Suppliers to the carriers have little choice but to support ISDN capabilities demanded by the LECs. As local monopsony buyers of switching equipment, the LECs call the tune. AT&T Network Systems is quickly moving toward ISDN, announcing that the November 1986 software release 5E4 for its #5 ESS central office switch will fully support 2B+D and primary rate access.\footnote{J. J. Keller, "AT&T Backs ISDN Pledge with Four New Products," \textit{Communications Week}, May 27, 1985, pp. 1 ff; L. Mantelman, "AT&T's ISDN Begins Its Earthly Descent," \textit{Data Communications}, May 1985, pp. 45-48.} According to current plans, ISDN primary...
rate access will be available by 1987 from every #4 ESS in AT&T's network.\textsuperscript{13} Similarly, GTE and Northern Telecom, who share 94 percent of the U.S. central office market with AT&T, have reported that they are working on ways to adapt their existing digital switches to handle ISDN traffic.\textsuperscript{14} European switch manufacturers, who have been hard at work developing ISDN-compatible switches for their use at home, see ISDN as a lever for prying open the U.S. market.\textsuperscript{15} The main issue for these companies revolves around the speed with which they should gear up to produce ISDN-compatible equipment. While AT&T is aggressively promoting ISDN, Northern Telecom seems to be waiting for greater evidence of a market demand for switching equipment with complete ISDN capability.\textsuperscript{16}

We conclude that islands of carrier-provided ISDN will be commercially available from selected central offices beginning in 1987, with widespread availability and interconnection of the islands by 1990. For the federal user, this means that within this time frame, the local operating companies will be able to propose Centrex service with circuit switched digital service. It also suggests that, in configuring data communications networks, users should consider the availability of 64 kbps lines on a switched rather than dedicated basis. However, it is likely to take the computer manufacturers some time after the introduction of ISDN to align their computer network architectures to take full advantage of this capability.

**PBX Manufacturers.** In contrast to the above participants, PBX manufacturers are benefiting from the absence of ISDN standards. By providing their own forms of integrated access, circuit switched digital service, interswitch signalling, and sophisticated calling features, they hope to draw customers away from Centrex and interexchange switched services. Because ISDN will strengthen Centrex and interexchange switched services as competitive alternatives, PBX manufacturers have

\textsuperscript{13}Del Myers, "ISDN Symposium Assessed the Market, Weighed the Risks and Signaled GO!", *Telephony*, October 28, 1985, p. 83.
\textsuperscript{14}E. E. Mier, "ISDN Standards: A Look Inside Integrated Services," *Data Communications*, May 1985, pp. 54-58.
\textsuperscript{15}Weber, op. cit.
\textsuperscript{16}Mier, op. cit.
little incentive to hasten its development. At the same time, if ISDN is eventually implemented, these same manufacturers hope to influence the specifics of the standards to minimize the costs of supporting ISDN protocols in their existing equipment.

According to one analysis of the PBX industry, AT&T supports ISDN standards because, being both a PBX and a central office switch manufacturer, it benefits from economies of scope in hardware and software by supporting similar standards in both sectors.\(^\text{17}\) Certain other manufacturers also support ISDN because, as low cost manufacturers, they will benefit from the creation of markets for standardized network equipment (switches, transmission gear) and peripherals (ISDN terminals and electronic phone sets).

But we expect yet other PBX companies to duplicate the strategy used by computer companies—using proprietary architectures to expand sales in other segments of the industry, while protecting their existing market share in switching equipment. Thus, most major PBX vendors may provide only limited capability to support standardized terminals connecting to the PBX over ISDN standard interfaces. For doing so would stimulate their sales of desktop devices and attached processors—an increasingly important goal as the share of total revenue accounted for by desktop devices and attached processors continues to increase.

Table 6.1 shows the shifting balance in the total revenues associated with a PBX sale. Recent studies confirm this trend toward isolating advanced features in proprietary systems. Forrester Research predicts that PBX proprietary terminals will account for 65 percent of desktop workstations in 1990, compared to 15 percent today; Hambrecht and Quist indicate that over half of PBX revenue will be derived from peripherals and application software by 1990.\(^\text{18}\) By offering advanced PBX features only through proprietary desktop peripherals connected by nonstandard links to the PBX, manufacturers will be better able to maintain or expand their sales in this shifting market.


\(^{18}\) Ibid.
Table 6.1

DISTRIBUTION OF PBX REVENUE
($/Line)

<table>
<thead>
<tr>
<th>Item</th>
<th>1984</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch</td>
<td>700</td>
<td>500</td>
</tr>
<tr>
<td>Application processor</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>Attached devices</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1000</td>
<td>1100</td>
</tr>
</tbody>
</table>

Source: Quackenbush, op. cit.

Even when the PBX vendor proclaims to use ISDN standard basic access—e.g., 2B+D on its access lines discussed below—the principal reason may be to take advantage of the availability of low-cost silicon interface chips. One should expect that the vendor's proprietary terminals will support extended message sets and advanced services over the D channel to maintain the bias in favor of the vendor's peripherals. Public standards will likely be supported in PBX markets as either "gateways" to competitors' office automation equipment base or to the public communications network.

To be sure, PBX manufacturers who use closed architecture defend their proprietary design as essential to improved communication systems, while they express concern that standards such as ISDN will not keep pace with technological advances. Nevertheless, we conjecture that their fundamental motivation is to protect their markets for terminal and related equipment.

Concern about losing desktop sales to PBX manufacturers has already led the European Computer Manufacturers Association (which includes U.S. firms with European manufacturing facilities such as DEC, Prime, Data General, and Honeywell) to develop standards for data processing

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terminals that will interface with ISDN-compatible PBXs and central offices. Those workstation manufacturers who are unaligned with a PBX vendor will probably be ardent supporters of ISDN standards.

These developments have several implications for federal users:

- A PBX purchaser will be better able to acquire terminals from third parties at competitive prices if the PBX provides a true ISDN standard interface.
- If a nonstandard interface operates between the PBX and proprietary terminals, users should assure themselves that the PBX is equipped with software to translate signalling received from the network from ISDN standard format to the PBX vendor's format.\(^{20}\)
- Users should check whether communications links between PBXs—for example to coordinate an electronic tandem network—are designed for the user-to-user signalling capability that will be provided as part of ISDN service from the carriers.

With respect to this last item, AT&T will begin providing ISDN primary access at 1.544 kbps to PBXs in 1987. The primary motivation is to facilitate provisioning of leased line or switched (packet or circuit) data services through use of a standard access link.

**Major Issues Associated with ISDN Standards**

ISDN is not a single standard; it is an architectural framework within which a wide range of services or capabilities can be provided to telecommunications users, and for which hundreds or thousands of specific technical choices will need to be standardized. ISDN standards specifications already run to hundreds of pages. We shall examine here four specific issues that merit close attention by federal communications managers: (a) the provision of basic access, (b) channel specification, (c) boundaries between carrier-controlled and customer-controlled equipment, and (d) multiplexed links from the PBX to the host computer.

\(^{20}\)However, as more complex messages and protocols are defined, such translation will become increasingly difficult. Vendors who adopt the proprietary route may have difficulty keeping up with the market.
Access Lines. For whatever services are supplied on an ISDN, a link must exist between the carrier's switch and the customer's premises. While digital transmission and switching have been gradually introduced in the rest of the network, the "last mile" to the customer remains an analog connection.

Thus, a prerequisite for any eventual ISDN is a standard configuration for a digital subscriber access line capable of supporting diverse services. In 1982, CCITT Study Group XVIII agreed on a "basic access" line of 2B+D, or 144 kbps full duplex. The B channels were to be capable of unrestricted digital traffic at 64 kbps. The 16 kbps D channels were to be packetized using a newly developed LAPD link protocol, derived from the LAPB link protocol used in the X.25 packet network interface standard.

Basic access can be supplied on standard two-wire copper loops using one of two techniques: (a) time compression multiplexing (TCM)--the so called "ping pong" technique--in which bursts of data at more than twice 144 kbps are sent sequentially in each direction to simulate a full duplex channel; and (b) echo cancelling technology (ECT), which allows data to be sent in both directions simultaneously and uses sophisticated signal processing to prevent the echo of the sender's own signal from interfering with his reception of the incoming signal. The industry consensus is that echo cancelling is the preferred technology. However it will be three to five years before ECT is ready for widespread use. 21 Thus, in the near term, basic access will be provided primarily with TCM.

Despite the blessing of the CCITT, there has been much discussion among manufacturers and carriers as to whether this particular configuration of 2 B+D is well suited to conditions in the United States. TCM at 144 kbps does not work well for loop lengths over about 12,000 feet. Although this was of little concern to the Europeans and Japanese at the CCITT because loop lengths in those countries are generally less than 12,000 feet, in the United States 48 percent of all loops are longer than 12,000 feet. 22 It will not be possible to

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21 Bell Communications Research, Industry ISDN Seminar, February 5-6, 1985; Mier, May 1985, op. cit.
22 G. T. Hawley and R. A. McDonald, "The Technological Evolution of
directly convert these longer loops to ISDN basic access. To provide a full 144 kbps for the longer loops, it would be necessary to introduce digital loop carrier (DLC) equipment out to a remote terminal closer to the end user (e.g., T1 carrier) to reduce the effective length of the basic access line.

To avoid the cost of DLC equipment for the longer loops, some local operating companies are considering other standards for the digital access line. One is a configuration consisting of one 32 kbps clear channel for voice or data and a 19.2 kbps signalling channel containing a full 16 kbps D channel. (The CCITT recently approved a standard for 32 kbps voice using adaptive delta modulation.) The total is less than 64 kbps and thus could be more readily carried over longer distances. According to one report, Bell South will introduce this configuration to U.S. standards bodies as an additional option alongside the international CCITT specification.\textsuperscript{23}

**Channel Specification.** A second issue relates to the specification of the B channel as 64 kbps clear channels. In the United States, digital speech channels are encoded at 64 kbps. However, one bit in eight is "robbed" to carry in-band signalling and for fill bits to meet requirements for a minimum density of "ones." Thus, the clear channel rate of U.S. PCM is only 56 kbps. Of the millions of miles of digital T1 carrier in the United States, most are not designed to carry clear 64 kbps channels. Thus, some manufacturers have argued for a 56 kbps channel specification, or a "restricted" 64 kbps, as the standard rate for data devices designed to work over ISDN channels.\textsuperscript{24} AT&T's recently announced circuit switched digital service (CSDS), for example, runs at 56 kbps to avoid problems with T1 carriers. This issue affects switch manufacturers as well, many of whom have designed their products around 56 kbps clear channels rather than 64 kbps. BellCore's recent technical advisory acknowledges this problem and discusses specifications for a "restricted" B channel, as well as a clear channel version.\textsuperscript{25}

\begin{thebibliography}{1}
\bibitem{1} J. Wilke, "Bell South Leads the Pack with Lightwave, Data Services," \textit{Data Communications}, May 1985, pp. 68-69.
\bibitem{2} E. E. Mier, "Northern Telecom, AT&T Square Off over ISDN Issue," \textit{Data Communications}, November 1984, pp. 50-52.
\bibitem{3} Bell Communications Research, February 1985, op. cit.
\end{thebibliography}
The Europeans do not face this same problem because their equivalent T1 specification uses common channel signalling and thus has always provided a clear 64 kbps channel, even for voice.

This issue is significant to federal users for two reasons. First, cost-effective implementation of digital access lines will require implementation of the standards in hardware, not software. Thus, commitments to one configuration or another cannot readily be changed without changing equipment. Second, users should beware of acquiring equipment that provides support only for "restricted" 64 kbps if it looks as though the clear channel specification is going to become dominant.

We conclude that federal users should consider carefully whether to insist upon equipment or services capable of meeting the full CCITT specification of 2B+D. Despite concerns that have been raised, for several reasons we believe that this technology will become the dominant standard.

First, the two largest vendors of PBXs and central office switching equipment have committed to supporting the 2B+D specification. Current AT&T PBX products, for example, support a digital communications protocol consisting of two 64 kbps channels plus one eight kbps signalling channel. The apparent intent was to design the Systems 75 and 85 to match as closely as possible the evolving ISDN standards, the drafts for which were using a working figure of eight of 1981 when AT&T committed its PBX design to silicon. (Indeed, AT&T stands to benefit if a restricted 64 kbps channel is not supported, since its PBX and digital switch products, unlike those of some of its competitors, were designed with clear channel service in mind.)

Second, AT&T and four other integrated circuit manufacturers have announced that they will build chips to support 2B+D.²⁷

Third, early users of ISDN will be the large, multinational corporations. They will likely insist upon compatibility between equipment used in their European and U.S. branches; and the Europeans will be implementing the full 2B+D.

Fourth, as noted earlier, most large businesses that will be early users of ISDN are located close to their serving wire centers; thus 144 kbps is not a problem. Even Bell South, which is proposing the alternative configuration of 32+19.2, will conduct trials in 1986 of a standard 2B+D ISDN configuration. Alternatives such as Bell South's 32+19.2 will be used primarily to provide residences and small businesses with advanced voice services that require the signalling capabilities of the D channel, or with home information services that use its packet data capacity.

Finally, large organizations will, in many cases, be served not by basic access but by primary rate access to the subscriber's PBX (except in the case of Centrex). Thus, a T1 carrier supplying 1.544 Mbps service will be the primary type of digital access line. Reflecting the extent to which large businesses are driving the demand for ISDN, both AT&T and Nynex have indicated that the first ISDN offerings, scheduled for introduction in 1987, will be primary rate access (23B+D).

Regulatory Boundaries

A third issue that may delay the deployment of ISDN-compatible access technology in the United States arises from a 1983 decision by the FCC defining the boundary between carrier-controlled and customer-controlled equipment. In Europe, carriers expect that the standard boundary between carrier-controlled equipment and customer-controlled devices will leave the PBX on the carrier side of the boundary. This is the so-called "S reference point" that has been developed in CCITT deliberations, illustrated in Fig. 6.2. In contrast, because of the FCC's detariffing of CPE in its Computer II decision, U.S. participants have supported development of a "T" reference point that divides NT2 or

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28 Wilke, May 1985, op. cit.
PBX type equipment from NT1 or network circuit terminating equipment (NCTE), presumed to belong to the carrier.

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Customer premises  Serving local exchange

Transmission line

ST  Subscriber terminal equipment
TA  Terminal adaptation equipment for existing terminals, e.g., X.21
NT2  Network termination equipment to include protocol handling, switching, statistical multiplexing, physical contribution/concentration
NT1  Network termination equipment to include maintenance functions (e.g., test loops), power feeding, timing, line transmission termination
LT  Line transmission termination
ET  Exchange termination


Fig. 6.2—ISDN access line reference points
However, ruling on a case involving NCTE for AT&T's Digital Dataphone Service (DDS) in 1983, the FCC judged that NCTE is customer premises equipment and thus cannot be provided by the carrier as part of a tariffed offering.\textsuperscript{30} This has left the United States in the position of having to define a new interface not recognized by the CCITT—the so-called U interface shown in Fig. 6.2, as the boundary between CPE and the network.

Putting NCTE on the CPE side of the boundary prevents the development of a single interface for CPE that is independent of, for example, whether the access line is provided using ECT or TCM technology. The LECs denounced the application of the DDS decision in responding to the FCC's inquiry on ISDN.\textsuperscript{31} In its Computer III inquiry, the FCC has proposed to retain the classification of NCTE as CPE but to allow the BOCs to provide it on a tariffed basis.

Maximum terminal portability will be achieved by purchasing only CPE that interfaces with the network at the T reference point. Since a mixture of TCM, ECT, and T1 technology will probably be used for digital access lines, terminals built to a U interface standard will not be as portable. Moreover, if the carrier supplies NCTE, the line can be monitored end-to-end by the carrier. This is likely to lead to faster problem diagnosis and a reduction of finger pointing between CPE providers and the carriers. To be sure, loopback and diagnosis facilities can be included in customer-provided NCTE; but a difficulty that occurs in NCTE equipment may not be readily distinguishable from certain forms of failure on the carrier's lines. Thus, carrier-provided NCTE simplifies overall network management.

When a PBX is used to link individual terminals with a large mainframe computer, computer port costs can be reduced if terminal connections coming from the PBX can be multiplexed onto one high-speed line into the computer. But the best method for linking computers to a PBX with a multiplexed stream of data calls is unclear. Northern

\textsuperscript{30}Amendment of Part 68 of the Commission's Rules Concerning Connection of Telephone Equipment, Systems and Protective Apparatus to the Telephone Network, 94 FCC 2d, pp. 5-31.

\textsuperscript{31}FCC, Report, Docket CC 85-341, April 1984.
Telecom and Digital Equipment Corporation have developed the Computer-PBX Interface (CPI) protocol based on 56 kbps channels and in-band signalling. AT&T has proposed its Digital Multiplexed Interface (DMI) protocol that supports 64 kbps channels and common channel signalling. Each proposal has gained commitments for support from several computer companies. Some have even agreed to build interfaces for their computers to both specifications.\(^{32}\)

The issue here is primarily one of timing. CPI is much simpler to implement with the existing base of digital PBXs such as the Northern Telecom SL1. The DMI format more closely resembles the 2B+D format of ISDN primary rate access and can be further developed to meet the full ISDN requirement. Because of the large base of existing Northern Telecom digital PBXs in the United States that do not support 64 kbps unrestricted, it is likely that the CPI format will be widely used in the United States during the near future. In contrast, in Europe, where there are far fewer digital PBXs in place, CPI may not get off the ground. Because of its alignment with ISDN standards, DMI is clearly the preferred choice for computer-to-PBX standards for the long term. Moreover, it is unlikely that the CCITT would ever approve the CPI format as an international standard.

Fortunately, many computer manufacturers have agreed to provide CPU interfaces for both standards. Thus, federal users are free to choose, depending on the PBX equipment they have in place. However, whenever choice is not dictated by existing equipment, the selection of DMI is likely to provide a smoother transition to the eventual CCITT standard, which we predict will eventually dominate.

**OPEN SYSTEMS INTERCONNECTION**

The second area in which important standards developments are under way is in computer communication. The goal is to allow computers from different manufacturers to operate compatibly with each other. The OSI reference model, developed by the International Standards Organization (ISO), has provided a basis for the development of a modular set of

\(^{32}\)C. Barney, "AT&T Campaigns for ISDN Norm," *Electronics Week*, January 21, 1985, p. 29; *Communications Week*, July 30, 1984; *Communications Week*, July 9, 1984.
protocols covering seven separate layers (Fig. 6.3). At each layer, one or more specific protocols has been defined (Fig. 6.4). Each of these protocols is then supposed to work with any of the protocols at the other layers.

The development of specific protocols by the ISO to implement each layer of the OSI hierarchy has been a difficult effort, extending over more than eight years. The difficulty reflects (a) the diversity of applications for computer communications, and the need to accommodate all of these applications in the standards; and (b) the varying interests of the carriers and the computer manufacturers, each wanting protocols that best suit its needs and market position.

**The Movement Toward OSI Standards**

Virtually every manufacturer claims that his proprietary architecture "conforms to the OSI reference model." The reference model, however, specifies only how the task of writing protocols should be broken up into modules. It is support for the specific ISO protocols for each layer that insures that products from different manufacturers will interwork.

Of the seven layers of the OSI model, formal protocols have been adopted for layers 1 through 5. Today, electronic mail is the only application protocol (layer 7) that has progressed to the stage of a formal standard. Other application protocols such as file transfer and management, remote login (virtual terminal), and remote job manipulation are still in the draft stage. Once these protocols are finalized, it will take another two or three years before products conforming to these standards will be available.

We see four scenarios for the eventual adoption of ISO/OSI standards:

1. Equipment vendors support the use of ISO standards as a cannonical gateway format for the exchange of information between proprietary networks.
2. New computer companies adopt ISO protocols as their internal network architecture rather than inventing yet another proprietary scheme.
Fig. 6.3—Open systems interconnection layered model
Fig. 6.4—OSI layers and protocols
3. Some established companies convert--layer by layer--from the use of their proprietary schemes to ISO standards as it appears economically attractive to do so.

4. A few large buyers insist on the use of ISO standards in their procurements and thus prompt the development of OSI protocol implementations, even where these are not the vendor's principal networking offering.

Virtually all major computer manufacturers will support a gateway between their private corporate network architectures and ISO/OSI standard protocols. This will allow, for example, the exchange of files and, especially, electronic mail between computers from different vendors over public data networks based on the X.25 standard. Products providing these capabilities will appear in 1986 and will probably become widespread by 1990.

Some manufacturers will support ISO/OSI protocols as part of their corporate network architecture. Honeywell and Digital have already indicated their intention to do so. However, such a transformation must be introduced gradually and is likely to extend over three to five years. Moreover, since the OSI options that they will support for internal use will likely not be those best suited for use over X.25 networks, these companies will need to provide gateway products of the type described in the preceding paragraph, just as much as those companies that do not use the ISO/OSI protocols internally.

A few smaller vendors have introduced ISO/OSI protocol implementations for local area networks. Although these implementations support communications only among a vendor's own products, at the application level, they position the vendor for eventual intervendor communication over the network, once higher-level applications are standardized. For a vendor with no proprietary architecture to

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34OSI application standards will probably be used for interworking across nonstandard networks. For example, 3COM corporation is working on an implementation of the X.400 electronic mail application standard
support, this is a good strategy. But vendors with an installed base of
equipment supporting proprietary protocols will move more slowly to
convert to the use of OSI internetwork and transport protocols.

Existing protocols make little or no provision for network
management functions (network configuration, problem determination, and
load management). Since network management accounts for the majority of
the software in a real network protocol implementation (e.g., Systems
Network Architecture), this lack is significant. Consequently, we
expect that incompatible, proprietary approaches to network management
will appear in the early OSI implementations and that robust network
operation will not be possible with multivendor OSI systems for some
time.

The National Research Council has recently recommended to the
Department of Defense that it shift as rapidly as products become
commercially available from the DoD-developed protocol family (TCP/IP)
to the comparable subset of ISO/OSI protocols (TP-4/INP) endorsed for
government use by the National Bureau of Standards. However, the DoD
has decided instead to subject the ISO protocols (and their integration
with existing higher-level DoD protocols) to rigorous testing before
elevating the TP-4 and INP to be costandards with TCP/IP. This move is
estimated to delay by up to 18 months the issuance of any procurement by
DoD which specifies ISO protocols; operational use will come even
later.\textsuperscript{35} Given the installed base of TCP/IP based equipment, it will be
at least five to seven years before ISO standards are used in a
significant fraction of DoD networks.

As noted earlier in this section, standards adopted by
international standards bodies are rarely capable of immediate
implementation. Key points may be left "for further study."
Engineering parameters, such as timeouts, may need to be specified only
after there has been practical experience. Furthermore, to reach
agreement in the consensus environment of international standards

for exchanging mail between servers on a local area network. It intends
to support the exchange of standardized documents using nonstandard
(Xerox Network Systems) protocols at levels 3-5.

\textsuperscript{35}National Research Council, Board on Telecommunications and
Computer Applications, Committee on Computer Communication Protocols,
Transport Protocols for Department of Defense Data Networks, National
bodies, such groups may often "agree to disagree" by adopting standards proposals with multiple options. Such standards may simply be a way of disguising an inability to agree on a single proposal. In this environment, significant effort is required to further specify a "standard," and to agree on compatible options. For example, the National Bureau of Standards has conducted a series of "OSI Workshops" designed to encourage major manufacturers, both in the United States and from around the world, to agree on compatible subsets of the ISO standards for open systems interconnection. This effort has been of importance in insuring that OSI implementations done according to the standard will in fact interwork. Government users will continue to depend on assistance from NBS in defining the meaning of standards "conformance."

The Relationship Between OSI and ISDN

Both OSI and ISDN standards developments have a long history. The former grew out of the work on packet switching and the development of the X.25 packet switching standard. The latter grew out of work on standards for circuit switched digital networks. Thus, they differ fundamentally in their approach to data carriage: packets versus circuits. Packets are well suited to terminal-to-computer traffic and very bursty communications. Circuit switching is better suited to bulk file transfers and facsimile. Thus, an ISDN can effectively substitute for a packet network for some types of data traffic. The OSI effort is also broader in the sense that it deals with standards for applications, a subject not included in ISDN, which deals primarily with data transport (layers 1-3). In principle, the ISO Transport Protocol could run just as well over a digital circuit established via an ISDN as over a packet virtual circuit. By the end of the decade we should see networking software that automatically chooses the most appropriate network--packet or circuit switched--as a function of the application.

The two efforts also come together in the area of ISDN common channel signalling. The D channel used for signalling in an ISDN is designed to handle bursty packetized information. Efforts are under way to use the same OSI layered approach to design the protocols for signalling between an ISDN terminal and a switch: a clear example of
computer-to-computer communications. Thus, the D channel link protocol is similar to the data link protocol contained in X.25.

CONCLUSIONS

A number of conclusions flow from our discussion of ISDN and ISO standards. With respect to ISDN, six points are especially notable:

- The local exchange carriers as well as AT&T Communications have committed to offering selected ISDN-compatible services beginning in 1987.
- ISDN-compatible services will provide both performance and operational cost advantages in comparison with current carrier offerings, particularly once ISDN interfaces are implemented in silicon--probably by 1988.
- Some PBX manufacturers may attempt to lock customers in to proprietary terminals by using line protocols other than ISDN standards. Under pressure from users, they will support ISDN standard interfaces. Federal users should seriously consider insisting on ISDN compatibility for Centrex and PBX procurements scheduled for installation beginning after 1986.
- There will probably be multiple incompatible standards for the U interface based on different technologies; the T interface standard will be more stable and will offer greater terminal portability.
- Because millions of miles of currently installed carrier plant cannot carry clear 64 kbps channels, ISDN data channels may be limited to 56 kbps until new plant is installed or existing plant is upgraded.
- Two alternative standards for interconnecting a PBX and time-shared computers will be supported by manufacturers: CPI and DMI. The former is an interim approach compatible with existing PBXs. The latter is closer to the eventual ISDN standard likely to be adopted by the CCITT and should be preferred by federal users.
With respect to ISO standards, even in the absence of standardized applications, federal users may gain by specifying these standards for the lower protocol layers (e.g., X.25 for packet networks, IEEE 802 standards for local area networks) of their data networks. Doing so simplifies the problem of translating between incompatible systems by assuring the ability to move data from one system to another in a standard way. Moreover, since the lower-level standards are more often implemented in hardware than are higher-level ones, they are the more difficult to change later once standardized applications become available.

One higher-layer standard—the electronic mail standard (X.400)—has already been ratified by the ISO. As yet other higher-layer standards, such as File Transfer and Management, are ratified, federal users should insist that suppliers support these standards as well, if this can be done at reasonable cost.

Because the federal government is such a large purchaser of data processing equipment, the availability of products embodying ISO protocols is not wholly independent of the government's actions. By making a strong commitment to procure only products conforming to ISO protocols, the government could significantly accelerate the introduction of these products. Since, in the long run, the existence of standardized products favors the government as a user, by reducing translation costs and facilitating competitive bidding, one can argue that the federal government should be aggressive in specifying ISO protocols, even when ISO-compatible software is not currently the lowest-cost solution to a particular network need. The DoD may have been prudent in not aggressively supporting OSI in view of its groundbreaking efforts to develop the multivendor TCP/IP protocol suite and its large existing investment in that protocol family. However, for federal agencies without an existing investment in an open standard, the ISO/OSI protocols seem clearly the better choice for the future.
VII. DECISIONMAKING AND GOVERNMENT REGULATORY POLICY

As emphasized in the preceding sections, government regulatory policy plays an important role in the choices available to federal and other telecommunications users. In Sec. III we discussed those policies especially relevant to choices between PBS and Centrex procurements. In this section we discuss the following major regulatory actions and issues that will affect the broader range of future procurements:

- Access charges imposed on end users and carriers, which affect the rates charged for both public and private services.
- Rates for bulk discounted services, where the problem of establishing "just and reasonable" rates led to the demise of Telpak and has posed uncertainties for WATS users.
- Rates for private line services, which have also been subject to much controversy in the face of competitive pressures that have grown steadily since the 1960s.
- The current controversies about separation requirements imposed by the FCC between basic and enhanced services, which affects not only choices between PBX and Centrex, but the availability of other services as well.
- The degree of future competition in long-distance markets permitted by federal and state regulators.

We cannot hope to cover here all issues in the regulatory arena. But the discussion is sufficient to show why the federal user should follow regulatory developments closely.

\footnote{Discussion of many issues not included here is contained in National Telecommunications and Information Administration (NTIA), Department of Commerce, \textit{Issues in Domestic Telecommunications: Directions for National Policy}, Washington, D.C., July 1985.}
ACCESS CHARGES

Probably the most controversial single subject in recent regulatory annals relates to access charges imposed on users of local exchange networks. Access charges fall into two categories: (a) those imposed on end users for access to the interexchange network, and (b) those imposed on interexchange common carriers for access to the local network required to connect to end users. Access charges on common carriers are, in turn, divided into two categories—"switched" and "special" access charges. A brief discussion of these various access charges is important because they very much affect the rates that federal users pay for both switched and private line services. Moreover, continuing controversy about these charges causes uncertainty about future tariffs that users must take into account in making their procurement choices.

End-User Charges

The FCC imposes a $1 monthly charge on residential and single-line business, effective June 1, 1985, with the charge rising to $2 monthly a year later.\(^2\) This decision comes after long controversy in Congress and elsewhere about the effects of such access charges on small users, particularly low-income groups, and the consequences for maintaining universal telephone service. The purpose of the access charge is to discourage bypass of the local telephone network by users who, given tariffs that would otherwise exist, have an incentive to build or lease facilities directly linking their offices with the local switches of long-distance carriers.

Although the FCC has backed away from earlier decisions that would have imposed higher access charges and more quickly, even the current plan could be modified or abandoned. Legislation has already been introduced in Congress that would impose a ban altogether on single-line user access charges. This continuing controversy creates uncertainty for federal users to the extent that the smaller the cost imposed on certain groups (such as residential and small business users)

\(^2\)FCC, MTS/WATS Market Structure and Amendment of Part 67, Decision and Order, 50 Fed. Reg. 939. As noted in the earlier discussion of the Centrex-PBX debate, the access charge is set at up to $6 monthly for multiline business users.
the larger will be the charges imposed on others if telephone companies are to meet their overall revenue requirements.

In addition to end-user charges discussed earlier, local telephone companies are allowed to add an access surcharge (subject to FCC approval) of up to 35 cents for each single-line user. The intent is to permit a reduction in access charges paid by long-distance carriers to local telephone companies for access to "large volume" users.³ The purpose of this surcharge, as with the basic end-user charge, is to discourage bypass of the local telephone network.

The degree to which local telephone companies make use of a surcharge is important to federal agencies. Being large users they are among the organizations most likely to bypass local telephone facilities, and, thus, are among those most likely to benefit from discounts on switched long-distance service made possible by the end-user surcharge on single-line users.

These end-user charges or CALCs are important, not only because of the direct cost they impose, but also because they can affect the relative merits of switched and leased lines. As these charges are phased in, long-distance carriers may reduce their transmission line tariffs, with possible differential price effects on alternative network configurations.

**Switched Access by Common Carriers**

Common carriers also pay access charges for using local networks to connect with their customers. The access charges currently in effect were established in 1984, again after long controversy relating especially to the charges levied against AT&T's competitors whose access to local networks was technically inferior to that enjoyed by AT&T. To reflect differences in access, MCI and other competing interexchange carriers were given a 55 percent discount below the rate paid by AT&T. This discount is being eliminated, exchange by exchange, as equality is achieved in access—a process which is rapidly progressing at the present time. Debate is centering around the question of whether some of AT&T's competitors will be able to survive after they are forced to

pay nondiscounted access charges. Concerns about the viability of competitors could lead to pressure to maintain the discount even after these carriers achieve equal access with AT&T, adding to the uncertainty confronting those contemplating procurement from those carriers.

**Special Access Carrier Charges**

These charges, applied to the vast range of private line data, voice, and video services, were implemented on April 1, 1985. Most notably, lines installed as of November 1984 by carriers that compete with AT&T are to incur only 50 percent of the charge paid by AT&T for the first six months and 75 percent of the AT&T rate for the second six months, so that only by April of 1986 will all carriers pay equal charges. The rationale for this discount is different from that for switched access. Here there is no question of technical parity of access for private lines, unlike the situation for switched services. Rather the discount is a way of protecting AT&T's competitors temporarily from the "rate shock" that would otherwise occur when the special access charges replace current contractual agreements. As discussed below with respect to private lines, this access charge will increase tariffs for relatively short-distance private lines, while decreasing them for longer-distance private lines, when combined with AT&T's restructured private line rates approved by the FCC in April 1985.

**Activities at the State Level**

The preceding dealt with interstate access charges under the purview of the FCC. But state agencies, too, are actively engaged in considering, and in many cases imposing, access charges on intrastate traffic as well. Federal users, especially those with heavy intrastate communications requirements, must monitor carefully developments at their state levels to make procurement decisions that do not become quickly out of date as a consequence of state actions that users could, and should, have anticipated.

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BULK OFFERINGS

Possible continued restructuring of WATS rates will be of critical importance to government telecommunications users. One need only look to the history of Telpak to appreciate the importance of bulk offerings to large users. GSA observes that during the 1970s the FTS used Telpak almost exclusively, with savings to the government totaling some $1.25 billion. But after years of administrative review (during which time Telpak was repeatedly judged by the FCC to be unlawful), it was finally withdrawn in 1981, increasing annual FTS costs by more than $90 million.⁵

As in the case of Telpak (and private lines discussed below) the FCC has been concerned for years about whether the rates charged for WATS are "just and reasonable," as required under Sec 202(a) of the Communications Act of 1934. WATS shares use of the public switched network with Message Telecommunications Service (MTS). If rates for WATS are unreasonably low, other users of the network must make up the difference. The Commission observes that "One of our long term regulatory objectives is to insure fair and equitable treatment for all users of the public switched network so that any particular user class does not receive any undue preference over another."⁶

When AT&T introduced outbound WATS in January 1961, the user could select one or more mileage bands from point of origin and pay a flat rate for unlimited use per WATS line, with the rate level determined by the mileage band selected from point of origin. In mid-1974 AT&T restructured WATS with full-time WATS unlimited service converted to two usage-sensitive options: a full business day (240 hours per month) charge with measured service charges for use in excess of 240 hours; and a ten-hour per-month charge with measured service charges beyond that level.⁷

⁵U.S. General Services Administration, op. cit., p. 6. Pressure to withdraw Telpak increased after AT&T was ordered to allow resale of Telpak, narrowing the degree to which bulk discounts would be economically viable.
⁶69 FCC 2d at 1690 (emphasis in original).
⁷84 FCC 2d 158 (1980).
The FCC found these rates unjustified and hence unlawful but allowed the rates to remain in effect and ordered AT&T to file new rates. But only a year later the Commission found the new AT&T rates deficient and therefore rejected the filing.

The lawfulness of WATS rates was cast further into doubt in November 1978 when the Commission determined that WATS and MTS were "like services" within the meaning of Section 202(a) of the Communications Act. When the Commission ordered unlimited resale and sharing of WATS in October 1980, AT&T proposed, and was granted, a 75 percent increase in WATS rates. This move clearly reflected the fact that if users could freely sell and share WATS lines as a substitute for MTS, the previous low rate levels for WATS would not be sustainable. In May 1981 the Commission required AT&T to implement time-of-day pricing for WATS, recognizing that WATS services contributed to peak loads on the public switched system and therefore should bear a portion of capacity costs. In June 1981, AT&T incorporated time-of-day pricing and a tapered rate structure, with separate rate schedules for outbound and inbound WATS.

Even with these changes the lawfulness of WATS rates remains in doubt. In its most recent Memorandum Opinion and Order, the Commission lamented that

throughout these years of proceedings the Commission has been concerned that WATS customers may be paying too little, and users of Message Telecommunications Service (MTS) too much, for their use of the public switched network (PSN). Although WATS and MTS share the PSN, they have always been offered under separate tariffs and at different rates which do not permit meaningful comparison.10

The investigation into WATS rates has been long, tedious, and inconclusive, for the same reason that the FCC's investigations into the lawfulness of Telpak and private line rates suffered the same

1091 FCC 2d 338 at 339 (1982).
consequences. It is extraordinarily difficult if not impossible to determine the reasonableness of the rate for a service when that service shares the use of common facilities with others. The FCC has traditionally taken the approach that, to be lawful, a service must bear fully the additional costs it imposes on the system plus its "fair" share of the common or overhead costs. But determination of both of these cost elements has been subject to controversy in WATS, as in Telpak and private line services. Moreover, AT&T has argued that the service should not be discontinued simply because it does not cover some arbitrarily specified share of common costs. As long as it covers its own direct costs and contributes anything to covering common costs, the company's other customers are better off with the service being offered than without it, for in the latter case they would be forced to bear all the costs. Others have pointed out that, if WATS diverts users from services that make a greater contribution to common costs--e.g., MTS--a low contribution from WATS can increase the revenue that must be obtained from the remaining MTS users. It was arguments of this sort, fueled by a chronic lack of adequate cost data and other information, that extended the Telpak investigation to over 15 years before that service was withdrawn.

Thus, federal (and other large) users must take into account in their sensitivity analyses the possible continued restructuring of WATS rates. With the impact of reselling and sharing by this time fully incorporated in higher WATS rates, any likely changes in WATS rates in the future are likely to be downward (in real terms). For example, both WATS and MTS rates should decline as end-user access charges are phased in. While the FCC could, conceivably, determine that WATS rates remain unreasonably low, it is hard to maintain that position so long as small users otherwise dependent on MTS can rely on resale or sharing of WATS lines. Deregulation of AT&T, as discussed earlier, would likely lead to downward pressures on WATS rates in competition with the offerings by MCI and other carriers. This downward pressure will generally be reinforced by continued technological advance that will continue to reduce long-distance transmission costs for both AT&T and its competitors.\footnote{It is conceivable that AT&T would increase the shorter mileage}
to take existing WATS rates (in real terms) as an upper bound in
assessing the costs and benefits of future alternative procurements. A
major question they must address is how reductions in WATS rates by
various postulated levels affect the relative merits of their
alternative telecommunications procurements.

PRIVATE LINE SERVICES

Uncertainty about the future course of AT&T's private line rates
stems especially from two sources: (a) the FCC's concerns (spanning
more than two decades) that AT&T's private line services may be priced
at noncompensatory levels, forcing others who have few competitive
alternatives—primarily MTS users—to bear a disproportionate share of
AT&T's overall costs, and (b) more recent concerns that private line
rates proposed by AT&T in early 1985, and approved by the FCC in April
1985, discriminate in favor of AT&T's own customers and against other
common carriers who lease private lines from AT&T.

With respect to the first, issues about whether AT&T's private line
offerings were compensatory arose when it introduced Telpak after the
FCC's decision in 1959 to permit private entities to build microwave
systems for their own use. Responding to allegations of cross-
subsidization, the Commission sought to determine the rates of return
for seven interstate services, including Telpak, to judge whether prices
were "just, reasonable, and non-discriminatory." The Commission's
analysis was based on use of a particular "fully distributed cost"
(FDC-1) approach that involved adding to direct or identifiable costs an
allocation of common costs to each service on the basis of relative use.
The resulting evidence showed that Telpak was indeed earning virtually
no return, whereas MTS was earning relatively high returns.

After years of additional inquiry into the problem of allocating
common costs (similar to those discussed above with respect to WATS),
the FCC declared in 1976 that Telpak tariffs were illegal. But by that
time users of Telpak had become so dependent on the bulk rate service
that they protested its discontinuation. It was not until 1980, some 20

band WATS rates to put pressure on other common carriers (OCCs) that are
currently using WATS to reach LATAs not directly served by the OCC.
However, by 1987 both MCI and Sprint should have a presence in every
LATA and thus be less vulnerable to such pressures.
years after the Telpak tariffs were originally filed, that they were withdrawn.

AT&T subsequently filed new tariffs whose legality was also subject to long controversy. Its most recent tariffs, approved by the FCC in April 1985, involve a restructuring of rates to bring them more closely into line with underlying cost. Previously, AT&T private lines bore a constant per-mile rate regardless of distance (while costs of service rise less than in proportion to distance). Under the new structure, short-distance inter-LATA private lines will bear higher rates and longer-distance traffic will enjoy decreases, reflecting a decrease in the rate for the interexchange portion of the line and an increase to cover the special access charges discussed previously.

Bitter controversy has surrounded these new private line tariffs, and possible court challenges could force a reversal or modification of the FCC's approval. Complaints include allegations of inadequate cost justification, discriminatory rate disparities, and possible double recovery of some costs. AT&T's competitors charge that the tariffs discriminate against them while giving a preference to AT&T's large private line customers. As one example of the impact of prospective rate hikes, Western Union estimates that the cost of its private line facilities leased from AT&T will increase by nearly 30 percent, or by about $6.9 million annually over current charges.

The salient feature, we believe, for federal users is that the FCC's approval of the new tariffs may not make much difference in the longer run. While today some competing carriers are heavily dependent on AT&T for leased lines, this situation is rapidly changing. As has been widely publicized, new regional and national networks are rapidly expanding, based in part on rapidly growing use of fiber optics, with participation not only by telecommunications carriers but by railroads and electric utilities as well. According to one report:

12Telecommunications Reports, April 19, 1985, p. 3.
13This discussion draws heavily from Telecommunications Reports, February 18, 1985, pp. 21-22.
During 1984, more than 70,000 line miles of fiberoptics were announced by AT&T, MCI, United Telecom and numerous other long distance carriers. If all these networks are actually constructed, by 1989 the nation would have access to more than eight billion circuit miles of transmission capacity. By comparison, the current AT&T communications network has less than one billion circuit miles.

Use of single-mode fiber and very high speed (565M bit/sec) electronics will force these per circuit-miles down from the $10 range now experienced by AT&T to as little as $1 per circuit mile.14

Another notable development is the formation of the "National Telecommunications Network," a partnership of five regional fiberoptic firms designed to provide nationwide fiberoptic-based regional transmission services.15 The five partners have 980 route miles already constructed with plans to construct an additional 5566 route miles by 1986, to provide services "to every major market in the U.S."16

In their long-term planning, federal users should assume in their sensitivity analysis of alternatives that the long-distance segment of private line rates will decline (in real terms) as a consequence of competition among carriers and rapidly expanding networks.

A final, smaller, source of uncertainty relates to any changes in the surcharge that the FCC requires on private line users with "leaky" PBXs. Private line tariffs are designed to recover their own local loop and other "non-tariff sensitive" (NTS) costs. But unlike MTS and WATS, they make no general contribution to covering NTS costs in local exchange networks, since dedicated private lines do not make use of nontraffic-sensitive plant serving others. However, the FCC observes:

Private lines can also be used to access local exchanges for the purposes of originating or completing long distance calls. Although private lines are generally described as dedicated,

15Telecommunications Reports, February 11, 1985, p. 11.
16Ibid., p. 12. Of course, in addition to rapid expansion of terrestrial facilities, communications satellites also offer alternatives both to common carriers and directly to end users.
unswitched, point-to-point facilities, they frequently (perhaps even typically) originate or terminate at a private branch exchange (PBX) facility controlled by the subscriber. With a PBX the private line subscriber has the capability to "patch" an interstate call to off-network destinations in the local exchange.¹⁷

So that private line users of local exchange plant help cover its cost, the FCC imposes a surcharge of $25 for each private line termination in a PBX, capable of being switched as described above. No plans are currently under way to modify this surcharge. But it would become a source of controversy in the future, depending on final decisions (and changes in them) about access charges that could affect revenue requirements of local telephone companies and, hence, their need for a PBX surcharge.

THE COMPUTER II DECISION AND THE MODIFIED FINAL JUDGMENT

Computer II and Computer III

As illustrated in the earlier discussion about PBX vs. Centrex, the distinction between basic and enhanced service is becoming increasingly blurred. As a consequence, the FCC is undertaking a Computer III inquiry to reexamine the Computer II separation requirements on AT&T and on the BOCs.¹⁸

It earlier ruled that the BOCs may provide under waiver X.25 to X.75 protocol conversion as a basic service.¹⁹ However, it has rejected a BOC request for protocol conversion of asynchronous transmission to X.25 but with partial exceptions under which conversions are permitted with use of common equipment rather than through full structural separation.²⁰ Further relaxation of regulatory constraints is an important issue in the Computer III inquiry.

¹⁷FCC 2d at 868.
¹⁹FCC, Waiver of Sec. 64.702 To Provide Certain Types of Protocol Conversion, FCC 84-561, adopted November 21, 1984.
Moreover, the FCC has eliminated structural separation requirements imposed on AT&T for the provision of customer premises equipment that had been imposed in the Computer II decision.\textsuperscript{21}

It would be easy enough to defend the abolition of the Computer II rules for structural separation if AT&T-C and the BOCs had no significant monopoly power in their "basic" services. It was the fear of suppliers subsidizing their competitive "enhanced" services from their "monopoly" basic services that led to the structural separation requirement. Thus, issues of relaxing or eliminating the Computer II rules hinge on judgments about how much monopoly power these firms have in their basic services and the likelihood that cross-subsidization poses a real, as opposed to a theoretical, threat.

Federal users would benefit in at least two ways if the structural separation were relaxed or eliminated: (a) AT&T and the BOCs would be better able to provide integrated services packages rather than having to deal with others on an arms-length basis, thereby facilitating federal procurement decisions, and (b) it would lower the cost of procurement to users to the extent that the structural separations requirement imposes a substantial cost, as AT&T and the BOCs have long argued. Presumably, these costs include the unrealized economies of scope in providing enhanced and basic service in a single organization.

The Modified Final Judgment

The MFJ restricts the operations of the BOCs in several ways. Most notably, it imposes "line-of-business" restrictions that prohibit them from (1) providing interexchange or information services, or telecommunications equipment, (2) manufacturing CPE or other telecommunications equipment or (3) providing any other product or service, except exchange or exchange access services, that is not a natural monopoly service actually regulated by tariff.\textsuperscript{22}

\textsuperscript{22}Comments of American Information Technologies Corporation (Ameritech), filed with the National Telecommunications and Information Administration, March 29, 1985, p. 11.
The BOCs may seek waivers case by case, but the process is lengthy and uncertain, "even in the case of minor business ventures."\(^{23}\)

Similar to the situation posed by the Computer II decision, these line-of-business restrictions are the subject of continuing controversy. In contemplating new procurements, federal users should monitor issues here, and the way they are resolved, since the ability of the BOCs to offer integrated services could be markedly affected.

**COMPETITION IN LONG-DISTANCE MARKETS**

Two key issues relate to the level of competition permitted by state regulators for intrastate long-distance service, and the extent to which AT&T-C will be deregulated in competing with carriers in interstate markets.

**Intrastate Competition**

While competition is growing rapidly in interstate markets, the situation within states varies. At this writing 31 of the 38 states that have more than one LATA permit inter-LATA competition, whereas only eight states permit intra-LATA competition.\(^{24}\) Restrictions on intra-LATA competition are significant because many LATAs are large, encompassing areas far beyond what one would normally regard as "local exchange." Indeed, a dozen states each have only one LATA. There, and in other states where intra-LATA competition is prohibited, the BOCs retain a monopoly on long-distance service as well as local exchange service.

Moreover, although the MFJ requires the BOCs to reconfigure their systems to permit equal access by all interstate carriers, it does not stipulate that states enforce equal access provisions for intrastate inter-LATA or intra-LATA service. Whether states will require equal access, on their own volition, remains to be seen.

\(^{23}\)NTIA, op. cit., p. 39.

\(^{24}\)NTIA, op. cit., p. 7.
States are continuing to reevaluate their policies. Federal users (and others) should monitor these developments closely, since decisions to open intrastate markets to competition, and to require equal access, could have a substantial effect on intrastate tariffs and service offerings.

**Interstate Competition**

Many agree that at some point in the future AT&T-C should be deregulated, thereby placing it on parity with MCI, GTE-Sprint, and other competing long-distance carriers. The issue is one of timing and phasing.

Evidence filed in a current FCC proceeding dealing with this issue is inconclusive and subject to dispute. AT&T's competitors argue that it still has more than 90 percent of the interstate market, measured by revenues reported by major carriers during 1983.\(^{25}\) But AT&T argues that such a market share reflects only the past effects of regulation rather than market power. Market power, it argues, depends on the ease with which firms can enter the market, expand capacity quickly and, if necessary, exit the market. The fact that AT&T has a large portion of the market does not mean that it can easily raise prices in a deregulated regime because, it asserts, competing firms can and are entering long-distance markets throughout the country with a rapid expansion of capacity. Thus, any attempt by AT&T to raise prices would be thwarted. AT&T points to the fact that, for example, the combined 1984 construction budget for MCI and GTE-Sprint alone amounts to about 20 percent of AT&T's current net plant in its interexchange network.\(^{26}\) With such rapid growth of competing carrier facilities, AT&T estimates that its share of interstate capacity is only about 69 percent.

MCI rejoins that such capacity figures are misleading because AT&T overestimates the average terrestrial distance spanned by satellite circuits of its competitors, which constitute a large portion of AT&T's


estimate of their capacity. Taking a figure for average mileage which it judges more realistic, MCI estimates that AT&T's share of total capacity is approximately 86 percent rather than 69 percent.27

The above brief discussion is intended only to illustrate the kinds of arguments being thrown back and forth in the current debate. The FCC proceedings contain hundreds of pages in which these arguments and others are elaborated in great detail.

On the basis of the conflicting arguments, it is highly unlikely that AT&T will be fully deregulated soon. More likely is phased regulatory relief where current procedures for filing and defending tariffs will be gradually relaxed. After competing carriers have gained access equal to that of AT&T to most local exchange facilities (so that one can dial a number through a competing line as easily as dialing through an AT&T line), and after it is clearer that AT&T's market power has eroded, the prospects for full deregulation will be much brighter. Among other advantages of deregulation, the troublesome distinction between basic and enhanced services for AT&T (but not for the BOCs) would become moot. No longer would a need exist for keeping separate the activities of AT&T-C and AT&T-IS.

For purposes here the critical question relates to the implications for federal users of phased deregulation and ultimate full deregulation of AT&T-C. If they were affected at all, federal users would likely benefit rather than be harmed. If AT&T-C in fact has little or no market power, then the act of phased deregulation would, by definition, have no significant impact on prices. The most notable impact would involve AT&T's being able to respond more quickly to competitive initiatives by other carriers and to initiate its own new or modified services more quickly, once freed from the time delays and uncertainties arising from today's regulatory regime. If, in contrast, AT&T does have market power in a phased or full regime of deregulation, federal users would, if anything, benefit. Any price cutting that AT&T would undertake--of the sort alleged by competitors as predatory--would probably be directed toward large business and government users where the interexchange market is particularly competitive. If any groups

were disadvantaged, they would consist largely of residential and small business users with few competitive alternatives. Since federal agencies are among the largest users they would likely enjoy falling prices and better service offerings.

**IMPLICATIONS FOR DECISIONMAKERS**

Our earlier discussion of PBX vs. Centrex illustrated the importance of federal decisionmakers' monitoring state and local regulatory developments in making their procurement decisions. In addition, the above discussion of government regulatory policy highlights the need for close monitoring in four areas:

- **Access charges.** The subject of end-user access charges will remain a source of continued controversy, in part because decisions strongly affect politically vocal residential and other small users. Modifications in regulation access charges in response to these and other pressures, at both the state and federal level, will affect carrier revenue requirements and the amounts that large users, including federal agencies, must pay. Special access carrier charges, previously subject to much controversy, are now in place, so that in the near term at least federal users can proceed with relative certainty to the extent that these charges affect the prices they pay.

- **Bulk services.** We have seen very substantial restructuring of WATS rates in past years. No new significant developments are on the horizon, but federal users should take into account that the real cost of bulk service (and MTS) will decline during the coming years, as a consequence of the phase-in of end-user access charges, growing competition in transmission markets, and continuing rapid technological progress.

- **Private line services.** Although the FCC has approved AT&T's new private line rates, federal users must assume continuing change in this area and, as with bulk services, declining prices in real terms, especially for relatively long-distance traffic. Aside from the effects of AT&T's new tariff, the rapid growth of independent regional and national networks
(depending heavily on use of fiberoptics) will provide increasing capacity that will encourage lower prices.

• *Regulatory restrictions on carriers.* This will remain a topic of controversy for a long time to come, because (a) the distinction between basic and enhanced service is becoming increasingly blurred, and (b) concerns about cross-subsidization among services offered by regulated firms will persist so long as these firms have market power in the provision of basic services.
VIII. ASSESSING AND SATISFYING AGENCY NEEDS

In the preceding sections, we treated the technical and regulatory conditions that affect the supply of telecommunications services. We now turn to the final portion of this report and address methods of assessing agency needs and criteria for evaluating the relative merits of options for satisfying these needs, and provide a decisionmaking framework (capital budgeting) designed to encourage wise choices in the face of irreducible uncertainties about the costs and benefits of any particular option. More specifically, four topics are paramount:

- How the agency should assess its needs, within a telecommunications technology plan, including the kinds of usage data it should collect.
- What criteria it should use to select options for satisfying these needs.
- How the agency should compare the costs and benefits of these options under a common set of ground rules.
- What criteria it should use to rank options and to make final choices.

This section addresses the first two of these topics; Secs. IX and X are devoted to the last two.

ESTABLISHING A TELECOMMUNICATIONS PLAN

It is important, first, to emphasize that agencies should have a telecommunications plan that provides a framework into which individual investments can be placed in light of the agency's needs. The plan should have four major components that proceed from macro- to micro-level considerations.

The first involves a macro-assessment of needs based on the "requirements" and the "strategic" approaches discussed below. The second involves a gross comparison of telecommunications alternatives illustrated below in Table 8.1. The third involves analysis of more
specific options, based on evaluation criteria we discuss, as illustrated in Table 8.2. The fourth involves relating telecommunications services from specific options to the agency's output as a way to estimate the benefits of these options.

To be sure, this task is more difficult for government than for private firms, because the latter sell their outputs on the open market and, therefore, can more easily put a price tag on the inputs (including telecommunications) that are required to produce the outputs. Nevertheless, agencies must judge how various telecommunications options favorably affect programmatic effectiveness to develop estimates, even though crude, of the benefits of these options. Subsequently, these estimates of benefits, along with costs, feed into capital budgeting decisions discussed in Secs. IX and X.

THE NATURE OF NEEDS AND THEIR QUANTIFICATION

An agency's need for communications services can be viewed as an economic demand for an intermediate product. It derives from the demand for the agency's own services, its budget, and the prices for communications services.

Higher-quality, faster, and more automatic voice and data communications can almost always improve the quality of service that federal agencies provide. But "need" is also basically affected by telecommunications costs. At the extreme, if all communications services were available at no cost, agencies would see their needs as much greater than otherwise. A realistic assessment of need, therefore, cannot be undertaken without considering first the kinds of communications services that are available now and in the near future. It is for this reason that we have treated the multitude of topics relating to telecommunications supply before turning in this section to questions of need.

An agency's need for telecommunications services can be assessed from two different perspectives. The conventional approach is to consider requirements for communications and for office space in much the same way. Each provides essential resources needed by the agency's staff. Telecommunications requirements can be related to staff size, function, location and other related measures of the agency's
organization, and changes in these needs can be developed in terms of past trends in telecommunications use and expected changes in agency size and activities. This requirements approach works best when both the agency's own activities and the telecommunications environment is changing slowly.

However, at least some needs for telecommunications services can best be developed from a strategic perspective that reexamines the agency's mission. Many government organizations, for example, provide a variety of information services directly to the public or to other agencies as a central component of their overall mission. New technologies and changing costs of telecommunications services provide the opportunity to assess how an agency can best provide these services in the future. For this approach, longer-term strategic planning can be used to relate the agency's objectives to alternative technologies for delivering its services.

In general, agencies should use both strategic planning and traditional requirements approaches to obtain a satisfactory assessment of their telecommunications needs.

Requirements Planning and Collection of Data

The conventional approach to determining telecommunications needs is to collect statistics on an agency's current communications equipment and use, assess recent trends in these factors, and project the trends after adjusting for expected changes in principal agency activities--growth in staff, change in office locations, etc. This "requirements" approach is complementary to the strategic planning assessment discussed below. It provides necessary data on the extent and cost of the agency's present telecommunications activities and serves as a benchmark from which to assess alternatives.

To assess its communications requirements, the agency should assemble key statistics summarizing both current-year and recent patterns of its use of and expenditures on telecommunications services, the extent of capacity use, and indicators of service quality. These statistics should be accompanied by summary indicators of the agency's level of activities.
Most of the data on the quantities and costs of an agency's telecommunications services can be assembled from operating records kept by the agency's telecommunications manager. The service categories suggested below will be useful but other functional divisions of services could also serve. It is important, however, that the agency use a consistent classification of services and expenditures over a several-year period, so that changes in demands and service use will be correctly represented.

Expansion, replacement, and modification of an agency's telecommunications services frequently involve the introduction of new services that the agency has not previously used, a situation that complicates the comparison of needs and prior use. Where possible, the new services should be evaluated in terms of the equivalent existing services. For example, a proposed changeover from Centrex lines to a PBX can compare the number of Centrex lines (and cost per line) with the equivalent number of PBX main stations (and their cost per station). For higher-speed data communications lines, the comparison can be made in terms of cost per unit of data at the agency's average levels of use.

For totally new services, the agency should attempt to quantify the added benefits from new features in terms of cost reductions in other activities. For example, features such as call-forwarding, message-recording, and detail billing may provide cost reductions by increasing productivity and recovering costs of personal calls. Agencies should estimate both added benefits and costs of such options, using measures of their current traffic patterns.

Communications needs should be divided into three broad categories: access to voice networks, voice network services, and data network access and services. The principal statistical categories may be summarized in a few tables, as indicated in the following outline.

**Voice Access Equipment and Services.** Summary statistics should be tabulated for the most recent year, and several preceding years.
Major Service Categories

<table>
<thead>
<tr>
<th>Service</th>
<th>No.</th>
<th>Annual Rental</th>
<th>Price to User</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-line stations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Key telephone stations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main telephone lines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk lines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrex lines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBXs, by size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moves and changes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Service quality measures should be developed from agency records on:

- Average wait to fill order
- Repair/out of service frequency
- Frequency of busy-signals, separately for incoming and outgoing calls

Suitable indicators of agency activity are:

- Annual budget
- Number of personnel
- Number of offices, personnel/office

**Voice Network Services.** Summary statistics for voice services would include volume and cost data on major services. In addition, indicators of predominating calling patterns and communities of interest should be provided, where possible.

<table>
<thead>
<tr>
<th>Service</th>
<th>Units</th>
<th>Annual Cost</th>
<th>Price to User</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local area calls</td>
<td>Number, message units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDD calls</td>
<td>Number, hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Out-WATS</td>
<td>Hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-WATS</td>
<td>Hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCC calls</td>
<td>Number, hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private line</td>
<td>Miles, and hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FTS</td>
<td>Hours</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Utilization measures should be developed for the major types of services:
Local area calls  Annual calls/line or trunk
Long distance call  Minutes/employee
WATS, PL, FTS  Hours/line

Quality of service is primarily determined by use relative to available capacity and voice quality of circuits.

Data Network Access and Services. These services should be reported, to the extent possible, in the following categories. However, because of the wide variation of particular data communications installations, agencies should also report separately their major systems, with indicators of use, cost, and performance.

Virtual Networks

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>No.</th>
<th>Hours</th>
<th>Annual Cost</th>
<th>Cost/Minute</th>
<th>Price to User</th>
</tr>
</thead>
</table>

Private Networks

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>No. of Nodes</th>
<th>Mileage</th>
<th>Annual Cost</th>
<th>Price to User</th>
</tr>
</thead>
</table>

In the suggested tables both the annual costs to the agency and some indication of the charges levied on the individual users of the service within the agency should be determined.

From these baseline data, the agency should project the cost of meeting its future needs based on the costs of maintaining and expanding its existing telecommunications plant. This set of calculations provides the basis for one option, let us say Option A—that involves a simple expansion of its existing plant. Of course, this is only one of several possibilities that the agency should consider. The costs of expanding the present plant may be prohibitive, or the agency may overestimate the importance of its needs.\(^\text{1}\) Or many other ways may

\(^{1}\)Again, we must emphasize that "needs" cannot be satisfactorily estimated in a vacuum. They should be assessed in combination with careful consideration of the costs of meeting various kinds and levels of needs.
satisfy these needs as an alternative to simply expanding the old plant. These alternatives should be assessed within a framework that illuminates the key similarities and differences among them.

**Strategic Planning**

Strategic planning encompasses the broad range of an agency's mission and extends over perhaps five to 20 years. This longer-term perspective would, of course, assess the likely growth and change in the scale of the agency's major activities, including size of staff, location of major offices, and principal services.

In particular, the planning process should identify the principal agency activities that make significant use of information technology. These activities can be roughly divided into those that directly serve the public and those that are internal to the agency or are primarily directed to serving other government agencies.

For example, the Agricultural Extension Service provides technical information to farmers, the IRS provides taxpayer information to the general public, the Census supplies public-use copies of census data to research organizations. In addition, each of these agencies' activities require particular types of within-agency communications—to maintain current weather and crop data, to process and audit tax returns, to conduct and tabulate a census.

For each principal activity, the agency's strategic assessment should assemble data that indicate the benefits obtained from the current method of performing the activity and how these benefits would be changed by use of an alternative technology. Measuring the absolute benefits of the current system may be problematic, but it is essential to assess the incremental benefits that would be realized from an alternative relative to the benefits currently obtained.

Suppose agricultural extension offices had on-line access to computer-based expert systems for analyzing current crop and weather data and could respond to public inquiries either by voice telephone or personal computer connection. Such a system, by providing more timely and more specific information, could possibly increase farm productivity. The technology to provide such a system would perhaps include a regional or national data network and public access to a
component of the network through extension-office telephone numbers with low-speed data capability.

The strategic assessment may uncover several promising alternative methods of performing the activity. For each, the agency should estimate the increased value that would be expected to result. At the same time it will need to assess the changes in cost that would be required.

A Matrix of Strategic Options

As the first step in constructing a framework for longer-term strategic planning, we present here a matrix that relates to a key variable: As emphasized in Sec. II, the single most important dimension that distinguishes among the various telecommunications options is the extent to which the agency takes responsibility for the acquisition and operation of its telecommunications services. To bring together the assessment of the needs described above, and these options for satisfying them, the user should consider the following kinds of options that reflect varying degrees of ownership and management.

1. Buy and operate its own PBXs—a capacity purchase.
2. Share a specific switch with others at a contract price (e.g., Centrex, CCSA)—a contract purchase.
3. Buy switching by the call (ordinary switched service, SDN)—a usage-priced purchase.

Similarly, with respect to transmission, the user can:

1. Build or buy dedicated transmission capacity such as private microwave—a capacity purchase.
2. Share dedicated transmission capacity with others by opting for leased lines at a fixed price—a contract purchase.
3. Buy transmission by the call (e.g., WATS)—a usage-priced purchase.
These alternatives are arrayed in a matrix shown in Table 8.1. Each cell corresponds to a different degree of user control over switching or transmission, and the extent to which costs are fixed. For example (upper left), a user can build a private network by building transmission links (fiber, private microwave) and coupling them with user-owned PBXs and tandem switches. Alternatively (lower right), the user can take advantage of software defined networks that provide a high level of custom services but share facilities with the regular public network priced by the call.

Which combination is best for a particular organization depends upon a number of factors, including:

1. Whether network traffic patterns and prevailing tariffs make usage-based or capacity-based pricing more attractive.
2. The particular capabilities of specific switching or transmission alternatives.
3. Whether the option provides the user with the desired level of managerial control over his telecommunications system; or conversely, whether the organization is willing to assume the burden of managing its telecommunications system.

Table 8.1
USER CONTROL OVER TRANSMISSION AND SWITCHING COSTS

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Own Switches</th>
<th>Contract Switching</th>
<th>Buy Switching Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own transmission links</td>
<td>PBX, tandems, plus user-owned</td>
<td>Centrex and CCSA plus user-owned</td>
<td>Bypass access to virtual network</td>
</tr>
<tr>
<td></td>
<td>transmission</td>
<td>transmission</td>
<td></td>
</tr>
<tr>
<td>Contract transmission links</td>
<td>PBX, tandems, plus leased line</td>
<td>Centrex and CCSA plus leased line</td>
<td>Leased line access to virtual network</td>
</tr>
<tr>
<td></td>
<td>network</td>
<td>network</td>
<td></td>
</tr>
<tr>
<td>Buy transmission services</td>
<td>PBX, tandems, plus WATS virtual</td>
<td>Centrex plus WATS</td>
<td>Public switched access to virtual</td>
</tr>
<tr>
<td></td>
<td>networking</td>
<td></td>
<td>network</td>
</tr>
</tbody>
</table>
This is indeed a wide range of possible options, and preliminary analysis should concentrate on assessing only major cost elements and key differences in benefits to eliminate inferior combinations. The most promising of the options (or variants of these options) can then be evaluated in terms of costs and benefits by applying more detailed evaluation criteria, to which we now turn.

EVALUATION CRITERIA

The following are suitable criteria for assessing the costs and benefits of the major options that are in serious consideration after the preliminary strategic analysis of the full range of possibilities.

- Cost, including initial investment, subsequent investments, and recurring operating and maintenance expenses.
- Performance, including reliability, responsiveness, upgradeability, and security.
- Organizational impact, including staffing requirements, ease of use, and user support.
- Systems management capability, including switch operation and management, operational management, provisioning, and administration.
- Risk to the agency.

Issues relating to the first category--cost--will be treated at length in Secs. IX and X. The penultimate category--system management capability--has already been treated in Sec. II. The purpose here is to discuss criteria for evaluating the remaining three--performance, organizational impact, and risk.
Performance Criteria

Performance criteria reflect not only the technical sophistication of the system's design but the ability of the vendor (or user) to provide the level of product service and maintenance necessary to assure system availability and reliability. Because performance is dependent, in part, on ongoing service from the vendor, the rating of a system on this dimension may change over the life of the system—changes difficult to anticipate. However, the decisionmaker can survey current users of the system to determine the adequacy of the vendor's current level of support and, assuming no future serious problems for the vendor, extrapolate this level of user satisfaction into the future. If the user is considering undertaking product service and maintenance itself, a survey of similar users is especially important to determining the likely problems that might be encountered, the level of in-house expertise required, and the savings that might be expected.

In any case, performance criteria will combine straightforward design performance measures (mean time between failures) and subjective judgments of the reliability of the organization that undertakes the ongoing system maintenance and management. These subjective judgments are unavoidable when assessing a system as complex as a communications network.

We now turn to specific performance criteria, including system reliability, vendor (or, if self-maintained, user) responsiveness, upgradeability, and system security.

Reliability. To determine reliability, measure the availability of the system and features to users as a function of the level of user demand (time of day and peaking) and mix of services demanded (level of data transmission for switches such as PBXs). Maintainability, including self-diagnosis, ease of fault location and repair, speed of system recovery after a failure, and modularity of hardware and software design are also key elements of overall reliability. A basic benchmark for reliability is mean time between failures (for systems with a reasonably long track record).
Responsiveness. This feature is heavily influenced by the capabilities and professionalism of the organization that manages the communications system. The speed with which system problems and requests for reprovisioning of features are handled is obviously important to overall system usefulness. For example, innovative designs (e.g., private line reconfiguration from terminals located on the user's premises) can enhance system responsiveness by decoupling system operational control (day-to-day service needs) from system maintenance (long-term system "health"). If the manufacturer is also the system manager, synergies can develop between responsiveness to current users needs, awareness of unmet needs, and the ability to develop new products and services to better meet future needs. Measures of responsiveness performance include average wait for service request, ability of the system manager to anticipate and prevent problems, size and time-of-day coverage of maintenance staff, and availability and adequacy of user training.

Upgradeability. This feature reflects the ability of the system to respond economically to user growth, changing user needs, and improved technology. From the user's viewpoint, a service will have advantage in incorporating new technology (provided the vendor is sufficiently well-financed to supply advanced services), whereas a user-owned system may more readily respond to user growth (if the system permits growth over a wide size range and capturing economies of scale is not possible through nonuser-owned systems). Measures of upgradeability include cost per unit (minute of use, line, etc.) as the system expands, cost of add-on services (versus basic services and equipment), commitment of the manufacturer or vendor to providing upward compatibility (incorporating new technology into existing designs), and financial strength of the manufacturer or vendor.

Security. This focuses on the system's ability to provide secure communication facilities. The ease with which encryption can be added or the inherent security from interception are important ingredients. For example, it is difficult to tap an optical fiber but easy to intercept a satellite channel. If encryption is to be added, comprehensive support for key management is a prime consideration.
Organizational Criteria

Two decisionmaking criteria are important here—staffing and training requirements resulting from the purchase of a communications system or service.

Staffing Requirements. As communications systems become more complex and subject to the demands of rapidly changing technology, the burden on in-house (user) staff increases. Well-informed purchase of a communications system, or selection of communications services, requires a high level of technical knowledge and management skills. Moreover, the need for continuous user support and for system management put an even higher continuing demand on in-house skills and the agency's ability to attract and retain knowledgeable communications professionals. Because such individuals are scarce and can therefore demand high compensation, government agencies can often afford their services only on a consulting basis. Thus, these agencies may be unable to staff a full-time communications management center.

The severity of the problem of obtaining in-house skills depends in part on the agency's basic mission, since some agencies have more synergies between their main business and their in-house telecommunications skills than others. Thus, those heavily engaged in the telecommunications or information processing businesses, such as the National Aeronautics and Space Administration or the Internal Revenue Service, probably face a less difficult task than many other agencies of assembling in-house management skills for advanced telecommunications systems.

In any event, options are available to retain many of the benefits of in-house expertise while recognizing the limits of the government's ability to staff high-paid positions. These could include managing some segments of the communications system while purchasing others (e.g., managing intra-building and campus communications while purchasing long-distance service) or using third-party managers (e.g., buying bulk long distance and using outside managers to develop value-added services).²

²Some agencies may have more leeway to attract and pay communications professionals. Thus, not all agencies need to behave identically in meeting this problem.
Ultimately, however, the agency cannot delegate all responsibility for telecommunications to third parties, especially as telecommunications and information technology become more essential to fulfilling an agency's missions. Agencies should anticipate increasing the quantity and quality of their telecommunications staff in the present environment if only to provide the expertise needed to make intelligent choices among the available alternatives.

In any case, staffing requirements impose severe limitations on government communications systems buyers. Before any product or service decision is made, the impact on government (or agency) staffing policies and current staff mix should be evaluated.

**Ease of Use and User Support.** As telecommunications systems become more complex and more diverse in their capabilities, the time required to learn how to make best use of the system becomes greater. Moreover, if users find it difficult or impossible to master the use of advanced services because they are not "user friendly," capabilities will go unused and real value will fall far below the potential.

Where systems are complex, agency personnel--whether all users or only systems managers--must be trained. Thus, support for teaching and training must be part of the overall procurement evaluation. Documentation, training courses, and video-based instruction must all be assessed. In most cases, vendors of equipment and services provide initial training and offer an ongoing training contract. For a large system, in-house training may provide significant cost savings. Regardless of which organization provides the training, more end-user time and effort will be involved if the system is difficult to learn and use. Thus, in selecting communications procurements, both the training and learning requirements should be considered.

**Risk**

Telecommunications managers are all too familiar with the problem of vendors falling short of their promises, especially in promoting new and advanced hardware. Moreover, the ability of the agency to handle the risks involved in the prospective procurement—including the quality of in-house management expertise or the reliability of management groups
brought in from the outside--can raise serious questions. Consequently, risk is paramount as a decision criterion. While this dimension is difficult or impossible to quantify, it should be possible to rank options by the degree of risk or to assign ratings such as "low," "medium," and "high." These ratings would be based, in part, on the track record of the proposed vendor, as discussed earlier under the performance criterion. These risk scores can be combined with assessments of the other criteria discussed above in an evaluation matrix, to which we now turn.

AN EVALUATION MATRIX OF OPTIONS

The five major evaluation criteria--cost, performance, organizational impact, system management capability, and risk--and other subcategories provide the basis for comparing an agency's leading telecommunications options. For each option the evaluation procedure should assemble at least basic statistics on the various subcategories. Cost data should be available for every option. We discuss in the next section how to compare investment, operating, and leasing costs of different options). Benefits, if they can be quantified, will take the form of changes in performance, such as average wait for a station change or move or ability to encrypt data. Where possible, these benefits should also be translated into dollar measures by estimating their effect on agency productivity, change in staffing requirements, and value to the public of a change in agency responsiveness.

However, quantifying benefits is not easily accomplished and for some criteria may not be realistic. For most purposes it is sufficient to estimate the change in benefits that would be realized by selecting a particular option relative to the current level of benefits. Using these criteria, we can construct the matrix, shown in Table 8.2. On the left are ranked the several categories of cost, reliability, responsiveness, and the other criteria discussed above and in Sec. II. The options are arrayed along the top. (Option A, for example, might involve a PBX, tandems, and user-owned transmission shown in the upper left cell of Table 8.1.)
Table 8.2

EVALUATION MATRIX FOR SPECIFIC OPTIONS

<table>
<thead>
<tr>
<th></th>
<th>Option A</th>
<th>Option B</th>
<th>...</th>
<th>Option n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
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<td></td>
<td></td>
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<tr>
<td>Performance</td>
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<tr>
<td>Reliability</td>
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<tr>
<td>Responsiveness</td>
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<tr>
<td>Upgradeability</td>
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<tr>
<td>Security</td>
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<tr>
<td>Organizational Factors</td>
<td></td>
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<tr>
<td>Staffing needs</td>
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<tr>
<td>Ease of use and user support</td>
<td></td>
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<tr>
<td>Systems Management</td>
<td></td>
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<tr>
<td>Switch operation</td>
<td></td>
<td></td>
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<tr>
<td>and management</td>
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<tr>
<td>Operations management</td>
<td></td>
<td></td>
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<tr>
<td>Provisioning</td>
<td></td>
<td></td>
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<tr>
<td>Administration</td>
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<tr>
<td>Risk</td>
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<tr>
<td>-(score separately each of the above items)</td>
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</tbody>
</table>

Table 8.2 can then be used to compare the costs and benefits of the various options. The matrix can represent the costs and benefits of each option in one of two forms. If the data are for the actual amounts of costs and benefits that each option would provide, the matrix should include the agency's current telecommunications configuration as one additional option--the "no-change" option. Alternatively, the options and data can represent the incremental costs and benefits of changing from the current configuration to a new system. An agency may be better able to estimate the change in benefits it can anticipate for each criterion of a new system than it can value the total level of benefits. If the evaluation matrix is used in this incremental form, the cost entries would then measure the costs net of the costs of the current configuration.
Two points are especially notable with respect to evaluation. First, although comparing incremental costs and benefits is a useful analytical approach, one must guard against the opportunities for "gaming" an analysis to justify a predetermined result. To illustrate, suppose that a particular basic option (say a PBX) shows overall costs that exceed benefits, but the agency nevertheless prefers that option to others for unjustified reasons. It might seek to defend the option on grounds that incremental benefits outweigh its incremental costs for adding to service under the basic option (say purchasing the basic PBX with upgraded features). Whether the option should be selected on economic grounds would depend on whether an irreversible commitment has been made to the option. If so, incremental analysis would be irrelevant since, for better or worse, the agency has made a mistake (here by purchasing the PBX) and, by definition, nothing can be done about it. However, if the procurement can be reversed, the overall cost and benefit comparisons are relevant. For this reason, it is important to examine both overall and incremental costs and benefits and, in unfavorable cases, to determine whether commitments are reversible.

Second, the last item in Table 8.2—risk—is especially notable. As a general rule, the "value" of telecommunications services is greater than its costs (except at the margin). The "cost" of a phone system failure can overshadow the ongoing costs of operating and maintaining the system. Consequently, many telecommunications are designed less to minimize costs than to minimize the chance of a system failure. Thus, it is important for the agency to devise a contingency plan for each of the options depending on the degree of risk associated with each.

In the following two sections, we provide a decisionmaking framework within which estimates from Table 8.2 are incorporated—taking special account of the problems of quantification, uncertainty, and contingency planning.
IX. CAPITAL BUDGETING AND DECISIONMAKING

After all of the above considerations have been taken into account, the key question remains about how the data and other information should be put into an analytic framework that will contribute to sound final decisions. Our recommendation is to use principles of capital budgeting applicable to both private sector firms and to government organizations. To be sure, decisionmaking procedures are different in the federal government from those in the private sector. Moreover, the government correctly looks at costs without regard to taxes, whereas private firms focus on after-tax expenditures. But the criteria for making decisions are basically the same. In both cases it is important to consider all the costs (defined in the manner relevant to the organization, be it public or private), and it is important to identify and quantify benefits if possible. The objective in both the public and private sectors should be to select options whose benefits exceed their costs and, in the case of competing options, to select the one that shows the greatest overall difference between benefits and costs.

In the remainder of the study we discuss in detail a framework within which such options can be compared under a common set of ground rules, taking into account the many difficulties, including uncertainties about costs and benefits that almost always arise to one degree or another in quantitative comparisons.

Under some circumstances, the decisionmaking process is straightforward. Suppose the agency faces two alternative and mutually exclusive procurements, A and B. Both involve no initial investment cost, but they have a constant annual cost—a situation characteristic of equipment rentals, as one possibility. Suppose further that the benefits are judged to be the same for A and B and large enough to justify procuring either A or B. Under these circumstances, the decision between them would depend merely on which one has lower annual costs. Or suppose that A and B have the same annual costs but that A requires an initial investment but B does not. Here the decision clearly lies in favor of B.
But usually the situation is clouded by numerous complications including (a) options with varying combinations of operating and maintenance costs, investment costs, benefits, and lifetimes, (b) options that are not mutually exclusive, (c) price changes caused by inflation and other forces, (d) uncertainty with respect to benefits, costs, and other factors, and (e) constraints on agency budgets.

In these cases, procurement decisions should be made by evaluating options under a common set of ground rules. Although several analytic procedures are available, the "present value" approach is widely used because it avoids problems associated with others.¹

The purpose of this section is to show why present value analysis should be used, taking into account numerous complications. To do so, it focuses on three areas:

- How to carry out present value calculations, illustrated by actual cost estimates provided by one of the companies we interviewed that faces an acquisition decision (to procure a new PBX) similar to those confronting many federal users.
- How to identify and choose among options either complementary to or independent of each other, as well as those that are mutually exclusive.
- How to rank and select projects when the agency faces budgetary constraints on current-year procurement—a situation of "capital rationing."

¹One notable alternative is the "internal rate of return" approach that, however, can lead to more than one solution or to erroneous solutions. For this reason, we focus only on the present value approach. More detailed discussions of capital budgeting can be found in many places. A particularly good treatment is contained in Jack Hirshleifer, James C. De Haven and Jerome W. Milliman, "The Practical Logic of Investment Efficiency Calculations," Ch. VII, Water Supply, Economics, Technology and Policy, University of Chicago Press, 1960.
PRINCIPAL ELEMENTS OF PRESENT VALUE CALCULATIONS

The net present value of a project is given by: (a) the sum of discounted benefits during the life of the project, plus the discounted salvage or tradein value of assets at the end of the project's life, minus (b) the initial investment cost plus the sum of discounted costs incurred during the life of the project.

The sum of discounted costs--or the present value of the time stream of costs--is given by

\[ C_0 = I_0 \]
\[ = c_1/(1 + i) + c_2/(1 + i)^2 + \ldots + c_n/(1 + i)^n - S/(1 + i)^n \]  \hspace{1cm} (9.1)

where \( C_0 \) is the present value of the cost stream; \( I_0 \) is the investment cost incurred at the outset (period 0--the very start of period 1); \( c_1, c_2, \ldots, c_n \) are costs incurred at the end of each successive period (i.e., at the end of year 1, 2, \ldots, n, if the year is the period used); \( i \) is the interest rate or discount rate; \( n \) is the last period in which the acquisition has any effect (i.e., the end of the project's life); and \( S \) is the salvage or tradein value of assets at the end of the project's life.

If the cost incurred each period is constant (\( c = c_1 = c_2 = \ldots = c_n \)), a simplified formula for computing the present value of the cost stream is given by

\[ C_0 = I_0 + \frac{c[(1 + i)^n - 1]}{i(1 + i)^n} - \frac{S}{(1 + i)^n} \]  \hspace{1cm} (9.2)

where \( c \) is equal to \( c_1, c_2, \ldots, c_n \).

The present value of the benefit stream, denoted by \( B_0 \), is computed using the same formulas, with the benefit terms \( b_1, b_2, \ldots, b_n \) substituted for the cost terms \( c_1, c_2, \ldots, c_n \), and with \( I_0 \) and \( S \) deleted.

The net present value of the acquisition, \( V_0 \), is given simply by the difference between the present value of benefits and of costs, i.e.,
\[ V_0 = B_0 - C_0 \]  

(9.3)

or alternatively

\[ V_0 = -I_0 + \frac{NB_1}{(1 + i)} + \frac{NB_2}{(1 + i)^2} + \ldots + \frac{NB_n}{(1 + i)^n} \]  

(9.4)

where \( NB_1, NB_2, \ldots, NB_n \) are equal to the differences between benefits and costs in each period, and \( NB_n \) includes the salvage value of remaining assets.

Only if the net present value, \( V_0 \), is positive should the acquisition be made. If mutually exclusive acquisitions are being contemplated, the one with the highest present value should be selected.

**AN ILLUSTRATIVE EXAMPLE**

To illustrate how present values are computed and used, we draw on actual calculations given to us by one of the companies we interviewed (Company X). This case treats a specific acquisition decision similar to those faced by many government users. In addition, it identifies omissions in the company's analysis to show pitfalls that others should avoid.

Company X is considering replacing existing step-by-step PBX switching service and rotary dial telephone equipment (all rented from the local telephone company) with procurement of a digital PBX and a mixture of digital and analog telephone instruments. Its analysis is complicated by the fact that Company X may vacate its existing quarters in perhaps four years, in which case portions of its new investment must be either moved or abandoned. It assumes that the new PBX and associated equipment have a useful life of 10 years and can be moved to the new location but that cable plant would have to be abandoned with no salvage value at the time of the move. The company's analysis is shown in Table 9.1.

Because benefits are so difficult to quantify, as discussed in Sec. III, Company X did not attempt to place a price tag on them. Rather, it concluded that the additional benefits of the digital PBX system are
Table 9.1

COMPANY X’S MONTHLY COST COMPARISONS:
EXISTING SERVICES AND NEW PROCUREMENT
(1400-Line System)

<p>| | |</p>
<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing step-by-step switch and rotary dial:</td>
<td></td>
</tr>
<tr>
<td>Switch and equip. (rent and maint.)</td>
<td>$24,966</td>
</tr>
<tr>
<td>Moves and changes</td>
<td>2,213</td>
</tr>
<tr>
<td>Other</td>
<td>1,902</td>
</tr>
<tr>
<td>Total Monthly Expense</td>
<td>$29,081</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proposed digital PBX system:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PBX and instruments ($1,377,000 est. cost)</td>
<td>$18,194</td>
</tr>
<tr>
<td>10 year lifetime at 10% interest</td>
<td>6,343</td>
</tr>
<tr>
<td>Maintenance</td>
<td>1,106</td>
</tr>
<tr>
<td>Moves and changes</td>
<td>1,000</td>
</tr>
<tr>
<td>Equip. upgrade and exchange</td>
<td></td>
</tr>
<tr>
<td>New cable plant and site preparation</td>
<td></td>
</tr>
<tr>
<td>($292,000 est. cost)</td>
<td></td>
</tr>
<tr>
<td>4-year, straight line depreciation</td>
<td>6,083</td>
</tr>
<tr>
<td>Total Monthly Expense</td>
<td>$32,726</td>
</tr>
</tbody>
</table>

Note: The tax consequences facing Company X are not taken into account here, since they would be irrelevant for federal users.

larger than the estimated increase in monthly cost, shown by the difference between the $32,726 and $29,081 figures in Table 9.1. Among the important factors is that the continued growth of Company X is straining the capacity of its existing PBX. Moreover, Company X, having faced a 10 percent increase in rates charged by its telephone company within the last two years, concluded that procurement of the new system would protect it from such future price increases. On that basis, Company X has decided to issue a request for proposal to a set of qualified vendors of the new system.

However, three problems arise in the comparisons in Table 9.1, a discussion of which carries useful lessons for others facing similar decisions. First, Table 9.1 does not account for training personnel to use the new system or for costs of delays and disruptions caused by cutting over and debugging it. This omission illustrates the importance
of considering all costs associated with the acquisition. Unfortunately, it is easy to lose track of costs for design, transition and start-up, user support, system management, and space requirements (or savings) and building upgrades required for new equipment. Frequently, such costs are embedded in the monthly rental prices local telephone companies charge for their existing services. Company X should account explicitly for these elements to avoid underestimating the overall costs of going to its own system. Of course, federal users facing similar situations should do the same.

Second, the investment in new cable plant and site preparation is spread over a four-year period without the inclusion of interest—in contrast to the treatment of the PBX and associated equipment that is calculated with an interest rate of 10 percent. Company X justified this difference in treatment on grounds that it would probably pay cash for the relatively small investment in cable plant and site preparation, whereas it would have to borrow funds for the PBX and other equipment. Clearly, however, this line of reasoning is defective. Money has an "opportunity cost" regardless of whether expenditures come out of cash or from borrowings. Because the company forgoes the interest it could otherwise have earned on cash that would be invested in cable plant and site preparation, this investment should include an interest charge, in the same manner that an interest charge is included for acquisition of the PBX and associated equipment. The constant monthly expenditure, beginning one month after the initial investment, required to cover the investment cost of $292,000 plus interest at 10 percent can be calculated from the formula

\[
p = \frac{I_0[i(1+i)^n]}{(1+i)^n - 1}
\]

(9.5)

where \( P \) is the constant monthly expenditure, \( I_0 \) is the initial investment, \( i \) is the interest (or discount) rate (here 10 percent per year or 0.00833 per month), and \( n \) is the number of periods (here 48). The estimate of \( P \), calculated from Eq. (9.5) is $7406—somewhat greater than the figure of $6083 shown in Table 9.1.2

2Equation (9.5) is also used to compute the figure of $18,194 in
A third problem with the comparisons in Table 9.1 is the failure to account for differences in lifetimes between the investment in the PBX--estimated at 10 years--and the investment in cable plant--estimated at four years. The PBX (and associated equipment) would be useless during the last six years of its life, after it is moved to its new location, without the construction of new cable plant. (We will return to the question of the economic lifetime of an investment later in this section.)

When the company moves to its new location it will have to either acquire a new PBX system or relocate the previously acquired digital PBX. In either case it will incur the costs of new cable plant for the new site, so that cost is immaterial to the comparison. Given that the move occurs in four years, the PBX investment can be evaluated on a four-year basis by including its economic value to the firm at the end of that period. The evaluation of economic lifetime, as contrasted with physical lifetime, will be discussed below. For illustrative purposes, we shall use straight-line depreciation and estimate the remaining value of the PBX (and associated equipment) at the end of four years at 60 percent of $1,377,000 or $826,200.

To account for both the initial investment and its value at the end of four years (48 months) we make present value estimates on the basis of the formula shown in Eq. (9.2) (where \( n = 48 \) and \( i = .00833 \)). For the existing system--whose monthly estimated cost is $29,081 as shown in Table 9.1--the present value is $1,147,129 (with \( I_0 = 0 \)) as shown in Table 9.2. The present value for the proposed system is $1,347,450 also shown in Table 9.2.

Table 9.2 shows that the proposed system is about 17 percent more expensive than the existing system (without including transition and other costs noted earlier), in contrast to the 13 percent difference computed from the monthly figures in Table 9.1. This difference in

Table 9.1 for the PBX and associated equipment, where \( n \) is equal to 120 and \( I_0 \) is equal to $1,377,000.

To avoid complicating the illustration we assume that the firm knows that it will relocate in four years. A more complete analysis would recognize this uncertainty by evaluating the PBX acquisition under alternative lengths of life for the cable plant.
Table 9.2

REVISED COST COMPARISONS BETWEEN EXISTING AND PROPOSED SYSTEMS
(48-Month Timespan)

<table>
<thead>
<tr>
<th></th>
<th>Present Values</th>
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<tbody>
<tr>
<td><strong>Existing System</strong></td>
<td>$1,147,129</td>
</tr>
<tr>
<td><strong>New System</strong></td>
<td></td>
</tr>
<tr>
<td>PBX and instruments</td>
<td>$1,377,000</td>
</tr>
<tr>
<td>Cable plant and site prep.</td>
<td>192,000</td>
</tr>
<tr>
<td>Monthly constant costs ($8449)</td>
<td>333,280</td>
</tr>
<tr>
<td>Salvage value</td>
<td>-554,830</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$1,347,450(^a)</td>
</tr>
</tbody>
</table>

\(^a\)This figure is computed from Eq. (9.2), where \( I_0 \) is equal to $1,377,000 plus $192,000; \( c \) is equal to $8449--the estimates of constant monthly costs for maintenance, moves and changes, and equipment upgrade and exchange, taken from Table 9.1; and \( S \) is equal to the remaining value of the PBX and instruments, assumed to be $826,200.

Relative cost arises, as discussed earlier, because of failure (a) to include an interest or discount rate on the investment in cable plant and site preparation, and (b) to adjust investments to account for differences in lifetimes.

Of course, this analysis does not necessarily mean that Company X should not procure the new system. But it does mean that the benefits from the procurement will have to be greater than the minimum that would be necessary to justify the new system on the basis of comparisons presented in Table 9.1.

Three variables that enter into present value calculations, included in the earlier equations and illustrated by the experience of Company X, are particularly important for discussion here: the discount rate to be used, the treatment of inflation, and the calculation of project lifetime.
THE DISCOUNT RATE

An obviously important factor is the particular discount rate chosen for estimating costs and benefits. For example, if Company X had used an interest rate of 15 percent instead of 10 percent, our present value analysis would show the proposed system to be 28 percent more expensive than the existing system, rather than 17 percent more expensive. Conversely, a discount rate below 10 percent would reduce the differential. These results would be even more sensitive to the discount rate if the lifetime of the investments being considered were extended beyond the relatively short four and 10 years to 15 years. Figure 9.1 shows how present values are increasingly sensitive to the discount rate chosen as the lifetime of the project is lengthened.

Much debate has focused on issues of which discount rate is the most appropriate—without general agreement. The discount rate for evaluating a stream of costs and benefits of a government project can be based on either (a) consumers' subjective rate of time preference, or (b) the opportunity cost of resources invested in the private sector. Consumers lend funds and forgo current consumption by purchasing government bonds, in return for a higher rate of return in the future. After adjusting for the expected rate of inflation, the real rate of interest on government securities is one measure of consumers' rate of time preference. Real rates of return on government bonds have ranged from about 3 to 6 percent.

The second method is to base the choice of the discount rate on the opportunity cost of resources invested in the private sector. In a full-employment economy, any increase in public sector investment will require a corresponding reduction in private sector spending. If society's resources are to be used efficiently, the rate of return on the additional public spending should be equivalent to the rate of return that is forgone in the private sector. However, to cover corporate income taxes and the risk of loss to lenders and investors in private securities, the rate of return on private investment must be

"See, for example, the discussion by W. J. Baumol, "On the Social Rate of Discount," American Economic Review, Vol. 58, September 1968, pp. 788-802."
considerably greater than interest rates on government bonds. Thus, a
discount rate based on the opportunity cost concept will tend to be
higher, in the range of 10 to 15 percent.

To encourage consistency in decisionmaking by federal agencies, OMB
"prescribes a standard discount rate to be used in evaluating the
measurable costs and/or benefits of programs or projects when they are
distributed over time." This discount rate is prescribed at 10 percent
in real terms, which "represents an estimate of the average rate of
return on private investment, before taxes and after inflation."

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6Ibid., p. 4.
INFLATION

It is essential to compare costs and benefits in different years of a project under a common assumption about changes in the general level of prices. Either of two approaches may be used. Costs and benefits can be calculated in current (nominal) dollar amounts by projecting the rate of inflation for each year of the acquisition. For example, if general prices are expected to increase 4 percent per year, then operating and maintenance expenses, future investment expenditures, and the value of service benefits should be increased by 4 percent each year above the level they are expected to be in real terms.

Alternatively, constant (real) dollar amounts can be used for the comparison. In this case the per-unit cost of expenses would change in future years only if prices, adjusted for inflation, are expected to change. For example, future equipment purchases might be assumed to have a lower per-unit real cost, based on recent trends, but real operating and maintenance expenses would be projected to be stable or rising.

For government agencies, OMB has prescribed the second alternative--to express all estimates in constant dollars.

All estimates of the costs and benefits for each year of the planning period should be made in constant dollars; i.e., in terms of the general purchasing power of the dollar at the time of decision. Estimates may reflect changes in the relative prices of cost and/or benefit components, where there is a reasonable basis for estimating such changes, but should not include any forecasted change in the general price level during the planning period.7

Company X also follows this approach, since it does not use cost escalation factors in its analysis. However, one key point must be noted. One reason Company X is planning procurement of its own PBX is to protect itself against future price increases by the local telephone company. Prices have increased in the past for Company X and it believes that the trend may continue in the future.

7Ibid., p. 3.
However, Company X must bear in mind the three possible sources of price increase: (a) general inflation, (b) increases in telephone company real costs, and (c) regulatory policies permitting price increases of some telephone services and price decreases elsewhere. Increases in the prices of telephone services due to general inflation have already been accounted for in Company X's analysis, because it has compared costs of the present system and its alternative in real terms.

The second possibility—increases in telephone company real costs—is unlikely. In the face of technological advance, costs will likely go in the other direction. Thus, Company X needs to be aware that although telephone company prices have risen in the past (in part due to general inflation), this situation may not continue into the future.

The third possibility—structured telephone company prices—is to be taken seriously. Consequently, Company X should assess regulatory developments at the state and federal level to determine the likelihood of changes in telephone company prices for its existing services. If changes are judged to be likely, their effects should be included in the analysis illustrated in Table 9.1. If it is impossible to determine the likely changes that might occur, Company X's analysis could remain as is. But in this case Company X should not place weight on likely telephone company price increases as a reason for going to its own PBX. For under the circumstances described here, it would have no more reason to expect price increases than to expect price decreases for its existing services.

We will discuss in more detail the above possibilities of price increases, and implications for federal users, in Sec. X where we focus explicitly on problems of coping with cost, and other uncertainties, in future procurements.

ESTIMATES OF ACQUISITION LIFETIME AND REPLACEMENT

Of obvious importance are assumptions about lifetime. If Company X had assumed a 10-year lifetime for the entire proposed new system (including the cable plant) in Table 9.2, its present value would be essentially the same as that of the existing system. Thus, federal users should pay close attention to estimates of acquisition life in their sensitivity analyses.
In doing so, they must be careful to focus on economic rather than physical lifetime. But the concepts of both physical and economic life are not easy to grasp. For example, a PBX could be made to last indefinitely if one were willing to spend a sufficient amount for maintenance to keep it going. What criteria should one use to define and judge economic lifetime? And how should decisions be made once estimates of economic lifetime are available?

In answering this question, one must avoid pitfalls that can bias decisions. In the typical case, the lifetime of a new (or existing) investment is assumed to end at the point where the investment is replaced by some other option. For example, although the physical lifetime of the new investment might be, say, 20 years, the lifetime used in present value calculations might be only five years, for example, if the investment is expected to be replaced at that time because of rapid technological advance. Under these circumstances, it would be erroneous to take the relevant lifetime as longer than five years because decisions would be biased toward investing in technologies soon to become obsolete. The problem, then, is (a) to decide whether the relevant lifetime is five years, or some other number, and (b) to treat properly the value of the investment that will be used as the replacement. We will show how use of erroneous decisionmaking criteria in coping with this problem can cause a bias toward either uneconomically postponing decisions to adopt new systems, or prematurely acquiring new systems.

To illustrate, we consider three cases: (a) a decision about a single option when costs and benefits are known with certainty; (b) a decision about two options, when the first may be adopted, and then may be replaced by the second after a specified time, when costs and benefits of both are known with certainty, and (c) a decision about the two options when costs and benefits are uncertain.
Case 1: A Single Option, No Uncertainty

Consider a single option, A, the decision to invest in a new system today (or to continue to use an existing system). We assume that the flow of benefits from Option A is constant over time (b_1 = b_2 = \ldots b_n from Eq. (9.2)) whereas the annual operating and maintenance costs of using the system rise over time (c_1 < c_2 \ldots < c_n in Eq. (9.1)) as the system ages. The situation is illustrated in Fig. 9.2. For this example, we assume that all of the investment, I_0, occurs when the system is adopted, and that benefits and annual costs are first realized a year later. We could assume that the Option A has a finite physical lifetime, i.e., that the system simply "dies" at the end of year 13 as shown in Fig. 9.2. But we could as well assume that the system continues indefinitely beyond year 13 with ever-increasing operating and maintenance costs.

Figure 9.3 shows the net benefits (b_i - c_i) of Option A, which necessarily decline over time as operating and maintenance costs mount. (b_1 - c_1 > b_2 - c_2 > \ldots > b_n - c_n). The key point is that net benefits fall to zero in year E (here, year 9). At that point, the system should be scrapped, even if it is not replaced, because the continuing benefits of using it are not sufficient to justify incurring the increasing operating and maintenance costs. We define the economic lifetime as the length of time during which annual benefits exceed annual costs. Thus, in Fig. 9.3 the economic lifetime ends at year E. Figure 9.4 shows a smooth curve that connects the lines in the preceding figures to show the continuous flow of net benefits that will facilitate subsequent comparisons.

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*If Option A involves continuation of an existing system, I_0 would not appear in period zero but rather we would start in year 1 with the continuing stream of annual benefits and costs shown in Fig. 9.2.

*If either, or both, benefits and costs fluctuate over time, rather than remaining constant or continuously declining, it is necessary to define economic lifetime more generally, in terms of present value. Economic lifetime extends to the point at which the present value of remaining net benefits falls to zero.
Fig. 9.2—Benefits and costs of Option A

Fig. 9.3—Net benefits of Option A
A key point is that, according to our definition, the economic lifetime of Option A depends solely on the benefits and costs of Option A; it does not depend on either the absence or presence of other options that might replace it.

Case 1 reduces to a two-way choice: Do nothing, or adopt Option A for E years of use. The best choice is whichever option has the higher present value of net benefits. If Option A involves the acquisition of a new system, the present value of doing nothing (not acquiring the system) is necessarily zero. Thus, Option A should be adopted (the new system acquired) if its present value, evaluated over its economic lifetime E at the appropriate discount rate, is positive. If Option A involves continuing use of an existing system, Option A should be
adopted (the existing service continued) if its present value is
positive. Otherwise the correct decision is to abandon the existing
service and to not replace it.

Case 2: Two Options, No Uncertainty

Consider now Option B in addition to A. We assume that Option B
provides the same service as A, but that initially (in year 0) its costs
are higher than those of A. Hence, if any decision is made to adopt an
option in year 0, the decision would be in favor of A. However, we also
assume that the investment cost of adopting B falls over time, as a
consequence of technological progress. Thus, the question is whether
the user should adopt A now and replace it later with B, or whether the
user should simply wait for B and not adopt A, or whether the user
should reject both options.

Figure 9.5 illustrates the situation. The pattern of net benefits
for Option A (now $NB^A_0$) is taken directly from Fig. 9.4. The net
benefits of Option B are shown for two alternative years of adoption,
year 1 and year 4, with the investment cost of B lower in year 4 because
of technological advance. The pattern of net benefits of Option B could
also be shown for other years—with investment cost falling as adoption
is delayed—but these patterns are omitted from the figure to avoid
cluttering the illustration.

The decision problem is more complicated than the straightforward
comparison of investment opportunities considered in Case 1 because the
two options, A and B, cannot be used concurrently. A decision to
acquire one option necessarily precludes obtaining the benefits of the
other during the time the first is being used. This means that the
correct decision rule must explicitly account for the interdependence of
the options over time. The key question is whether to acquire A now and
to replace it later with B, or to wait and acquire only B. The task
involves choosing between two decisions.

Decision $D_1$: Adopt Option A in year 0 and replace it in some year R
with Option B. The best year to replace A with B will depend on the
costs and benefits of both options and the rate at which the costs of B
are falling with time. By keeping A for another year the agency will
realize the discounted value of an additional year's benefits from A.
Note: Technological progress causes decline in investment cost of Option B from years 1 to 4.

NB₀ᴬ — Net benefits of Option A, adopted in year 0.
NB₁ᴮ — Net benefits of Option B, adopted in year 1.
E₀ᴬ — Economic life of Option A adopted in year 0.
I₀ᴬ — Investment cost, Option A adopted in year 0.
I₁ᴮ — Investment cost, Option B adopted in year 1.
I₄ᴮ — Investment cost, Option B adopted in year 4.

Fig. 9.5—Analysis of Options A and B
But these gains must be balanced against postponing the benefits from acquiring B. In the early years, putting off B may be advantageous if B's costs are falling rapidly. But eventually the present value of B will begin to decline as B is postponed further.

To determine the best year of replacement, \( R^* \), the decisionmaker must calculate a series of present values, one for each possible year of replacement. To make this calculation for any particular year \( R \), the decisionmaker calculates the net present value of A for a lifetime of \( R \) years and adds to it the present value (in year 0) of the net benefits of adopting B in year \( R \).\(^{16}\) The year yielding the largest present value is \( R^* \). Let us call this highest present value "\( PV_1 \)" and, for illustrative purposes, let \( R^* \) be year 5, shown in Fig. 9.5, as the optimal time at which B should replace A, after the investment in Option B is made one year earlier (year 4).

An equivalent way to describe the optimal date of replacement is to determine when the net present value of retaining A, calculated at that point (year 5), falls below the net present value of B, calculated at the same point. In other words, A should be replaced when the present value of its remaining net benefits falls below the net present value of B, taking into account the initial investment cost required for B.

**Decision \( D_2 \)--Do not adopt Option A but adopt Option B at the best time to do so.** In this instance, the decisionmaker calculates a series of net present values (in year 0) of Option B at each possible year of adoption \( t \). Postponing the adoption of B for a year has two effects--B's costs are reduced because of technological change but at the expense of deferring the benefits from B. Let us denote \( t^* \) as the year in which Option B should be acquired, i.e., the year in which B's net present value is maximized, and let us call this maximum present value \( PV_2 \).

In most cases, \( t^* \) will be less than \( R^* \). That is, if A has been acquired, it will usually be optimal to hold A longer and replace it at a later date than the date at which it is optimal to acquire B in the absence of A.\(^{11}\)

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\(^{16}\) We assume that retirement of Option A is cost-free. Otherwise, the additional costs should be deducted from the net benefits in year \( R^* \) under decision \( D_1 \).

\(^{11}\) To see why this is so, suppose that A has been acquired and that
Once the present values of the two decisions have been determined, the final choice is straightforward. The decisionmaker simply selects the decision $D_1$ or $D_2$ with the higher present value. If $PV_1$ exceeds $PV_2$, he should acquire $A$; otherwise it is better to wait for $B$.\(^\text{12}\)

Although these calculations are not more difficult than the present value computations needed to evaluate a single option for an assumed length of life, they do need to be carried out for each decision at each possible date of replacement or acquisition.

We caution that, in contrast to this approach, the decisionmaker could be tempted to use other criteria that lead to biased choices between $D_1$ and $D_2$. Four possible pitfalls are worth mentioning.

1. He may fail to recognize that a decision may involve a combination of options, and, therefore, consider the value of only a portion of the decision. In evaluating $D_1$, he may consider only the present value of $A$. Thus, if he expects to replace $A$ with $B$ at an assumed year $R$, he would compute only the present value of $A$, taking $R$ as its operating lifetime, in deciding whether to choose $D_1$ rather than $D_2$. The replacement year assumed for the calculation may be an educated guess about the best replacement date, rather than a complete evaluation of alternative years. But even if the optimal replacement year $R^*$ is used, this procedure undervalues $D_1$ because it fails to include the net present value of $A$'s replacement--$B$. This procedure would bias the choice in favor of $D_2$--not to procure $A$ at all but rather to wait for $B$.

one considers replacing it in year $t^*$. To illustrate, suppose that this year is $t^* = 2$. If $A$ still has large annual net benefits in year 3 (or in subsequent years), or if the cost reductions from further delaying $B$ are limited, or both, it will be best to enjoy another year of benefits and to postpone replacing $A$ with $B$ until some later date $R^* > t^*$. Thus, a decision to acquire $A$ now will usually mean that it will be optimal to introduce the new technology at a later date than if one decides to wait for the technology to mature. Having acquired $A$, the agency should use it so long as its net benefits exceed the net benefits of switching to the new technology.

\(^{12}\)Of course, at least one of the two values must be positive. Otherwise, the optimal decision is to adopt neither option.
2. If he recognizes that it is not enough to evaluate Option A only over its expected operating lifetime ($R^\ast$ years), he may attempt to adjust by extending the evaluation over a longer lifetime for $A$, such as $A$'s economic lifetime at $E$ years, shown in Fig. 9.4. But using $E$ years to calculate the present value of $A$ only reduces, but does not eliminate, the bias of case 1. If it is optimal to replace $A$ with $B$ at year $R^\ast$, the net present value of $B$ must exceed the remaining net present value of $A$ from year $R^\ast$ to year $E$. Thus, decision $D_1$ would remain undervalued relative to $D_2$.

In both cases (1) and (2) the error lies in considering Option $A$ alone vs. Option $B$ alone rather than properly considering Option $A$ and its replacement Option $B$ as a single decision vs. Option $B$ alone as a single decision.

Another possibility is that the decisionmaker recognizes the importance of including both $A$ and $B$ in his evaluation of $D_1$, but he is tempted to use the same date for evaluating both $D_1$ and $D_2$, leading to either a third or fourth outcome.

3. The decisionmaker may evaluate Decision $D_1$ by using as the replacement year $t^\ast$, the best year to acquire $B$ by itself. This year is a convenient choice, because it should have already been determined when considering $B$ as a single acquisition. In this case he calculates the present value of $A$ to year $t^\ast$ and adds to it the present value of acquiring $B$ in $t^\ast$. Although this method accounts for additional benefits of acquiring $B$, it still undervalues $D_1$. The reason is that the best time to switch to $B$ is not $t^\ast$, but $R^\ast$, for which $D_1$ has the greatest net present value.

4. Finally, the decisionmaker may evaluate both $D_1$ and $D_2$ at year $R^\ast$. In this case, the $D_1$ value will be correct. But the $D_2$ will be undervalued because the net present value of $B$ alone is higher for year $t^\ast$ than for year $R^\ast$. Thus, this approach biases the choice in favor of acquiring current technology (by
choosing $D_1$ in response to an undervalued $D_2$). In contrast, the three other approaches above are biased toward waiting for the new technology.

A final question, however, is how important this bias is likely to be for federal agencies. The answer is that the bias becomes more important the shorter is the time period during which Option A is expected to remain in service before being replaced. If, for example, the possibility exists that A will perform for only five or six years before it is replaced, it is especially important that the decisionmaker compute and explicitly compare the present values of the two decisions discussed above: Procure A and replace it by B at the end of the five- or six-year period, or do not procure A but wait for B.

In contrast, if it is clear that A is expected to perform for more than 10 years or so, explicit inclusion of the present value of the benefits of replacing A with B becomes less important, because present values of both benefits and costs occurring in distant time periods are relatively small, as suggested by Fig. 9.1.

The federal government tends to keep equipment a long time--probably longer than its optimal operating life. We have heard complaints, for example, that a good many electromechanical PBXs should have been replaced years ago. Under these circumstances, a more realistic formulation of federal choices might be (1) Option A now, Option B in 10 years, and (2) Option B in three years, kept for 10 years. Such options can be examined within the above framework to determine how well they compare with alternatives.

Using this framework systematically for both short-lived and long-lived investments can be a very useful input to decisionmaking for two reasons: (a) It provides a quantitative basis for deciding whether to buy immediately or to wait for more advanced offerings, and (b) it shows the losses that the government incurs (in terms of net present value forgone) by keeping equipment longer than is economically justified.

It is easy enough to understand why the government follows the practice of postponing investments in light of budget constraints that are becoming increasingly severe as a consequence of current concerns about the federal deficit. We will further treat questions of budget constraints in our discussion of "capital rationing" below.
Case 3: Two Options with Uncertainty

All the above may strike the reader as unrealistic because costs and benefits cannot be easily quantified. It is difficult enough to estimate the costs and benefits of an acquisition contemplated today, let alone trying to estimate the characteristics of an alternative or replacement acquisition five or 10 years down the road where uncertainties about continuing technological progress abound.

In light of irreducible uncertainties the following may be a useful strategy:

1. Estimate the time at which the acquisition in question (Option A) is likely to be replaced. This assessment involves estimating the remaining net present value of the acquisition relative to the net present value of its possible replacement.

2. If benefits are particularly hard to quantify, but if the benefits of both the acquisition and its replacement are judged to be about the same, the comparisons can be confined to costs. Thus, replacement would be determined by the time at which the present value of the remaining costs of the acquisition exceeds the present value of costs of its replacement.

3. If the time of expected replacement exceeds 10 years or so, the problem of estimating lifetime is eased. Assumptions about lifetimes may have rather little effect on overall results if the discount rate is 10 percent and if the minimum reasonable lifetime is beyond 10 years or so (as opposed, say, to five or six years). The present values of both cost and benefit stream beyond that time are relatively small, as illustrated in Fig. 9.1.\(^\text{13}\) Thus, for lifetimes beyond at least 10 years, the sensitivity analysis can be simplified, with little loss, by using a

\(^{13}\)For example, if an acquisition were expected to be replaced in 15 years, but were, in fact, to last forever, the increase in the present value of a constant stream of costs or benefits discounted at 10 percent annually would rise by only some 31 percent.
single lifetime assumption in combination with varying assumptions about costs and benefits.

4. If, on the other hand, replacement is estimated to occur in less than about 10 years, the decisionmaker should estimate the present value of the replacement extended out to at least the end of the 10-year period, and add that present value to the present value of the acquisition in question. Again, if benefits cannot be quantified, but costs are tolerably well known, the analysis can be done in terms of discounted costs as discussed above.

5. If the decisionmaker simply does not have the information needed to estimate the characteristics of the replacement, but nevertheless "feels" that the acquisition (Option A) will be replaced in, say, five years, special precautions should be taken against biasing the choice in favor of forgoing the acquisition and waiting for what would otherwise be its replacement.

As noted earlier, the procedure of using a lifetime equal to the expected replacement date can lead to pitfalls in decisionmaking. Suppose that the acquisition does not have a positive net present value when evaluated only with a five-year life. The decisionmaker should then inquire: How long would the economic lifetime of the contemplated acquisition have to be for the acquisition to be justified? That is, over how many years would the annual benefits of the acquisition have to exceed its annual costs to make the present value positive? If the acquisition does not look good with an assumed lifetime of five years, but does at six or seven years, the decisionmaker might wisely go ahead with the acquisition even if "opinion" suggests that it will be replaced in five years. In contrast, if the lifetime must be in the neighborhood of 10 years or more to justify the procurement, a decision to forgo it would likely be wise if replacement is indeed expected in five years. But throughout, the decisionmaker should know what this "opinion" is based on. If the basis is strong, it should also be enough to estimate the characteristics of the replacement and to incorporate them formally in the present value analysis. If the basis is weak, the decisionmaker
would have better reason to assume a lifetime substantially longer than five years in determining whether the procurement should go forward.

PROJECT INTERDEPENDENCE

The preceding discussion is based on the assumption that only one out of the range of alternative acquisitions can be selected. But this represents only one limiting case—where two or more acquisitions are either physically incompatible or so economically competitive that only one would be attractive.

But other possibilities exist. The acquisitions could be independent of each other, in which case the costs and benefits of one would be unaffected by whether or not the other is adopted. Or they could be complementary, such that the net benefits of both exceed the sum of the net benefits of each taken separately. Finally, they could be economically competitive, such that the net benefits of the combination fall below the values of each taken separately.\(^{14}\)

These possibilities are illustrated in Table 9.3, where acquisitions A and B are related to each other in various ways, whereas C is independent of both A and B in all cases. (The independence of C could result, for example, from C's being a project outside of and unrelated to telecommunications.) Case 1 shows the present value of net

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<tr>
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<td>75</td>
<td>A, C</td>
</tr>
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<td>100</td>
<td>50</td>
<td>110</td>
<td>75</td>
<td>A, B, C</td>
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\(^{14}\)Project interdependence is one reason why agencies need a telecommunications plan, as discussed in Sec. VIII.
benefits for A of 100 and for B of -20 when the two are considered in isolation. On that basis alone, A would be selected and B rejected. But in Case 1 the adoption of one alternative increases the net benefits of the other—a complementary relationship—so that acquiring both A and B yields a combined present value of 175 and it pays to acquire both. Acquisition C is also selected here, and in all the other cases, because of its positive net present value throughout.

For example, Option A may consist of upgraded terminal equipment that, working with existing switching facilities, would show a positive net benefit. Option B might consist of a new PBX that, working with existing terminal facilities, would also show a net benefit. But the combination, better exploiting the capabilities of both the terminal equipment and the PBX, generates net benefits that exceed the sum of the net benefits of the two options taken separately.

In Case 2, the projects are again complementary but not by enough to offset the negative present value of B considered separately. Only A is selected, rather than the combination, because of A's higher present value. In Case 3, A and B are independent of each other, shown by the equality between the sum of their separate present values and the present value of their combination. Case 4, shows a competitive relationship similar to that assumed in our early discussion. Both A and B have positive present values taken independently (perhaps A is a PBX system and B is a Centrex system). The combination of A and B shows a positive present value, but it is less than that of A taken separately. Hence, only A is selected. Case 5 illustrates a competitive relationship that is weaker than that in Case 4. The present value of the combination is less than the sum of the present values of A and B taken separately, but it is still higher than that of either. Both A and B are selected despite the presence of a competitive relationship.

These examples illustrate how important it is for agencies to consider carefully a range of choices, rather than selecting only one option for detailed analysis and accepting or rejecting it based on a comparison of costs and benefits. Other possibilities may be more beneficial, or combinations may render advisable procurements that, by
themselves, would not be attractive. For example, in Case 1 acquisition
A might represent an office automation system with particular specified
telecommunications components, with B representing additional
telecommunications components. By itself B is unattractive; but when
combined with the components in A the overall combination is superior to
the selection of A only.

It is important to note that the options A, B ..., etc., need not
denote only individual telecommunications systems; they can also denote
alternative means of procuring a given telecommunications system. Thus,
A might involve a lease-with-option-to-purchase a given PBX system; B
could involve a straight purchase; yet other options could involve a
straight lease or a lease-to-ownership plan. Because a sound
procurement methodology is required in addition simply to making a good
"basic" choice among products, present value analysis is directly
relevant to satisfying this requirement as well.

Moreover, not all the options (or even any of them) need be related
to telecommunications. Agencies face a wide variety of demands where
present value analysis can be a key tool for helping to make wide
decisions both within and outside of the telecommunications field.

To be sure, agencies cannot be expected to offer such precise
estimates as those illustrated in Table 9.3. Given unavoidable
uncertainties, as discussed in more detail in Sec. X, the quantification
of some variables will be difficult or impossible. Nevertheless, this
discussion identifies the kinds of information agencies should collect,
and the kinds of decisionmaking criteria that they should apply to this
information to make wise decisions.

CAPITAL RATIONING AND INSTITUTIONAL CONSTRAINTS

A fundamental problem with using present value calculations as an
input into decisionmaking is that the whole approach is based on the
assumption that agencies' own time preferences are equal to the social
discount rate. Equality between the two would be assured only if the
agency could borrow or lend any amount of money at the social discount
rate. But, of course, agencies do not function in that kind of world.
Depending on their current budgets and future expectations, managers'
true preferences can vary widely from the social discount rate.
For example, "capital rationing" occurs when the amount of funding available in the current period is insufficient to cover all projects (or combinations of projects) that enjoy a positive net value of benefits. To illustrate, suppose that in Case 1 the agency would not be able to proceed with all three projects A, B, and C shown in Table 9.3 because of insufficient funds in the current year. To rank the projects in priority, the agency should calculate a ratio of present value of net benefits to the investment cost of the project ($I_0$). To make this calculation, it should use a "modified" present value of net benefits, $V_1$, given by

$$V_1 = NB_1 + \frac{NB_2}{1 + r} + \frac{NB_3}{(1 + r)^2} + \ldots + \frac{NB_n}{(1 + r)^{n-1}}$$  \hspace{1cm} (9.6)$$

where $NB_1$, $NB_2$ ... $NB_n$ are equal to the difference between benefits and costs in each period, respectively, as in Eq. (9.4).\footnote{For a fuller discussion see Hirshleifer et al., op. cit., p. 172. Note that Eq. (9.6) is the same that one would use to calculate the}  

Thus, in Case 1 the modified present values of A, AB, and C (but not B independently) would be divided, respectively, by their initial costs. The projects would then be ranked by the descending value of these ratios and enough projects selected for acquisition so as to remain within the overall funding constraint. Thus, although C shows a lower present value than either A or AB, it might be selected because its current funding requirements are relatively low, while the agency might have to forgo one or both of the other choices.

A constraint on current spending forces the agency to choose projects that have relatively small current costs and relatively high subsequent costs (relative to alternative projects)--a choice it would have made directly from its present value calculations if it had used a higher discount rate. Thus, capital rationing, in effect, forces the use of a higher discount rate than is socially optimal, if the discount rate used in present value calculations (such as the 10 percent figure recommended by OMB) is itself socially optimal.
Keeping an investment longer than the optimal time of replacement, as a consequence of budget or other constraints, is consistent with the use of a discount rate higher than is socially optimal. Using such a rate in present value formulas tends to reduce to a greater degree the net present value of a new contemplated acquisition than the net present value of an existing investment. With a reluctance to undertake new investments in the absence of clear-cut and large expected net benefits, it is easy to understand why an agency's decision would be slanted toward keeping an investment too long.

Using the above formula for capital rationing helps to assure decisions that \textit{maximize} the value to society of the investments made within budget constraints--i.e., decisions that maximize net present value per dollar invested--for both telecommunications and nontelecommunications projects evaluated together under a common set of ground rules.

\textit{Present value of the project in period 1, after the initial investment has already been made.}
X. CAPITAL BUDGETING AND UNCERTAINTY

The preceding section was concerned primarily with the mechanics of capital budgeting and criteria for decisionmaking and paid little attention to issues of uncertainty, except as they entered into the discussion of acquisition lifetime. Obviously, however, one of the most serious problems facing the decisionmaker is uncertainty about costs and, even more, benefits.

The standard prescription for dealing with uncertainty is to do sensitivity analysis. The difficulty is that the combinations of variations one could consider with respect to benefits, costs, and other factors could quickly generate dozens of present value estimates that might obfuscate more than they clarify. To avoid information overload, one must selectively identify key factors for detailed analysis. In this section we identify those factors likely to be most important to federal decisionmakers and suggest ways in which they might best be handled. This section focuses on two areas:

• How users can reduce uncertainty about costs, performance, and benefits used in present value calculations and how to best cope with remaining uncertainties.¹

• How to make selections when benefits cannot be satisfactorily quantified but where, as a "second best" alternative, options can be assessed using partial information about their benefits.

We will consider issues of uncertainty with respect to initial investment, annual cost, and annual benefits. Because of the difficulties that arise in assessing benefits, we devote a separate

¹Occasionally we use the term "performance" in addition to the terms "costs" and "benefits" here and in other sections to highlight this factor. However, in the cost-benefit analysis above, performance is subsumed under costs or benefits or both. For example, an increase in performance could be considered as a reduction in costs for a given level of service or as an increase in benefits for a given cost.
subsection to decisionmaking criteria when only partial information about benefits is available. We then summarize the most important factors for assigning priorities in sensitivity analysis. Drawing from the discussion also in Sec. IX, Sec. X concludes by offering a set of guidelines for federal decisionmakers.

INITIAL INVESTMENT

Initial investment (the term \( I_0 \) in Eq. (9.2)) is a key variable in assessing the effects of uncertainty. Inclusion of an initial investment cost of 100, as shown in the final column of Table 10.1, would greatly affect present values, driving most of them to below zero. The degree to which varying assumptions about investment cost should be emphasized in sensitivity analysis depends primarily on these factors: (a) whether investment cost is subject to uncertainty, (b) the size of initial investment relative to subsequent benefits and costs, and (c) the lifetime of the investment.

Reducing Uncertainty

Users can easily enough reduce uncertainty by sticking to well demonstrated technologies. At the same time, new equipment and facilities coming onto the market may offer services and features valued highly by the user at low quoted prices. What level of confidence can be attached to such quotes and, more generally, what precautions can be taken against unpleasant surprises?

<table>
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<th>Case</th>
<th>Annual Benefits ($)</th>
<th>Annual Cost ($)</th>
<th>Annual Net Benefits</th>
<th>Lifetime (yr)</th>
<th>Present Value ($) ( I_0 = 0 )</th>
<th>Present Value ($) ( I_0 = 100 )</th>
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<td>-55</td>
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*Note:* Present values are calculated from Eq. (9.4).
Use of fixed-price contracts is an obvious way to reduce buyer's uncertainty about cost and performance. Reluctance by competing vendors to enter into fixed-price contracts, or willingness to do so only under terms obviously unfavorable to the buyer, would be prima facie evidence that the acquisition should not go forward. To be sure, fixed-price contracting generally does not offer full protection. Installation of a PBX, for example, may require more costly space—including air conditioning, for example, not covered by fixed-price provisions—than foreseen by the buyer.

Moreover, the protection offered by fixed-price contracts involves a cost to the buyer to compensate for the risk that is shifted to the seller. However, since the seller can be presumed to be more knowledgeable about the product than the buyer, the cost to the seller of bearing risk is less than that to the buyer. Thus, the additional cost to the buyer for the "insurance" offered by a fixed-price, competitively bid, contract is likely to be money well spent.²

Use of competitive bidding helps to ensure that the government is able to purchase at the lowest possible price. However, competitive bidding does not necessarily ensure against risks of poor performance by the vendor. Important questions include whether the prospective vendors have been responsive to their customers in the past, whether they have a long track record of generally keeping their promises, and whether their long-run prospects look good relative to other vendors.

One way to obtain this information, and to reduce other uncertainties, is to draw from the experience of other purchasers. Examples of information sources include telecommunications managers who are associated with the International Communications Association (ICA), and those who recently purchased the same equipment or service from the same vendor.³ For purposes of assessing others' experiences, the

²At the same time, the government should take on risks due to changes in its uses, since it has more knowledge than the vendor about how its needs may change. For example, a contract with termination liabilities should be less than one in which the contractor bears that risk and charges accordingly.

³The present membership of ICA represents approximately 510
prospective purchaser should also require that the vendor supply the names of recent purchasers before making final decisions.

To be sure, some of this information from other recent purchasers may be irrelevant, or in need of adjustment, because of the idiosyncratic nature of particular purchasers' acquisitions and uses of the equipment or service. Moreover, the reliability of comparative cost analysis depends on how long the equipment or service has been on the market. New products, for which the history of experience by other purchasers is severely limited, merit close scrutiny in sensitivity analysis and the incorporation of generous contingency allowances in the upper-bound estimates of costs. In facing these tasks, agencies should seek help and advice from (1) the GSA, (2) other government agencies, (3) experienced private firms, (4) professional associations such as the ICA, and (5) outside consultants.

Size of Initial Investment

Typically, uncertainty about the cost of an initial investment will increase with the size of that investment cost. The higher its estimated level relative to annual net benefits, the greater the need to take varying assumptions into account in sensitivity analysis. If \( I_0 \) were only 20 instead of the 100 shown in Table 10.1, all present values would remain positive. As another example, Tables 9.1 and 9.2 show that Company X would be well advised to consider alternative assumptions about investment cost, since the PBX, instruments, cable plant, and site preparation (less salvage value) constitute over 70 percent of the cost (in present value) of the new system.
Lifetime of the Acquisition

The shorter the lifetime of the acquisition (for given levels of size and cost uncertainty of the initial investment) the more important it is to include various assumptions about investment cost in the sensitivity analysis. With just a short lifetime, variations in the size of the initial investment have a larger effect on the present value of an acquisition than do variations in the level of annual benefits and costs.

In summary, the importance of including initial investment cost in the sensitivity analysis increases, (a) the greater the degree of uncertainty about the cost of the initial investment, (b) the larger its expected size, and (c) the shorter the acquisition lifetime.

ANNUAL COST

Variations in annual cost can greatly affect present values. As with fixed-price contracts for investment, uncertainty about annual cost can be reduced with long-term maintenance and service contracts. Information from other users can also help to reduce uncertainty. But many factors can arise, especially over a course of years, that cannot be insured against. Unless annual cost is very low relative to initial investment, present value calculations should include several sets of assumptions about annual costs—perhaps a "best estimate" along with an upper and a lower bound. The deviations of these bounds from the best estimate would depend on the level of uncertainty that remains after taking into account the use of maintenance contracts and information from other users.

One other aspect relating to annual costs must be emphasized. A frequently cited justification for users to buy their own equipment is that they will be protected from possible price increases by telephone companies. For example, Company X's decision to procure a new PBX, discussed in Sec. IX, was based in part on concerns that the local telephone company would continue to raise prices for its existing services, as it has done in the past.
However, one must be careful to distinguish between price increases that arise from general inflationary pressures and those that arise for other reasons. As noted in Sec. IX, the analysis should be carried out in a consistent fashion, either by making all calculations in constant dollars or by calculating all costs and benefits in current dollars using escalation factors based on alternative assumptions about the future course of inflation.

But price changes can arise from factors other than general inflation, making all the more questionable attempts by users to simply extrapolate from past trends of price changes. *Prices for particular services can go either up or down because of factors that are not reflected in past experience.*

For example, one major reason for recent price increases by local telephone companies is their move to accelerated depreciation of assets that then requires higher rates to cover the increase in current depreciation charges. In decades past, when telephone companies operated as traditional monopolies, they tended to depreciate plant and equipment on the basis of physical rather than economic lifetimes. With the restructuring of the market for telephone service and growing competitive pressures, telephone companies are finding themselves with obsolete facilities that must be written off over a shorter period than the lifetime used under their former depreciation practice as regulated monopolies.4 However, once these relatively high current charges are absorbed, subsequent prices will be lower than would have been possible under earlier depreciation practices. In other words, the change in depreciation practice affects the telephone companies' time profile of revenue requirements, increasing rates in the near term and reducing them in the more distant future. Therefore, particularly in states where the move to accelerated depreciation has already taken place, current increases in rental rates for telephone-company supplied equipment should not be extrapolated into the distant future.

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Another important consideration is state and federal regulatory policies that affect both the nature of services offered and the terms under which they are available to various classes of users. Regulatory policy with respect to access charges, private line tariffs, and Centrex offerings in competition with PBX equipment are of such importance that we devote a separate discussion to them elsewhere in this report. As emphasized in that discussion, it is extremely important that telecommunications users monitor current federal and state regulatory activities to help them avoid choices that quickly turn out to be poor because of intervening regulatory decisions. The problem is all the more serious because the government planning process is lengthy—with perhaps several years required to go from initial conception to actual execution of a project.

BENEFITS

In most cases, estimating benefits will be the most difficult aspect of the analysis. The easiest situation is one where the acquisition merely replaces existing equipment or service that has exactly the same features and, hence, confers the same benefits. So long as the present value of the existing equipment or service itself is positive, the decision about whether to replace would hinge only on whether the discounted cost of the acquisition falls below the discounted cost of retaining the existing equipment or service. If the present value of the existing equipment or service is negative (which implies that the existing equipment or service should be abandoned regardless of whether it is replaced), the decision to acquire the new equipment or service would depend on whether the discounted benefits of the existing (equal to the new) equipment or service exceed the acquisition's discounted costs.

But generally the analysis will be more complicated. The acquisition will likely contain new features and capabilities that permit the agency to do things it never did before. Putting a price-tag on these benefits is difficult or impossible. Drawing from the experience of others will help to gain a better notion of how well the claimed capabilities of the contemplated acquisition actually work. But
here the comparative experience of other buyers is likely to be less useful than for cost estimation. The benefits depend on needs, activities, and goals that vary among buyers, making comparative analysis difficult, and the agency will be left with the task of identifying and quantifying benefits to itself of these capabilities. Therefore, particular attention must be devoted to determining how various assumptions about benefits affect the estimated present value of the contemplated acquisition.\(^5\)

In many cases, a qualitative analysis is the best that can be done. The agency should assess how each new feature of a contemplated acquisition will help it to accomplish better its existing mission or a new mission to which it may have been assigned. Any special needs of the agency, such as a high level of security, should also be listed and assessed in terms of the capabilities of the telecommunications options that might include, for example, encryption of data or using a dedicated network rather than the public network. These new or additional benefits should be described in summary, itemized form. This list of benefits can then be subjectively weighed against the calculated present value of the additional cost of the proposed acquisition.

In this form, the cost analysis invites two key questions:

1. Can some, or the most important, of the benefits be obtained by a lower-cost alternative?
2. Would this level of expenditure from the agency's budget on other projects, including nontelecommunications activities, yield greater benefits?

Because the benefits cannot be quantified, the answers to these questions must be subjective. This process is similar to that pursued by Company X in deciding that the benefits of the new PBX system, although unquantified, outweigh the increased cost involved in abandoning its existing system.

\(^5\)A common characteristic of benefit-cost analysis is that benefits are more difficult to estimate than are costs. For example, the costs of installing seat belts in new automobiles are easier to estimate than are the benefits, quantified in dollar terms, of saved lives and reduced injuries. Similar examples could be drawn from the environmental and other fields.
Yet another possibility exists. Even if the agency cannot attach a dollar value to the benefits of each option, it may have enough information on benefits to rank options in a way that leads toward (although does not guarantee) the same choices as those when complete information is available. We shall now illustrate these possibilities.

USING PARTIAL INFORMATION ABOUT BENEFITS TO ASSESS OPTIONS

We will illustrate the use of partial information about benefits, taking into account (a) options that are both interrelated and independent of each other, and (b) situations where the user faces capital rationing. The analysis demonstrates a "second best" approach to ranking and selecting options when the agency faces budget constraints and lacks the full information required to put a price-tag on benefits—a common situation in the real world. We shall consider two cases: The first, a "base case" for comparison purposes, involves benefits for which full information is available, with and without capital rationing. The second involves benefits for which only partial information is available, with and without capital rationing. The key question is the degree to which the decisionmaker is led to the same choices based on partial information as those based on full information in the base case.

Case 1: Quantified Benefits

The rows of Table 10.2 show seven options, listed in Column 1 along with the initial investment ($I_0$ in Eq. (9.4)) shown in Column 2 and the quantified annual (constant) benefits and costs associated with each (where the difference between them is given by $NB_1$, $NB_2$, ..., $NB_n$ in Eq. (9.4)) in Columns 3 and 4.\(^6\) Column 5 lists the present value of net benefits computed from Eq. (9.4), under the assumption of a 10-year lifetime and a 10 percent discount rate. Options A and B are complementary, since AB has a greater present value than the sum of the two; Options C and D are competitive, since CD has a lower present value than the sum of the two; and E is independent of all other options. In

\(^6\)For simplicity we use small dollar amounts. But we could just as well speak of thousands or millions.
Table 10.2
SELECTING AMONG OPTIONS [a]

<table>
<thead>
<tr>
<th>Option</th>
<th>Initial Investment ($)</th>
<th>Annual Benefits ($)</th>
<th>Annual Costs ($)</th>
<th>Net Present Value Benefits ($)</th>
<th>Options Selected</th>
<th>( \frac{1}{t_0} )</th>
<th>Options Ranked</th>
<th>( \frac{1}{t_0} ) Ranked</th>
<th>Benefits Ranked</th>
<th>Prob. of Selection</th>
<th>Total Costs ($)</th>
<th>Gross Benefits ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50</td>
<td>20</td>
<td>10</td>
<td>11</td>
<td>1.16</td>
<td>1.16</td>
<td>6</td>
<td>3</td>
<td>0.00</td>
<td>111</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>45</td>
<td>20</td>
<td>3</td>
<td>59</td>
<td>2.20</td>
<td>0.39</td>
<td>1</td>
<td>3</td>
<td>0.50</td>
<td>63</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>20</td>
<td>30</td>
<td>10</td>
<td>103</td>
<td>X</td>
<td>5.82</td>
<td>1</td>
<td>X</td>
<td>2.91</td>
<td>7</td>
<td>2</td>
<td>0.50</td>
</tr>
<tr>
<td>D</td>
<td>40</td>
<td>20</td>
<td>5</td>
<td>52</td>
<td>2.18</td>
<td>0.73</td>
<td>2</td>
<td>3</td>
<td>0.25</td>
<td>71</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>80</td>
<td>30</td>
<td>15</td>
<td>12</td>
<td>X</td>
<td>1.09</td>
<td>4</td>
<td></td>
<td>1.09</td>
<td>5</td>
<td>2</td>
<td>0.00</td>
</tr>
<tr>
<td>AB</td>
<td>70</td>
<td>45</td>
<td>12</td>
<td>133</td>
<td>X</td>
<td>2.75</td>
<td>2</td>
<td>X</td>
<td>1.00</td>
<td>4</td>
<td>1</td>
<td>0.25</td>
</tr>
<tr>
<td>CD</td>
<td>100</td>
<td>30</td>
<td>15</td>
<td>-8</td>
<td>X</td>
<td>0.87</td>
<td>3</td>
<td>2</td>
<td>0.25</td>
<td>192</td>
<td>184</td>
<td></td>
</tr>
</tbody>
</table>

[a] 10 percent discount rate; 10-year lifetime.
[b] Budget constraint = $100.
[c] P.V. = present value.
the absence of capital rationing, the rule that all options with positive present values should be selected results in the choice of C, E, and AB, as shown in Column 6, with A and B subsumed under AB, since they are complementary. Option CD is not chosen and, since C is chosen, D is not.

To illustrate the situation of capital rationing, Column 7 shows the values of the ratio of the present value of net benefits to initial investment cost, $V_1/I_0$, computed from Eq. (9.6). In Column 8 the options are ranked by the descending order of this ratio. If the overall budget constraint is assumed to be 100, only C and AB are selected, shown in Column 9, since including E as well would bring total investment to 170, violating the constraint.

Case 2: Partial Information about Benefits

Although information on the costs of alternative investments frequently is less satisfactory than one would desire, the more difficult--but typical--problem facing users is the impossibility of quantifying the benefits of the various options. Nevertheless, in many cases the user can obtain partial information about the benefits of alternatives. We will consider the following possibilities:

a. Benefits of different options can be ranked (e.g., C is better than B as shown in Column 12 of Table 10.2) but no information is available about the amount of difference.

b. The additional benefits of different options can be determined (e.g., C provides $10 more benefits per year than B) but total benefits are not known.

c. The relative benefits of different options are known (e.g., C is 50 percent better than B).

In all cases, we assume that costs are well enough known so that the initial investment and annual cost estimates shown in Table 10.2 are accurate.
Benefits Ranked

We assume that the decisionmaker is able to rank benefits to be consistent with the quantified "true" values shown in Column 3, even though these values are unknown to the decisionmaker. Thus, he ranks Option AB the highest, as shown in Column 12; at the next highest level he is indifferent among C, E, and CD; and below them he is indifferent among A, B, and D. In other words, the decisionmaker has enough information to conclude, for example, that AB is the most beneficial of the options, but he does not have enough information to estimate a $15 annual difference between AB and the next best option.⁷

Given the same $100 budget constraint as we assumed previously, which projects does he choose, and how closely do they match the projects he would have chosen if he had complete information?

To help answer the question, the discounted annual costs, \( C_1 \), of the options are computed from Eq. (9.6) where only costs are included, and Column 10 shows the ratio of these costs to the initial investment cost, \( I_0 \).

\[
\frac{C_1}{I_0} = \left( \frac{c_1}{1 + r} + \frac{c_2}{(1 + r)^2} + \ldots + \frac{c_n}{(1 + r)^{n-1}} \right) / I_0
\]

(10.1)

Using this information, the decisionmaker can rank the options in terms of their annual costs per dollar of investment. On this basis, Option B, the option with the lowest annual cost per dollar of investment ranks first (as shown in Column 11 of Table 10.2) and Option C last.

With the rankings of the seven options for both the annual costs and the benefits established, the decisionmaker's task is to narrow the number of possible choices by using this ranking information and the limit on his total budget. In most cases, the ranking of benefits will serve to eliminate some options but will leave the decisionmaker with a

⁷For example, the options could be arrayed as shown in Table 8.1 and then ranked by their benefits reflected in the performance and other criteria listed on the left.
reduced number of alternatives, no one of which is demonstrably superior. We will illustrate how the decision can systematically incorporate the benefit-rankings by examining each of the possible decisions in the examples shown in Table 9.2. The following possible decisions are recapitulated in Table 10.3.

**Decision 1: AB and C.** First, consider each of the first-rank options when the options are ranked in terms of benefits. There is just one first-rank option, AB (shown in Column 12), since it is judged to have the greatest benefits of all options. If it is chosen, the remaining budget of $30 ($100 - $70) allows only C as a second acquisition. Therefore, the first possible decision includes only AB and C.

**Decision 2: CD.** Next, consider in turn each of the second-rank options (those ranked as number 2 in Column 12). These are C, E, and CD. But note that E and CD each dominate Option C, for although each has the same value of benefits, E has a lower annual cost, and CD a still lower annual cost. Thus, when second-place options are considered, CD should be selected. This choice costs $100 and exhausts the available budget. Therefore, the second possible decision is to choose only CD.

Table 10.3

<table>
<thead>
<tr>
<th>Decision No.</th>
<th>Options</th>
<th>Benefit Rank</th>
<th>Cost Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AB</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>CD</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>
Decision 3: B and C or Decision 4: B and D. Finally, consider the several third-rank options: A, B, and D (those ranked as number 3 in Column 12). Of these, B has lowest annual cost and dominates. So this decision is to acquire B, for $45, and use the remaining budget for an additional option. That second option could be A, but that choice is already subsumed under option AB in Decision 1. The other possibilities within the remaining budget are C or D. Therefore, the third and fourth possible decisions involve choosing either B and C, or B and D.

The decisionmaker's qualitative information about benefits thus enables him to eliminate some dominated options and narrow the possible decisions to these four distinct decision packages, summarized in Table 10.3, using rankings of benefits and annual costs as criteria. Without further information, no objective basis exists for selecting among these four choices. For example, Decision 1 achieves first- and second-rank benefits, but incurs fourth- and seventh-rank costs, whereas Decision 2 achieves second-rank benefits at only third-rank costs.

In this extreme case of no additional information, the decisionmaker can do no better than to select at random from among the four possible decisions listed in Table 10.3. Thus, Decisions 1, 2, 3, and 4 each have a probability of 0.25 of being selected. From these selections one can easily compute the probability of selecting each option listed in Tables 9.2 and 9.3. Options A and E each have a zero probability of being selected, because neither appears in any of the four decisions shown in Table 10.3. Options B and C appear twice and thus each has a probability of 0.50 of being selected. Finally, Options D, AB, and CD appear once, so each has a probability of 0.25 of being selected.

This procedure results in a 50 percent chance of selecting Option C and a 25 percent chance of selecting Option AB, both of which would have been selected on the basis of full information as shown in Column 9 of Table 10.2. On the downside, Option CD, which has a negative present value, would be picked 25 percent of the time.

Nevertheless, this outcome is preferable to one in which the decisionmaker has no information on which to base a ranking of benefits. In that situation, the only sensible strategy would be to pick the
options with the most favorable $C_1/I_0$ ratios—B and D—shown in Column 11 of Table 10.2, neither of which would be selected were full information available. The combined present values of net benefits of Options B and D is $111 (from Column 5 of Table 10.2), compared to $236 for Options C and AB under full information.

With ranking of benefits, the "expected" net present value of each option, shown in Table 10.4, is computed by multiplying its probability of being selected (Column 13) by its net present value (Column 5) from Table 10.2. The sum of these expected net values of $125 is higher than the $111 figure attained in the absence of any information about benefits. Thus, the ranking of benefits, although not assuring the optimal choices, is likely to lead to better outcomes than would be true if no information were available about benefits.

**Incremental Benefits Known**

The ranking of benefits narrows the range of choices to those likely to be most advantageous in light of budget constraints. If the decisionmaker can then obtain more information on the narrower range of choices, he may be able to improve on the outcome that arises from simply choosing at random among the four alternative decisions discussed above.

**Table 10.4**

<table>
<thead>
<tr>
<th>Option</th>
<th>Probability</th>
<th>Expected Net Present Value ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>B</td>
<td>0.50</td>
<td>29.5</td>
</tr>
<tr>
<td>C</td>
<td>0.50</td>
<td>51.5</td>
</tr>
<tr>
<td>D</td>
<td>0.25</td>
<td>13.0</td>
</tr>
<tr>
<td>E</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>AB</td>
<td>0.25</td>
<td>33.3</td>
</tr>
<tr>
<td>CD</td>
<td>0.25</td>
<td>-2.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$125.3</td>
</tr>
</tbody>
</table>
Here we consider the situation where the decisionmaker is able to determine the incremental dollar benefits of a given option relative to another although, lacking full information, he cannot estimate satisfactorily the overall quantitative benefits of any of the options. To illustrate, Column 15 of Table 10.2 shows the present values of the gross benefits. Although the decisionmaker does not know these actual values, he is able to determine the difference (increment) in benefits between any two options, that is, the difference between any two entries in Column 15. With this additional information, the decisionmaker can select a single best decision by successively comparing different pairs of possible decisions and selecting from each pair the decision that yields a net increase in benefits minus costs.

To illustrate this procedure, Table 10.5 again lists the four undominated decisions reached when options are ranked in terms of benefits and annual costs, with two additional columns—the present value of total costs (Column 14 from Table 10.2) and the present value of gross benefits (Column 15 from Table 10.2). Let us begin with the decision that has the smallest present value of total costs, Decision 4, which has costs of 134 and benefits of 246. Now compare this to Decision 3. If Decision 3 were selected, the costs would increase by 10 (144 - 134) and benefits would jump by 61 (307 - 246). Therefore, within a fixed budget, Decision 3 is superior to Decision 4. Now consider Decision 2. Compared to Decision 3 it requires 48 more in costs but yields 123 lower benefits, so it also is inferior to Decision 4. Finally, Decision 1 would increase costs 100 over Decision 3 but yield an additional 154 in benefits. The optimal decision, then, is Decision 1—the decision that includes the same options, AB and C, that would have been selected on the basis of full information. Thus, knowledge of incremental benefits is likely to markedly improve the outcome.
Table 10.5

DECISIONS COMPARED ON THE BASIS OF INCREMENTAL AND RELATIVE BENEFITS

<table>
<thead>
<tr>
<th>Decision</th>
<th>Options</th>
<th>Present Value of Total Costs</th>
<th>Present Value of Gross Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>AB,C</td>
<td>143+81 = 224</td>
<td>277+184 = 461</td>
</tr>
<tr>
<td>2.</td>
<td>CD</td>
<td>192</td>
<td>184</td>
</tr>
<tr>
<td>3.</td>
<td>B,C</td>
<td>63+81 = 144</td>
<td>123+184 = 307</td>
</tr>
<tr>
<td>4.</td>
<td>B,D</td>
<td>63+71 = 134</td>
<td>123+123 = 246</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Comparison of Decisions</th>
<th>Difference in Cost</th>
<th>Cost Ratio</th>
<th>Difference in Benefits</th>
<th>Benefit Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 vs. 4</td>
<td>10</td>
<td>1.07</td>
<td>61</td>
<td>1.25</td>
</tr>
<tr>
<td>2 vs. 3</td>
<td>48</td>
<td>1.33</td>
<td>-123</td>
<td>0.60</td>
</tr>
<tr>
<td>1 vs. 3</td>
<td>100</td>
<td>1.69</td>
<td>154</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Relative Benefits Known

The final possibility is that the decisionmaker may be able to rank options by their benefits and estimate relative, but not incremental, benefits. For example, in seeking to choose among the four undominated decisions listed in Tables 10.3 and 10.5, the decisionmaker is able to determine that Decision 3 yields 25 percent more benefits than Decision 4 but requires 7 percent more costs (Table 10.5, bottom), whereas Decision 2 would yield only 60 percent of the benefits obtainable from Decision 3 at 33 percent greater cost. Thus, Decision 2 is inferior to Decision 3. Decision 1 is also inferior to Decision 3, since it has 50 percent greater benefits, but 69 percent greater costs, than does Decision 3. Therefore, if a choice is to be made on the basis of relative benefits, Decision 3 would be selected.
Decision 3 includes Options B and C, neither of which would be selected if full information on benefits were available. But it still leads to better outcomes than does a choice based on no information about benefits, since the combined present value of net benefits for Options B and C of $163 exceeds the value of $111 for B and D, as discussed previously.

Thus, relative benefits are not as reliable a basis for reaching a final decision as incremental benefits. Because of varying cost and benefit values among the options, the selection of the decision with a ratio of incremental benefits greater than the ratio of present value of incremental costs could lead to wrong choices. At the margin, the gain from additional expenditure is better measured in additional dollars of benefits as discussed above, rather than in terms of percentage of benefits as discussed here.

**Use of Partial Information: Concluding Remarks**

In concluding this subsection, we must note two points: First, the choices made with partial information will, of course, depend on the particular "true" costs and benefits that exist for each option. Different numbers substituted in our numerical examples could have generated other outcomes. Conceivably, the options selected on the basis of no information about benefits—that is, selections based only on those with the least discounted annual cost per dollar of investment—would lead to exactly the same choices as those based on full information. More likely, however, this will not be so, and ranking benefits, especially when combined with quantified incremental benefits, will lead to outcomes closer to those based on full information.

Second, one might ask whether ranking of benefits is useful when capital is not rationed but when, again, benefits cannot be quantified. In this case ranking is simply irrelevant. In the absence of quantification the decisionmaker must decide, on whatever basis, whether the discounted benefits of each option outweigh discounted costs. With no limit on capital outlay, every option whose benefits are judged to exceed costs, e.g., whose net present value is positive, is selected. This situation highlights again the importance of careful analysis of benefits before procurements are made.
ASSIGNING PRIORITIES FOR SENSITIVITY ANALYSIS

The preceding discussion, helping to determine the variables most important for pursuing sensitivity analysis, can be summarized as follows:

- Project lifetimes, as discussed in Sec. IX, should be subjected to varying assumptions if they are expected to be shorter than about 10 years (at a 10 percent real discount rate). Longer lifetimes have rather little effect on results.
- Initial investment costs are progressively more important the greater is their degree of uncertainty, the larger they are relative to expected annual expenditures, and the shorter is the project lifetime.
- Annual costs are of progressively greater importance the greater is their degree of uncertainty, the larger they are relative to expected investment cost, and the longer is the project lifetime.
- Benefits are a key variable for sensitivity analysis. But in many cases the difficulty of quantifying them may limit the quantitative analysis to a comparison of costs among the options and subjective judgment about whether benefits outweigh these costs. Use of partial information on benefits to assess options can help.

CONTINGENCY PLANNING AND RISKS

Despite all of the above precautions and alternative analytical techniques, agencies will necessarily face risks that whatever options they seriously consider may turn out less well than expected. This is especially true when the options embody technologies not thoroughly proven in the marketplace or when vendors are used who have not established track records. The "value" of telecommunications services is generally much greater than its costs (except at the margin). The cost of a phone system failure is much higher than the ongoing costs of the system. As a consequence, many telecommunications investments are
(properly) designed less to minimize costs than to reduce the chance of a system failure.

Consequently, the agency should do contingency planning to keep risk within acceptable bounds. This planning might take several forms:

- Inclusion of contingency allowances in the options themselves. The proposed procurement of a PBX, for example, might include allowance for the cost of delaying cutover to the new system by a specified time period as a cushion against late delivery.

- Inclusion in primary and contingency plans of only proven technologies and reliable vendors. One could, of course, simply avoid all procurements where there is any doubt that the technology or the vendor will perform as advertised. At the same time, certain new and potentially quite valuable services may necessarily be available only from new vendors or in equipment embodying new technologies. In these cases it may be advisable for the agency to proceed with the procurement but only after it has exercised more than the usual care in demonstrating that the benefits would be relatively great and in showing how it would operate its overall telecommunications system if the procurement turns out less well than expected.

- Explicit inclusion of risk in selecting among options. In the preceding discussion we emphasized the decisionmaking criterion based solely on relative net present value. But risk needs also to be taken explicitly into account, which is made all the more difficult because the degree of risk cannot be nicely quantified. After assessing the kinds of risk involved and the probabilities that things will go wrong, the agency might modify its choices accordingly. For example, an option that has a lower net present value than another might nevertheless be selected as a substitute because of the lower risk that it entails. However, this does not mean that the agency should simply abandon a quantitative analysis as discussed above and select options
based solely on its subjective judgment of which are and are not less risky. One of the chief benefits of present value analysis is that it provides dollar magnitude (although roughly estimated) against which other considerations must be traded off. Thus, if the lower valued but less risky option is selected over another, the agency must confront the question explicitly about whether the reduction in risk is worth the estimated reduction in net present value.

GUIDELINES FOR DECISIONMAKING

Based on the treatment of capital budgeting in this section, and in Sec. IX, the following is a brief tabulation of guidelines for federal users seeking to choose wisely among telecommunications options.

- *Use present value analysis.* This provides a common set of ground rules for comparing dissimilar options. It is a key analytic tool in choosing not only among different kinds of telecommunications services but also among alternative procurement strategies for given services. This tool is no less useful in choosing among the broader set of options within and outside the telecommunications field.

- *Include all costs.* Adequate attention must be paid to such requirements as special employee training, debugging of equipment, and systems management, which can easily be overlooked in hastily performed analysis.

- *Consider various options.* Many projects are neither mutually exclusive nor totally independent of each other. Assessment should include combinations of separate projects to determine their complementary or competitive characteristics.

- *Use fixed-price contracts and competitive bidding.* This mechanism is a key component of reducing uncertainty about cost estimates and vendor capabilities. Because sellers generally have better information about their products than do buyers, they can bear risks at lower costs than can
buyers. Thus, the "insurance premium" that must be paid for fixed-price contracts is likely to be money well spent.

- **Talk with other users.** Another way to reduce uncertainty about cost estimates and vendor capabilities is to examine the experience of others using the same or comparable services. For this reason prospective vendors should supply the names of other recent purchasers. A central organization that can compare the experiences of many users also can be valuable in offering advice and evaluating the cost and benefit estimates made by particular users.

- **Perform sensitivity analysis.** It is obviously important to consider the effects of alternative assumptions about variables subject to uncertainty. At the same time one should avoid information overload by emphasizing those variables likely to be subject to the greatest uncertainty. The benefit side is especially uncertain when the acquisition being considered offers new services rather than replacing exactly those already in place.

- **Rank projects properly if faced by capital rationing.** Under conditions of capital rationing it is important to avoid selecting a particular acquisition just because it has a high present value—in contrast to the rule that all projects with positive present values (with interdependencies taken into account) be selected in the absence of capital rationing. By ranking projects in accordance with the relationship between their present value and current expenditure requirements, the user will obtain the mix that maximizes net benefits, subject to the budget constraint.

- **Use partial information about benefits if they cannot be fully quantified.** Ranking projects on the basis of judgment about their benefits may lead the user toward the same choices made on the basis of fully quantified benefits, while it narrows the range of options that the user should consider in greater detail to resolve ambiguities. Comparing options by estimating the
percentage differences between their benefits may help to reduce the ambiguities and improve outcomes. Comparisons based on estimates of the dollar differences in benefits may help even more.

- Do risk assessment and contingency planning. This involves inclusion of contingency allowances in the options, use of proven technologies and reliable vendors, and explicit consideration of risks, in addition to estimated net present values, in selecting among options.
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