Advances in Telecommunications Technologies That May Affect the Location of Business Activities

Leland L. Johnson
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PREFACE

There has been much speculation about how rapidly evolving telecommunications technologies are affecting decisions about the geographical location of business activity. It is frequently said that, as a substitute for face-to-face contact, telecommunications encourages decentralization from central cities to suburbs and rural areas. Moreover, many have conjectured that growth in telecommuting, with employees working at home instead of at the office, will save energy and reduce traffic congestion.

This study describes some of the major telecommunications advances that have reduced costs, triggered the emergence of new and improved services, and dramatically increased the levels of communications flows. Empirical analysis of the effects of these developments on locational choices is beyond the scope of this study. Rather, it describes how telecommunications technologies are evolving, in the hope that it will encourage future investigation into the linkages between the telecommunications infrastructure and the nationwide and worldwide location of business activity.

This study, financed under a grant from the Sloan Foundation, will be of interest to those generally concerned with the societal effects of new technology. It will be especially useful to those concerned with the determinants of locational choices and how technologies, including those discussed here, are affecting those choices.
SUMMARY

This study describes developments in telecommunications that may have a special bearing on choices about geographical location for business activities, and it offers briefly some thoughts about possible broader effects on society.

The study addresses six major areas to illustrate the evolution and growth of telecommunications services relevant to locational decisions:

- **Aggregate measures of telecommunications growth**—the growth of telephone and other traffic in domestic and international markets, and evidence of price changes during the last 10 to 20 years.
- **Computer-to-computer communications**—the rapidly growing use of computer networks, and the consequences of converting from analog to digital transmission, facilitated by use of fiber optic cable.
- **Facsimile transmission**—the striking improvements in the ability to transmit hard copy between any two locations with compatible facsimile machines anywhere on the worldwide public telephone network.
- **Software-defined networks**—ways that computer technology and software are being used to reconfigure telecommunications networks on demand, thereby expanding flexibility and reducing costs.
- **"800" telephone service**—a rapidly growing option that permits customers to dial without charge to distant organizations that subscribe to this service.
- **Teleconferencing**—the ability to hold meetings between two or more separately located groups connected by telephone or television links.

All these developments ease the constraints imposed by spatial separation. An individual, whether in Bozeman, Montana, or Los Angeles, can access a multitude of databases, use electronic mail, or dial toll free to thousands of numbers domestically (and even to many internationally). One would expect that, in cases where face-to-face contact becomes less important, (a) greater decentralization would occur to exploit the advantages of locations that, because of their spatial separation from related activities, would otherwise be foreclosed, and (b) greater centralization would occur of activities
(e.g., airline reservation offices and mail order houses) in which economies are possible by centralizing staff functions. In cases where face-to-face contact remains important, expanded communication flows would not have a notable impact on geographical location, but would increase the efficiency of business activities.

The need for further investigation is highlighted by the fact that use of telecommunications can have surprising or unanticipated effects. For example, it might be reasonable to assume that "telecommuting," with the employee staying home rather than going to the office, would save energy and reduce traffic congestion. However, substitution of communications for business travel could actually increase rather than decrease the use of energy and add to traffic congestion. Relocations encouraged by telecommuting could increase the demand for automobile transportation, as a substitute for mass transit, as well as place other new demands on the economic infrastructure.

The purpose of this Note is to stimulate thinking about such outcomes, and more generally to encourage rigorous empirical analysis of the determinants of locational choices and the role that telecommunications is playing.
ACKNOWLEDGMENTS

I am indebted to RAND colleagues Bridger Mitchell and Adele Palmer for their constructive comments and suggestions on a draft of this study. The study draws from RAND's own experience as a telecommunications user to illustrate some of the changes that have occurred during the last decade. Special thanks go to Brian Medley and Dorothy Arvanitis for patiently answering my many questions about RAND's experience and for digging through old RAND records.
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I. INTRODUCTION

This study describes important developments in telecommunications that may have a special bearing on choices about geographical location for business activities, and offers briefly some thoughts about possible broader effects on society. Although analysis of the determinants of geographical location, and the specific role of telecommunications, is beyond the scope of this Note, it is hoped that it will stimulate rigorous analysis of the effects of rapid advances in telecommunications on locational decisions, and an evaluation of the societal consequences.

To encourage further study, it is instructive to treat some of the developments in the telecommunications field that have greatly facilitated the transfer of information over both long and short distances. Of key importance are new services that have been perfected, ways that old services have been improved, and changes in prices to users. Obviously, much could be written about the myriad technological advances and new services in an area as dynamic as this. However, it is sufficient for purposes here to examine briefly some of the most salient advances to give the reader a broad appreciation for their potential to affect locational decisions.

The discussion is confined to services commonly available, on the premise that the effects on locational choices are a consequence of past and existing, rather than expected future, telecommunications options. Much could be written, too, about the array of new options likely to become available before the end of the century. But a discussion of new options would be less relevant to the objective of this study than a discussion of where the telecommunications industry stands today.

The empirical material cited in this study comes from a wide range of sources. Among them, the experience of RAND itself, as a user of telecommunications, provides instructive examples of how some services have evolved. RAND has a staff of nearly 1100—about 1000 in RAND’s Santa Monica headquarters and the remainder in its Washington office. The ways that RAND communicates between its two offices and with the rest of the world, and how it has been affected by technological advances, are useful to consider.

This study addresses six major areas to illustrate the evolution and growth of services relevant to locational decisions:
• Aggregate measures of telecommunications growth—the growth of telephone and other traffic in domestic and international markets, and evidence of price changes during the last 10 to 20 years.

• Computer-to-computer communications—the rapidly growing use of computer networks, and the consequences of converting from analog to digital transmission, facilitated by use of fiber optic cable.

• Facsimile transmission—the striking improvements in the ability to transmit hard copy between any two locations with compatible facsimile machines anywhere on the worldwide public telephone network.

• Software-defined networks—ways that computer technology and software are being used to reconfigure telecommunications networks on demand, thereby expanding flexibility and reducing costs.

• "800" telephone service—a rapidly growing option that permits customers to dial without charge to distant organizations that subscribe to this service.

• Teleconferencing—the use of audio and video links for communication among geographically separated groups.

Sections II through VII treat each of these areas in turn. Section VIII very briefly addresses implications for the geographical location of business activity.
II. AGGREGATE MEASURES OF TELECOMMUNICATIONS GROWTH

Telecommunications services have enjoyed rapid growth because of technological advances and the demands arising from overall domestic and foreign economic growth. Basic trends for the United States are shown in Table 1. The 5 percent growth rate in local calls outpaced the growth in real GNP and in population. Even more striking is the growth in number of toll calls in relation to GNP.

Table 2 shows price trends for "message toll" or ordinary telephone service (MTS) and for wide area telephone service (WATS), which is a specially priced bulk service tailored to the needs of large users. With adjustment by the GNP deflator, the real prices for all the services listed have fallen.

But even such large price decreases may be understated. Because large users can substitute among services in response to relative price changes, in ways not reflected in price indexes for specific services, price changes for aggregate service to particular users may be more favorable than Table 2 suggests.

The growth in telephone traffic, and the reduction in costs afforded by substituting certain services for others, is illustrated by RAND's experience. During the period

Table 1

<table>
<thead>
<tr>
<th>Year</th>
<th>Telephone Calls (Millions)</th>
<th>Real GNP (Billions $)</th>
<th>Population (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>101301 Local 3942</td>
<td>737</td>
<td>181</td>
</tr>
<tr>
<td>1983</td>
<td>309510 Local 39941</td>
<td>1535</td>
<td>235</td>
</tr>
</tbody>
</table>

Average annual percentage rate of growth

5 11 3 1

Table 2
PRICE INDEXES—DOMESTIC TELECOMMUNICATIONS SERVICES, 1972–1986

<table>
<thead>
<tr>
<th>Year</th>
<th>Interstate MTS</th>
<th>Intrastate MTS</th>
<th>Interstate WATS</th>
<th>Intrastate WATS</th>
<th>Interstate Private Lines</th>
<th>GNP Deflator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1986</td>
<td>133</td>
<td>157</td>
<td>106</td>
<td>150</td>
<td>168</td>
<td>245</td>
</tr>
</tbody>
</table>

Percentage Change—Real Terms
-44 -36 -57 -39 -31


March 19 to April 15, 1971, average long distance telephone usage per professional employee was about 128 minutes at an average cost per minute (CPM) of 37 cents. Much of this traffic was on WATS lines. In July 1987, RAND’s reconfigured network with tie lines and switched services of competitive common carriers, as described below, resulted in an average usage of 226 minutes per professional employee at a CPM of less than 23 cents.

Table 3 shows growth rates between 1975 and 1988 for three classes of service between the United States and foreign countries (excluding Canada and Mexico). Telephone traffic expanded at 23 percent per year. No less notable, for traffic originating in the United States the revenue per minute earned by U.S. carriers (such as AT&T) has fallen by an average of 5 percent annually, even in the face of general inflation. This pattern reflects increased use of direct distance dialing and price decreases as a consequence of technological advances in satellites and undersea cables.

Telex has shown much less rapid growth, and a smaller decrease in revenue per minute. Telegraph has shown a sharp decline in traffic and an increase, rather than a decrease, in price. Telex and telegraph have been less favorably affected by technological advance and they are coming under severe competitive pressure from communications alternatives. It is becoming progressively easier and cheaper to pick up the telephone, to use facsimile transmission, or to use direct computer-to-computer transfer, than to send a telegraph-type message.
Table 3


<table>
<thead>
<tr>
<th>Type of Traffic</th>
<th>1975</th>
<th>1988</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telephone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minutes (millions)</td>
<td>375.3</td>
<td>5,668.8</td>
<td>23</td>
</tr>
<tr>
<td>Revenue per minute from U.S.</td>
<td>$2.25</td>
<td>$1.18</td>
<td>-5</td>
</tr>
<tr>
<td>Telex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minutes (millions)</td>
<td>123.2</td>
<td>260.5</td>
<td>6</td>
</tr>
<tr>
<td>Revenue per minute from U.S.</td>
<td>$2.83</td>
<td>$2.51</td>
<td>-1</td>
</tr>
<tr>
<td>Telegraph</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words (millions)</td>
<td>511.3</td>
<td>131.7</td>
<td>-11</td>
</tr>
<tr>
<td>Revenue per word from U.S.</td>
<td>$0.17</td>
<td>$0.36</td>
<td>6</td>
</tr>
</tbody>
</table>


Telex is still widely used because telex machines, most of which were installed years ago, are available throughout the world. It remains attractive for short messages, especially where time zone differences make use of the telephone impractical. But facsimile transmission is an increasingly powerful competitor.

The growth of international calling rates at RAND mirrors the overall international growth shown in Table 3. During the period October 1987 to March 1988, five times more international calls per professional employee were made than during the same months in 1971 and 1972.

But these numbers by themselves fail to convey the increase in reliability, lower costs, and worldwide accessibility to a widening range of information services afforded by technological advance. Evidence from the international arena is perhaps the most striking. The first transoceanic telephone cable, with 74 circuits, was laid across the North Atlantic in 1956. Before then, the only means of transoceanic telephone transmission was by radiotelephone—a service subject to fading, blackouts, static, and severely limited capacity. By 1990 about 200 underseas telephone cables had been completed worldwide. But these cables—of coaxial design—have limited capacity which makes them economically unsuitable for television and other broadband services.
The development of fiber optic cable, for domestic as well as international use as discussed below, is a dramatic breakthrough. The first transatlantic and transpacific fiber cables were completed in late 1988, offering greatly expanded capacities for narrowband and broadband services. This transatlantic cable has the capacity of over 30,000 telephone circuits, exceeding by far the total of all 10 previously laid transatlantic coaxial cables. A second transatlantic fiber cable has been completed, a third is under construction, and a second transpacific fiber cable has recently been completed.

Communications satellites also illustrate striking advances, especially in providing access to remote regions of the world. The International Telecommunications Satellite Organization (INTELSAT) is a nonprofit cooperative of 112 member countries that invest in the "space segment" (the satellites and associated ground control facilities) in approximate proportion to their use of the system. INTELSAT launched its first satellite, "Early Bird," in 1965 to connect North America and Europe. This satellite was especially significant in that it permitted for the first time the transoceanic transmission of television. By early 1990, INTELSAT had a global network of far more advanced satellites (covering the Atlantic, Pacific, and Indian Ocean regions) with more than 2000 pathways supplying telephone, data, and television services to about 180 countries and territories. In 1988, INTELSAT charged $9360 per telephone circuit per year, less than one-fourth of the charge of $40,000 that it levied in 1970. INTELSAT had 118,885 voice channels in service at year-end 1989, a number 35 times greater than the 4258 circuits in use at year-end 1970. Television service has similarly grown, from 2428 channel hours in 1970 to 7386 in 1989.¹

Many countries, including less-developed ones, now use satellites for domestic service, either by maintaining their own systems or by procuring circuits from INTELSAT. Thus, even remote villages are now connected into domestic and worldwide networks.

III. COMPUTER-TO-COMPUTER COMMUNICATIONS

Probably the most significant single development during the last couple of decades is the emergence of computers that, with nationwide and worldwide telecommunications lines, can pass back and forth a wide range of information. A striking feature of computer communications is not only that text and data files can be transferred within seconds or minutes, but they arrive "on-line" to facilitate their revision and manipulation. As just one example, a text can be transmitted from one location to another, revised on the computer at the recipient location, and transmitted back to the originating location or, for that matter, to a hundred locations.

To illustrate the application of computer-to-computer communications, it is useful to describe briefly three examples: applications in banking and finance, access to electronic data bases, and use of electronic mail. The kinds of computer networks that support these services will also be described, followed by a discussion of digital transmission and fiber optics.

BANKING AND FINANCE

Telecommunications technologies have had a dramatic effect in banking and finance. Electronic methods of payments transfer have replaced the nearly sole reliance on paper transactions of earlier decades. Table 4 illustrates the composition of payments in 1983. Although nonelectronic methods constituted more than 90 percent of the number of transactions, they accounted for only about 22 percent of the value. Nonelectronic payments were dominated by cash and checks, but their average value per transaction was overwhelmed by the average value of wire transfers among financial institutions. Automated teller machines and point of sale transactions accounted for a tiny portion of volume and, because of their low value per transaction, they are lost in the rounding of value measures. Because the use of ATMs and POS terminals is growing rapidly, the figures may be notably different today.

1According to one study, the total number of ATMs installed in the United States rose from 48,118 in 1983 to 69,161 in 1986—a growth of nearly 50 percent in three years. William B. Trautman, Regulating Communication Technology: The Case of Automated Teller Machine Networks, RAND, N-2867-SF, October 1989, p. 6.
Table 4

VOLUME AND VALUE COMPOSITION OF U.S. PAYMENTS, 1983

<table>
<thead>
<tr>
<th>Type of Payment Instrument</th>
<th>Volume Composition (percent)</th>
<th>Value Composition (percent)</th>
<th>Average Dollar Value per Transaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonelectronic</td>
<td>99.50</td>
<td>21.50</td>
<td>247</td>
</tr>
<tr>
<td>Cash</td>
<td>70.41</td>
<td>1.54</td>
<td>25</td>
</tr>
<tr>
<td>Checks</td>
<td>25.14</td>
<td>19.80</td>
<td>910</td>
</tr>
<tr>
<td>Credit Cards</td>
<td>3.13</td>
<td>.11</td>
<td>42</td>
</tr>
<tr>
<td>Money Orders</td>
<td>.47</td>
<td>.03</td>
<td>67</td>
</tr>
<tr>
<td>Travelers Checks</td>
<td>.50</td>
<td>.02</td>
<td>35</td>
</tr>
<tr>
<td>Electronic</td>
<td>.35</td>
<td>78.50</td>
<td>258,993</td>
</tr>
<tr>
<td>Automated clearing houses</td>
<td>.25</td>
<td>.39</td>
<td>1,800</td>
</tr>
<tr>
<td>Automated teller machines</td>
<td>.05</td>
<td>.00</td>
<td>70</td>
</tr>
<tr>
<td>Point of sale terminals</td>
<td>.01</td>
<td>.00</td>
<td>30</td>
</tr>
<tr>
<td>Wire transfers</td>
<td>.04</td>
<td>78.11</td>
<td>2,500,000</td>
</tr>
</tbody>
</table>


Wire transfers are conducted largely over Fedwire and CHIPS (the Clearing House Interbank Payments System). Fedwire uses a telecommunications network to link over 7000 domestic banks with the Federal Reserve System. Among other things, it is used for deposit and loan payments among banks, and for transferring book entry securities among banks. CHIPS runs a telecommunications network to serve 140 member banks who act as correspondents for a larger number of domestic and international banks to clear mostly internationally related payments such as foreign exchange, Euro-dollar loans, and certificates of deposit.

In addition to these two fund transfer systems, a message-based computer and communications system called SWIFT (Society for Worldwide Interbank Financial Telecommunications) links over 2000 banks in more than 50 countries. In 1986 the network handled nearly 200 million messages—22 percent more than in the previous year.

Table 5 shows growth in the use of the wire services relative to GNP and to bank reserves. Total payments were 16 times GNP in 1970 and grew to 66 times GNP in 1985. They grew even faster relative to bank reserves.

The above is significant for our purposes because it suggests that geographical location is becoming progressively less relevant to activities closely linked with
Table 5

<table>
<thead>
<tr>
<th>Year</th>
<th>Fedwire + CHIPS ($) GNP</th>
<th>Fedwire + CHIPS ($) Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>1980</td>
<td>48</td>
<td>17</td>
</tr>
<tr>
<td>1983</td>
<td>65</td>
<td>38</td>
</tr>
<tr>
<td>1985</td>
<td>66</td>
<td>42</td>
</tr>
</tbody>
</table>


telecommunications. Remotely located financial institutions can have the same access to transactions services as those in major metropolitan centers. The geographical dispersal of these institutions goes hand in hand with the dispersal of their customers—contributing to decentralization of economic activities that would be impossible in the absence of computer-to-computer communications.

**ONLINE DATA BASES**

Computers provide information storage, search, and retrieval capabilities that, connected to telecommunications links, provide information to users throughout the world. Figure 1 shows the growth in the number of data bases and in data services (combinations of one or more data bases offered to customers). The number of data bases grew from about 500 in 1979 to over 3000 by 1986, stimulated in part by dramatic reductions in the cost of computer storage.

These data bases and services cover an extraordinary range of fields with full text, bibliographic references, or numeric data. A few of the hundreds of examples are described well by one author:

The largest full-text database services are sold by Mead Data Central, which provides Lexis, a legal database, and Nexis, which includes the Washington Post, the New York Times, and Time Inc. and McGraw-Hill publications. Dialog Information Services contains mostly bibliographic references—periodical citations and abstracts—in about 250 databases on topics as diverse as coffee, welding, and the Middle East. Statistical services, such as New York-based McGraw-Hill’s Data Resources Inc.,
Fig. 1—The growth in the number of online databases and online services provide data that can be downloaded into a spreadsheet for analyses. Each of these services, as well as scores of other online publishers, will package individual databases on specific topics for customers, giving them access to dozens of databases through one service.²

The user, with a microcomputer or a special vendor-supplied terminal, can access these data bases with either a local or a long distance telephone call that connects the terminal into a telecommunications network linked to the data base. Subscribers to these services, regardless of geographical location, can use their computers to search and retrieve printouts of material on particular topics at a tiny portion of the time and cost, and on a far more comprehensive basis, than is otherwise possible.

ELECTRONIC MAIL

An increasingly popular service is electronic mail because of its ease of use, flexibility, and speed. A person, perhaps at home with a personal computer and a modem, can transmit by telephone line a message to another person or to numerous persons at other locations. The message resides in the recipient's computer "mail box" until retrieved. Among the advantages, the storage capability of electronic mail avoids "telephone tag" that is especially frustrating when many time zones are involved. It can also provide a complete paper trail for all messages to all correspondents relating to a given subject. Moreover, correspondents need not be separated by hundreds or thousands of miles for electronic mail to be useful. Within a single building, electronic mail is faster and more convenient in many applications than are conventional interoffice mail and telephone service.

COMPUTER NETWORKS

The above services are made possible by the development of computer networks. These include "long haul" networks that can span continents and "local area" networks that interconnect, for example, an industrial complex or buildings on a college campus. A multitude of interconnection media can be used, including optic fiber, coaxial cable, satellite links, and copper twisted pair telephone lines. There are five basic kinds of networks.

Research Networks. These were started, usually by government sponsors, to explore the feasibility and usefulness of computer communications. Reflecting the usefulness of such networks, of which ARPANET is the best example, they are used by researchers on college campuses, government agencies, and related organizations for activities funded by government sources.

Company Networks. Many companies such as IBM, AT&T, DEC, and Xerox have developed internal networks to support their business operations. They vary from local area networks within buildings or clusters of buildings to networks providing international coverage.

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Cooperative Networks. These have developed among users with similar interests. Some, like BITNET, originated in the academic community for noncommercial applications. Others, such as ACSNET, JUNET, and USENET, have a mixture of academic, research, corporate, and other interests.

Commercial Networks. These provide services to heterogeneous users, similar to the operations of a telephone company or other common carriers. TYMNET and TELNET are leading examples. They are supported by fees charged to individual users for connect time or CPU time. Commercial networks are commonly used, for example, to provide access to online data bases discussed above.

Metanetworks. These are directed to connect existing and future networks for accessibility by a wide range of users—similar to the connection of individual telephone company networks to provide "universal" worldwide access.

These networks have many features: Some permit messages entered into a computer to be transmitted and printed out by facsimile or telex machines at locations without computer terminals. In light of the large worldwide base of telex machines, noted above, and rapid growth of facsimile services, discussed below, this added accessibility is quite significant.

DIGITAL TRANSMISSION AND USE OF FIBER OPTICS

The utility and cost of computer communications (as well as telephone and other telecommunication services) are being favorably affected by the conversion from analog to digital transmission and substitution of fiber optics for copper wire and over-the-air transmission. Digital transmission consists simply of sequences of "off" and "on" signals to form alphanumeric characters. Analog transmission consists of a continuously variable signal, analogous to the spoken word, where particular variations can be designed to depict characters of the alphanumeric alphabet or to reproduce the human voice or other sounds.

When either a digital or analog signal is transmitted over long distances, the signal is attenuated and, therefore, must be strengthened at points along the way by amplifier equipment. However, amplifiers add static to the signal, with static becoming worse as the number of amplifiers increases. The advantage of digital transmission is that the on/off signal characters can be distinguished through the static so that the signal can be reconstituted to arrive exactly in the form in which it was transmitted. But static adds to
the fuzziness of an analog signal so that it cannot be reconstituted in exactly its original form. Thus, errors in computer communication are less frequent and easier to detect and correct with digital transmission.

Because computers are inherently digital in their internal functions, digital transmission avoids the cost and complexity of requiring that the signal be converted to analog and then back again. Because voice signals can be broken down into digital signals and reconstituted at the receiving end, digital transmission can be used for ordinary telephone conversations, with the clean signals afforded by digital transmission providing better service over long distances than is possible with analog techniques.

Although digital transmission can be used over the whole range of communication media—coaxial cable, over-the-air, and copper wire—it has a particular affinity with fiber optic cable, which uses on/off light pulses for transmission. For large capacity communication needs, fiber optics are attractive because a single fiber the diameter of a human hair can simultaneously carry thousands of telephone messages. Consequently, it is not surprising that conversion from analog to digital, and substitution of fiber optics for other transmission media, are proceeding apace. By now, numerous fiber optic regional and transcontinental digital systems are operating. As noted above, during 1988 underseas fiber optic cables were completed to connect the United States with Europe and with Japan, as the first step in a worldwide undersea fiber network.
IV. FACSIMILE TRANSMISSION

One of the most revolutionary developments since the mid-1960s is the commercialization of facsimile transmission, which permits anything that can be written or drawn on paper to be transmitted by facsimile machine over ordinary telephone lines and reproduced by another compatible machine anywhere in the world. Reflecting rapid technological advance, machines now on the market can transmit a page in 15 to 20 seconds, compared with as long as six minutes on machines in the late 1960s. Many machines can be programmed to transmit at night to take advantage of off-peak telephone rates; some can transmit at the same time that they are receiving; and some can be programmed in a "broadcast" mode to transmit sequentially to as many as 100 or so locations. To enable transmission of computer printout and other large-format materials, at least one machine currently on the market can transmit documents up to 11-1/2 inches wide by 118 inches long. The price of such machines depends on their features, but some are advertised for under $1000.

Sales of facsimile terminal equipment have skyrocketed from about $100 million in 1985 to about $1.4 billion in 1988. With prices falling during this time, the growth in the number of machines (with steadily improving capabilities) is even more impressive.\(^1\)

RAND's experience illustrates the impressive growth of facsimile use. During the period April to October 1971, the Santa Monica office transmitted 278 documents at an average telephone charge of $6.74. During the same period in 1987, the number of documents had grown to 1186 at an average charge of only $1.52. The number of documents transmitted per professional employee during those months in 1987 was 3.6 times as large as the number during the comparable 1971 period.

The growth in per-person facsimile use may be even more impressive in businesses that use desktop machines in decentralized locations—in contrast to RAND's centralized facsimile facility.

V. SOFTWARE-DEFINED NETWORKS

A medium-size or large business with several geographical locations requires a corporate network for internal communications in addition to access to the worldwide public switched network. Until recently, such firms created their own networks by leasing dedicated privates lines (tie lines) from carriers such as AT&T and MCI to connect their establishments, in addition to purchasing access to the public switched network.

Private lines have two primary advantages over switched networks for internal communications. First, individual extensions can be reached in one office from extensions in the other by using the same abbreviated extension numbers (perhaps with an additional single digit prefix) that are used for interoffice calls. Thus, dialing the distant office is about as convenient and fast as dialing within the office. Second, the tie line is priced at a flat monthly rate regardless of usage. Thus, the greater the amount of traffic, the less the CPM. At sufficiently high volumes the CPM falls below that of using the switched network.

But tie lines can be disadvantageous if traffic is severely peaked. If the tie lines cannot handle peak load traffic, the excess flows over to the switched network at additional cost, while the tie lines are underused during the rest of the day. Thus, the CPM is relatively high if tie line traffic is concentrated over short periods.

To illustrate, RAND previously had five tie lines between its Santa Monica and Washington offices (in addition to the three data lines noted above) (see Table 6). In comparison to a CPM of about 20 to 22 cents for switched long distance, the CPM of the tie lines ran to about 34 cents because the lines were underused during much of the day, and a substantial amount of overflow had to be handled over the switched network during peak periods.

An alternative that has been commercialized during the last few years, and adopted by RAND in early 1988, is the "software defined" or "virtual" private line network. This approach combines the flexibility of switched service with the convenience of tie line service.

Characteristics of RAND's software-defined network are also shown in Table 6. The network includes 24 trunks out of Santa Monica and 12 trunks out of Washington as
Table 6

FORMER AND SOFTWARE-DEFINED NETWORK
CONFIGURATIONS AT RAND, 1988

<table>
<thead>
<tr>
<th>Location</th>
<th>Trunks in Former Network</th>
<th>Trunks in Defined Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santa Monica-Washington</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>office tie lines</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Santa Monica long distance</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Wash. office long distance</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Wash. office overflow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total trunks</td>
<td>38</td>
<td>36</td>
</tr>
</tbody>
</table>

a substitute for the five tie lines and other trunks in the former network, with a total of 36 trunks substituted for 38. Peak load traffic between the two offices can be accommodated by as many as 12 trunks with the same dialing convenience as with the former five tie lines. Moreover, the number of trunks available for other long distance points varies automatically with the traffic flow between the two offices. For example, when one trunk is in use between the two offices, 23 lines and 11 lines can be used by Santa Monica and Washington, respectively, for other long distance calling.

As another example of flexibility, suppose that during a few days each month traffic is extraordinarily heavy on a predictable basis between the two offices. By merely changing the software controlling the network, the total number of 36 trunks can be reallocated between the two. For example, 18 could be allocated to each (assuming that a sufficient number of local telephone access lines are available to the premises) to handle increased interoffice traffic while still accommodating other long distance needs. (Of course, if overall traffic grows over time, additional trunks can be added to the 36.)

Another feature of a software-defined network is that it can easily be configured to tie in additional offices with the same convenience and flexibility discussed above. Thus, an entity with dozens of offices scattered around the country can operate a network with tie line convenience among all the offices, while enjoying the flexibility to shift capacity for other long distance needs.
Finally, the software-defined network may reduce telecommunications costs—depending on the size and type of firm in question and the particular network packages offered by competing long distance carriers. In RAND's case, the software-defined network is expected to be about 5 percent less expensive, for the same level and composition of traffic, than the previous one. A fixed cost was incurred to set up the new network, but the operating cost savings will permit this fixed cost to be recovered in about nine months.
VII. TELECONFERENCING

TELEPHONE-BASED SYSTEMS

Using the telephone for meetings is becoming increasingly convenient and flexible because of the availability of equipment designed for communicating among geographically separated groups. To illustrate, consider currently available equipment for a meeting room.

— A control unit (about the size and weight of a home videotape recorder) that plugs into any telephone jack.

— One or more microphone units placed on a conference table as needed. The units can either be connected by wire to the control unit or, at additional purchase cost, wireless units can be placed as far as 100 feet from the control unit.

— One or more speakers wired to the control unit and placed around the conference room as needed.

Conferences in a room equipped with these components can communicate (a) with a group in a similarly equipped room, (b) with several people around a speakerphone-equipped telephone, (c) with a single person with a telephone, or (d) with several scattered groups of individuals, using bridging equipment in the telephone network.

To illustrate how this system might be used, consider the following. An individual is to give a briefing with screen-projected vugraphs at a conference attended, say, by a dozen people at site "A." The room is equipped with the control module and other teleconferencing equipment listed above. Another group of participants in a similarly equipped room, located at site "B" (perhaps halfway around the world) "sit in" on the meeting. Copies of the vugraphs are sent by facsimile to site B and photocopied so that each participant has a set.

As the briefer moves through the presentation, attendees at both sites can ask questions and make comments.¹ A general discussion follows the briefing. Moreover,

¹The main information that the attendees at site B miss would come through use of a pointer or other nonverbal means that the briefer might use, for example, to identify
attendees at site B might write comments, questions, reactions, and such in the margins of the vugraphs, which are returned via facsimile or overnight express to the briefer. (Of course, attendees at site A could also have hard copies to mark up.)

One can imagine many variants of the above. Site B might also be equipped with an overhead projector and screen, with an individual designated at site B to flip through transparent vugraphs (sent by overnight express) as instructed by the briefer, during the presentation. In some cases, this might be more effective than sole reliance on hard copy.\(^2\) With bridging equipment, multiple sites can be connected. For example, a single remotely located individual with nothing more than a telephone could listen to the whole proceeding, while being free to ask questions and offer comments.

Of course, audio conferencing—with no video component—is also widely used. It is less expensive and generally easier to set up than is videoconferencing.

The key point is that teleconferencing arrangements are cheap and effective. As just one example, RAND routinely uses these procedures for simultaneous presentations in its Santa Monica and Washington offices, as well as in communications with other organizations.

TELEVISION-BASED SYSTEMS

Two-way Television. There has been much talk of using two-way television for teleconferencing. But, in contrast to telephone-based systems, rather little use is made of two-way television for several reasons.

1. The cost of transmission is high. The telephone connection charge between sites A and B in the preceding illustration for a 90-minute meeting would run to less than $20 (figured at about 22 cents per minute). But the cost of a two-way television transmission would run to hundreds or thousands of dollars. For example, a one-way transmission using a transoceanic satellite provided by INTELSAT would cost about $437.\(^3\) Added to that figure would be the charges for the satellite earth stations and the particular points on the vugraph. For this reason, the briefer would have to be careful to verbalize for the benefit of out-of-sight participants.

\(^2\)A primary advantage of using transparencies is that the material can be color-coded and in other ways made more physically attractive. With today's technology, facsimile is limited to black and white.

landline extensions to the conference sites. Two-way television would involve a
doubling of these costs. Continued technological advances will reduce these costs, but
they will remain high relative to those of telephone-based systems.

2. Conference room equipment is complex and requires skilled operation. To make
most effective use of the television medium requires that camera angles be switched from
one speaker to another, and from the speaker to screen displays, depending on how the
conference is designed. But angle switching requires multiple cameras in the hands of a
skilled crew. Demands on camera operation are intensified if the conference involves
spontaneous give-and-take, with cut-ins from participants at the other location.

With the desirability of studio-like conference rooms and skilled manning for
interactive television, some telephone companies have established such facilities at
central points. This has the advantage of spreading the relatively high costs among
multiple users. But it adds the inconvenience of requiring all attendees to travel to the
conference sites. The author has uncovered no evidence that telephone companies have
met with notable success in marketing this service.

3. The added value of video presentation is limited. If the only problem of two-
way television conferencing were cost, it might still be a popular service if it could
substitute for the possibly even higher cost of travel for face-to-face meetings. A more
fundamental problem with television, however, is that video adds rather little to the value
of communication by telephone, computer, and facsimile. Its advantage is in conveying
whatever nonverbal content exists in the communications process. But television, limited
to its two dimensions and presentation on a screen, lacks the presence of face-to-face
meetings. It is for this reason, for example, that most people strongly prefer to see a
stage play live rather than on television. It is for the same reason that the video phone,
developed by Bell Laboratories during the 1970s, was a commercial failure. People are
not willing to pay much to see on a screen the person with whom they are talking.

At the same time, television is becoming more widely used in a one-way mode,
two examples of which are worth noting.

Delayed one-way television presentation. Some companies find televised
presentations useful for dissemination to distant locations. An example is a televised
company lecture, perhaps with questions from the audience, that is transcribed onto
videotape for express delivery for replay at other locations. Low-cost cameras and VCRs,
designed for home as well as business use, are generally adequate for this purpose.
*Real-time television with voice interaction.* The development of relatively low-cost satellite links working with small receive-only earth stations makes economically feasible for many applications the transmission from one point to multiple points. Perhaps the most striking example is the widespread use of satellites to feed programs into the thousands of cable television systems throughout the country.

Some large businesses and other organizations are also finding satellite transmission useful to connect a central point with multiple locations for live television presentations, combined with "call in" interaction. According to a recent survey, 56 organizations, including the "big three" automobile manufacturers, have installed a total of over 8000 earth stations nationwide for television reception from central sites. According to one source, more than 40 private networks are now operating (compared to only three in 1982), serving approximately 5000 locations. This rapid growth reflects technological advance that has made technically feasible and less costly a range of new services.

Practical satellite transmission came only several years ago, when the Federal Communications Commission set aside designated frequencies (called the Ku-band) for such services. This gives privately owned television networks a frequency that will remain free from interference from other broadcast signals. The band also permits the use of broadcast equipment that is less costly than conventional television. What's more, signals can be scrambled to assure that they will be seen only in authorized viewing locations—called downlinks—which may be in a company's offices, factories, suppliers' facilities, or anyplace else the satellite signal can reach.

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5*Newsweek*, "Broadcast News, Inc.," January 4, 1988, p. 34.
VIII. IMPLICATIONS FOR GEOGRAPHICAL LOCATION

All the developments discussed above ease the constraints imposed by spatial separation. An individual, whether in Bozeman, Montana, or Los Angeles, can access a multitude of data bases, use electronic mail, or dial toll free to thousands of numbers domestically (and even to many internationally). Organizations have increasing flexibility in connecting together their far flung operations with new and improved information services. One would expect that, in uses where face-to-face contact becomes less important, (a) greater decentralization would occur to exploit the advantages of locations that, because of their spatial separation from related activities, would otherwise be foreclosed, and (b) greater centralization would occur of activities (e.g., airline reservation offices and mail order houses) in which economies would be possible by centralizing staff functions. In cases where face-to-face contact remains important, expanded communication flows would not have a notable impact on geographical location, but would increase the efficiency of business activities. This last outcome characterizes, as one example, the situation faced by RAND.

It is easy to imagine that geographical moves stimulated by reliance on telecommunications services could have profound long-term effects. Central business districts may decline, with a consequent erosion of the tax base, and rising unemployment in business activities previously dependent on firms that have moved, while suburban and rural areas may face population growth and demands, difficult to meet, for new infrastructure. The growth of multinational corporations with their headquarters in one country and manufacturing facilities scattered worldwide is surely facilitated by the kinds of telecommunications services described in this study.

As noted above, rigorous examination of how telecommunications links are affecting locational decisions is beyond the scope of this study. But the revolutionary changes taking place in the telecommunications arena suggest that such an examination is needed because of the important societal repercussions that may now be taking place or should be anticipated for the future.

The need for further investigation is highlighted by the fact that use of telecommunications can have surprising or unanticipated effects. To illustrate, there has been much talk about how telecommuting, with the employee staying home rather than
going to the office, would save energy and reduce traffic congestion. Anecdotal evidence suggests that progressively more employees are spending time at home and using their telephones, fax machines, and personal computers as at least a partial substitute for working in the office.

It is important to realize, however, that substitution of communications for business travel could actually increase rather than decrease the use of energy and traffic congestion. To illustrate, consider the employee who commutes to his Wall Street office by subway from upper Manhattan. By living in an area blessed with extensive mass transit facilities, the employee does not own an automobile. Suppose, however, that the firm disperses its activities, since many employees can perform their tasks as well virtually anywhere in the United States as a consequence of telecommunications services of the sort described in this Note. Suppose that the employee ends up in Boulder, Colorado, where he needs an automobile even if he works at home. In comparison with mass transit travel in Manhattan, greater energy use and local traffic congestion could be a consequence.

The reader may identify other such examples. In any event, the hope here is to stimulate such thinking and to encourage rigorous empirical analysis of the determinants of locational choices and the role that telecommunications plays.