VOLUME I

# EXECUTIVE SUMMARY

NASA REPORT NO. CR 159619

(NASA-CR-159619) THE 30/20 GHz FIXED COMMUNICATIONS SYSTEMS SERVICE DEMAND ASSESSMENT. VOLUME 1: EXECUTIVE SUMMARY (International Telephone and Telegraph Corp.) 50 p HC A03/MF A01 CSCL 17B G3/32

N80-18262

Unclas
47359

# 30/20 GHz
# FIXED COMMUNICATIONS SYSTEMS SERVICE DEMAND ASSESSMENT

*by: R. B. GAMBLE*
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*M. WESTHEIMER*

*prepared for:*

NASA
**LEWIS RESEARCH CENTER**

U.S. TELEPHONE AND TELEGRAPH CORPORATION ITT

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1. Report No.
CR 159 619

2. Government Accession No.
–

3. Recipient's Catalog No.
–

4. Title and Subtitle
30/20 GHz Fixed Communications Systems
Service Demand Assessment

5. Report Date
August 1979

6. Performing Organization Code
–

7. Author(s)
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8. Performing Organization Report No.
–

9. Performing Organization Name and Address
U.S. Telephone & Telegraph Corporation
67 Broad Street
New York, N.Y. 10004

10. Work Unit No.
–

11. Contract or Grant No
NAS3-21366

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Lewis Research Center, Cleveland, Ohio

13. Type of Report and Period Covered
Contractual Report

14. Sponsoring Agency Code

15. Supplementary Notes
NASA Project Manager, William Poley, NASA Lewis Research Center, Cleveland, Ohio

16. Abstract

Demand for telecommunications services is forecast for the period 1980-2000, with particular reference to that portion of the demand associated with satellite communications. Overall demand for telecommunications is predicted to increase by a factor of five over the period studied and the satellite portion of demand will increase even more rapidly. Traffic demand is separately estimated for voice, video and data services and is also described as a function of distance traveled and city size.

The satellite component of projected demand is compared with the capacity available in the C and Ku satellite bands and it is projected that new satellite technology and the implementation of Ka band transmission will be needed in the decade of the 1990's.

17. Key Words (Suggested by Author(s))
Traffic Demand
Satellite Communications
Communications Forecast

18. Distribution Statement
Unclassified

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
46

22. Price
–

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# EXECUTIVE SUMMARY

This report summarizes the results of a study of telecommunications demand performed under NASA Contract NAS3-21366. Demand is projected through the year 2000 for each of the major communications services and is presented with supporting data concerning costs, reliability, and the geographical distribution of traffic. Particular emphasis is placed on that portion of the demand suitable for satellite delivery systems, and the potential role of 30/20 GHz systems in meeting the anticipated growth of demand. A more detailed presentation is contained in Volume II.

## 1. SCOPE

The study forecasts the demand for telecommunications services through the year 2000, with a primary focus centering on that portion of demand which offers a suitable target for transmission via satellite. The study therefore emphasizes long distance communications needs, i.e., communications which extend beyond local boundaries, nominally taken to be 200 miles.

### DEMAND FORECASTS BY SERVICE TYPE

The basic demand forecasts of this study are organized by type of service, the major categories of which are Voice, Video, and Data. Important subcategories of each of these services are identified and traffic demand for each is estimated.

### GEOGRAPHIC DISTRIBUTION OF TRAFFIC

The study also investigates the geographical distribution of traffic, both as a function of distance traveled and in relation to city size. Maps showing traffic density over the contiguous states are presented for each of the benchmark years 1980, 1990, and 2000.

### USER MARKET IDENTIFICATION

Sortings of the basic demand forecasts are presented to indicate the fraction of traffic demand generated by various user categories. The user categories are: Private Individuals, Business, Government, and Institutions.

### CASE STUDY OF A METROPOLITAN AREA

The study also includes a description of a large metropolitan area. The Atlanta region was selected for this purpose as being one of strong economic growth with rapidly expanding needs for communications facilities. The development of communications patterns in this region is typical of those urban areas undergoing substantial growth in population and in economic activity, and it is from these areas that the bulk of traffic demand may be expected.

## SERVICE COSTS

Communications is a commodity with an economic price tag and estimates are provided for the current and projected costs of telecommunications. The estimates include projections for the costs of terrestrial tails involved in distributing satellite traffic to users. Costs are also provided for terrestrial transmission facilities so that the costs of these facilities and those of projected satellite communications facilities may be compared. The elasticity of demand in response to changes in price is discussed in terms of telecommunications as a whole, and with respect to a limited segment of communications whose price behavior can vary with respect to that of telecommunications in general.

## DEMAND AS A FUNCTION OF RELIABILITY

Rain attenuation is an important design consideration for 30/20 GHz satellite communications. The cost of such a system is significantly dependent on reliability objectives. This study examines demand for satellite communications as a function of reliability for each of the service categories and subcategories. The degree of user acceptance at each level of reliability is established and the effectiveness of offering price reductions in compensation for reduced levels of reliability is discussed.

## REAL TIME VS. DEFERRED COMPONENTS OF DEMAND

Another important factor in telecommunications system design is the degree to which traffic can be deferred rather than immediately transmitted. A large component of deferred traffic permits more efficient use of the communications facilities by reducing peak loads. The demand forecasts of this study consider the real time and deferred transmission needs of the user community. That component of the demand requiring real time service is estimated as are those components that can tolerate various delays ranging from minutes to one day.

## SATELLITE CAPTURE

The portion of the total traffic that is likely to be carried by satellites for each of the benchmark years is estimated and expressed in terms of the number of satellite transponders that will be needed. This, in turn, is compared with the number of transponders that will be available in the C and Ku bands to arrive at the year in which C and Ku capacity would become saturated in the absence of new satellite technology.

# 2. METHODOLOGY

## SUBDIVISION BY SERVICE CATEGORIES AND SUBCATEGORIES

The primary demand forecasts of this study are developed by separating telecommunications into the three service groupings of Voice, Video, and Data. Each of these is divided into several major categories, most of which are further subdivided to arrive at a level of specialization at which the projection of future trends is facilitated. The major categories and subcategories used in this study are listed in Table 1, together with a brief indication of approach used in projecting demand.

## DEMAND PROJECTIONS

The division of overall traffic demand into the traffic components listed in Table 1 allows demand to be forecast by the methods most suitable for each in terms of available information sources and data bases. As indicated in Table 1, several different methods of forecasting were used. In some cases, extrapolation of existing trends (generally with additional considerations factored in) forms the primary basis for forecasting. In other cases, inputs are obtained from market research studies and from industry group surveys which forecast expected revenues and industry-wide expansion.

For newer telecommunications services, where historical trend data is non-existent, projections are based on the probable degree of displacement, by telecommunications, of services presently supplied by other modes. Demand for telecommunications in support of electronic mail, for example, is forecast on the basis of the replacement of a sizable portion of mail and other physical document delivery services. Similarly, a growing displacement of business air travel in favor of videoconferencing provides the basis on which videoconferencing traffic demand is projected.

## ANALYSIS

The segmentation of total demand into several categories and subcategories of traffic also facilitates the development of various analyses that were required. For example, the degree to which the reliability performance of a communications system may be expected to influence demand depends on the urgency of the various end user missions and applications. Clearly, a subcategory such as electronic mail can better tolerate occasional communications interruptions than can a subcategory with urgent real-time requirements such as Network TV.

## TABLE 1. CATEGORIES AND SUBCATEGORIES OF SERVICE DEMAND

VOICE

| CATEGORY | SUBCATEGORIES | PRIMARY BASIS FOR DEMAND PROJECTION |
|---|---|---|
| Message Telephone Service | MTS Residential<br>MTS Business | Correlated with pop. plus cost and social factors<br>Correlated with pop. plus economic factors |
| WATS | - | Extrapolated growth plus regulatory considerations |
| Private Line | Telccs<br>SCCs and OCCs | Revenue forecasts plus regulatory considerations<br>" |

VIDEO

| CATEGORY | SUBCATEGORIES | PRIMARY BASIS FOR DEMAND PROJECTION |
|---|---|---|
| Network TV | Commercial Nets<br>Non-Commercial Nets | Network expansion plans<br>" |
| CATV | Program Orig. and Distrib.<br>Superstations | Extrapolated growth trends<br>" |
| Videoconferencing | - | Displacement of air travel |
| Educational TV | Intrastate<br>Interstate<br>Specialized | Allocation by state<br>Expansion of existing experimental facilities<br>" |
| Health and Public Affairs | Telemedicine<br>Public Affairs | Industry group projections<br>" |

DATA

| CATEGORY | SUBCATEGORIES | PRIMARY BASIS FOR DEMAND PROJECTION |
|---|---|---|
| Message | TWX/Telex<br>Traditional FAX<br>Electronic Mail-Image<br>Electronic Mail-Char. | Extrapolated terminal population<br>"<br>Displacement of paper document delivery<br>" |
| Computer | Terminal/CPU<br>CPU/CPU | Extrapolated terminal population<br>Percent of terminal/CPU traffic plus E.F.T. |
| Narrowband Teleconferencing | FAX Mode Support<br>Character Mode Support<br>Freeze Frame TV | Displacement of air travel<br>"<br>" |

By analyzing each component separately, and aggregating the results, estimates of overall reliability requirements are obtained.

Similar considerations apply to the investigation of the relative magnitudes of real-time vs deferred modes of transmission and to such technical issues as peak factors and the degree of market penetration that may be expected for satellite communications.

## UNITS

Demand is expressed, at various points in the report, in different systems of units as appropriate to the particular subject under discussion. Initially, demand estimates are expressed in the units most commonly used for the traffic component in question. Thus demand for Message Telephone Service is first developed in terms of the number of call-seconds required, while demand for Network TV and CATV is expressed in terms of video channels. Similarly, requirements for Videoconferencing are originally developed in terms of the required number of teleconference hours per year, while Data traffic is estimated in terms of terabits per year (one terabit equals $10^{12}$ bit).

This approach has the advantage of simplifying the use of available data and allowing ready crosschecking of information from differing sources. However, it does not lend itself to comparisons of the amount of demand in one traffic category relative to the others, and it does not permit the aggregation of results. At a later stage in the report, when it becomes necessary to compare and combine the demand estimates for the various components of traffic, the estimates are converted to common units. Since most satellite technology over the time frame of this study will be digital, the units selected are bits, and demand for all traffic components is converted to terabits per year.

Finally, in order to estimate the communications resources needed to satisfy projected demand, the demand estimates are converted to peak hour traffic rates (megabits per second) and, after estimating the fraction of traffic that will be captured by satellites, into requirements for satellite transponders.

## CASE STUDY OF A METROPOLITAN AREA

Background data for the description of the Atlanta region was obtained by interviews with organizations in the Atlanta region. Primary sources of data are the Southern Bell Telephone Company and the Atlanta Regional Commission. Supplementary information was provided by various planning documents and reports. Nationwide demographic, economic, and telecommunication traffic data was used to compare results for Atlanta with general trends and to provide background information to supplement that obtained in Atlanta.

## NEED FOR NEW TECHNOLOGY

The demand studies reveal a large growth in requirements for satellite communications over the period of this study. The projected demand is compared with the capacity of present technology to determine the probable date at which new technology, beyond that presently contemplated for C and Ku band satellites, will be needed.

# 3. RESULTS

## DEMAND FOR VOICE SERVICES

Demand for voice services is presented in several different forms. The first projects voice service traffic in basic units of billions of call seconds per year for MTS and WATS, and in terms of the required number of nominal 4 KHz duplex lines for Private Line Service. These results are presented in Table 2. All requirements shown pertain to intercity traffic traveling 200 miles or more.

TABLE 2. VOICE SERVICE DEMAND - BASIC UNITS
(Greater than 200 Miles)

| | 1980 | 1990 | 2000 |
|---|---|---|---|
| MTS Residential (billion call-sec.) | 634 | 1540 | 2950 |
| MTS Business (billion call-sec.) | 686 | 1800 | 3920 |
| WATS (billion call-sec.) | 1250 | 2880 | 4470 |
| Private Lines (thous. of duplex lines) | 57 | 150 | 367 |

Voice traffic demand is also developed in terms of the number of voice circuits needed to accommodate busy-hour demand. Table 3 presents these results for the business peak hour which, when video and data traffic are added, becomes the controlling peak. Results for the residential peak hour, however, are virtually the same.

TABLE 3. VOICE SERVICE DEMAND - MILLIONS OF
PEAK HOUR DUPLEX CIRCUITS
(Greater than 200 miles)

| | 1980 | 1990 | 2000 |
|---|---|---|---|
| MTS Business & Residential | 0.11 | 0.28 | 0.59 |
| WATS | 0.18 | 0.41 | 0.63 |
| Private Line | 0.06 | 0.15 | 0.36 |
| TOTAL | 0.35 | 0.84 | 1.58 |

Lastly, Voice Service Demand is converted from the basic units of Table 2 to digital units to permit later comparison and aggregation with Video and Data Service Demand. Results are presented in Table 4. A basic voice digitization rate of 64 Kbps is assumed.

TABLE 4. VOICE SERVICE DEMAND - THOUSANDS OF TERABITS PER YEAR
(Greater than 200 miles)

| | 1980 | 1990 | 2000 |
|---|---|---|---|
| MTS Business & Residential | 169 | 427 | 880 |
| WATS | 160 | 369 | 572 |
| Private Line | 230 | 605 | 1441 |
| TOTAL | 559 | 1401 | 2893 |

The composite average annual growth rate for the first decade is 9.6 percent, decreasing to 7.5 percent in the period 1990 to 2000.

## DEMAND FOR VIDEO SERVICES

Demand for video services is summarized in Table 5. Videoconferencing demand is expressed in terms of thousands of teleconferences per year. All other components are stated in terms of video channels.

TABLE 5. VIDEO SERVICE DEMAND - BASIC UNITS
(Greater than 200 miles)

| | Units | 1980 | 1990 | 2000 |
|---|---|---|---|---|
| Network TV | Video Channels | 10 | 12 | 16 |
| CATV | Video Channels | 35 | 50 | 60 |
| Videoconferencing | Thous. of Teleconf/Yr | 5 | 830 | 3100 |
| Educational Video | Video Channels | 15 | 165 | 500 |
| Health & Public Affairs | Video Channels | 0 | 25 | 50 |

A video channel, in this context, expresses user needs for the one-way transmission of full motion images. However, not all of these channels are in full-time use, and quality requirements vary from category to category.

Table 6 takes quality variations into account by applying suitable bandwidth compression factors, and also accounts for the part time usage patterns estimated for each traffic category. Traffic demand in Table 6 is expressed in thousands of terabits per year. Videoconferencing demand is converted to terabits per year by assuming that the average teleconference requires the use of a two-way video channel for two hours. A basic digital rate of 42 megabits per second for each video channel is assumed, and after suitable bandwidth factors are applied a conversion to digital units is calculated.

TABLE 6. VIDEO TRAFFIC DEMAND IN THOUSANDS OF TERABITS PER YEAR
(Greater than 200 Miles)

| | 1980 | 1990 | 2000 |
|---|---|---|---|
| Network TV | 13.2 | 15.9 | 10.6 |
| CATV | 46.4 | 33.1 | 26.5 |
| Videoconferencing | 3.0 | 83.7 | 267.8 |
| Educational TV | 19.9 | 36.4 | 110.4 |
| Health & Public Affairs | 0 | 1.6 | 2.2 |
| TOTAL | 82.5 | 170.7 | 417.5 |

Videoconferencing, which starts modestly in 1980, grows to become the largest component of video traffic by 1990. Taken as a whole, demand for video service exhibits a 7.5 percent average annual growth rate during the first decade, which accelerates to 9.4 percent during the second decade.

## DEMAND FOR DATA SERVICES

Data service demand is forecast by a variety of techniques specific to each of the categories and subcategories that were investigated. Demand is initially obtained in terms of the quality of information to be transferred (for example, by estimating the number of documents to be transferred by electronic mail and the number of bits necessary to accomplish this transfer by image and character mode transmissions). These results, however, must be multiplied by factors of considerable magnitude to take into account the inefficiency inherent in most forms of data transmission.

Access from keyboard terminals to remote computers illustrates the high degree of inefficiency typical of many practical data transfer applications. Generally, when a terminal accesses a computer through dial-up facilities, a full voiceband channel is seized for the duration of the session. Similarly, in terminal/CPU applications using private lines, a voiceband channel is usually occupied by the terminal or terminals sharing that line and furthermore,that voiceband channel is reserved full time whether or not data is actually being transferred.

If the needed voiceband channels are derived digitally, as is most probable for advanced satellite systems, the digital equivalent of these channels will be required. This forecast assumes, that over the time frame projected, the 64 KBPS rate (128 KBPS for full duplex) widely used as the digital equivalent of a voice channel in the T-1 Carrier System will prevail.

Thus, remote computer access applications typically will occupy communications links capable of transferring thousands of bits per second but, because of human interaction times may actually transfer information at rates averaging only a few bits per second. The consequent high degree of inefficiency results in a very large multiplication of the service demands associated with these applications and this has been reflected in the demand estimates for data services presented in the forecast for 1980. Network approaches which avoid the high degree of inefficiency have begun to emerge, chiefly in the form of packet networks and similar specialized data network offerings of various carriers. Such approaches can be effective in improving efficiency by factors in the order of 100 to one. This forecast assumes that by 1990, one-third of the terminal/CPU applications will benefit by the avilability of such facilities and that by the year 2000 this will increase to 60 percent.

Even with these sizeable portions of traffic travelling via packet or other relatively efficient means, the overall efficiency of data traffic remains low throughout the forecast period. Average values for the efficiency of data communications, weighted according to the relative magnitudes of each traffic component are estimated at 0.2 percent, 1.5 percent, and 1.7 percent for 1980, 1990 and 2000 respectively.

Table 7 presents demand forecasts for data service for each of the benchmark years of this study. The results presented include the factors appropriate to each traffic component for each year to account for the inefficiency of facility usage. All demand elements are long distance (nominally 200 miles or more). Totals are rounded.

Data traffic during the first decade has an overall 9.6 percent average yearly growth rate which decelerates to 4.6 percent during the second decade. Deceleration in demand is due in part to projected technological improvements in efficiency and in part to market saturation effects in some categories of traffic.

TABLE 7. DATA SERVICE DEMAND IN THOUSANDS OF TERABITS PER YEAR (Greater than 200 Miles)

| | 1980 | 1990 | 2000 |
|---|---|---|---|
| MESSAGE TRAFFIC | | | |
| TWX/Telec | Neglig. | Neglig. | Neglig. |
| Fascimile | 0.3 | 1.7 | 4.4 |
| Electronic Mail | --(1) | 5.9 | 6.7 |
| Total Message Traffic | 0.3 | 7.6 | 11.1 |
| COMPUTER TRAFFIC | | | |
| Terminal/CPU | 110.0 | 265.0 | 389.0 |
| CPU/CPU | 1.2 | 7.0 | 34.1 |
| Total Computer Traffic | 111.2 | 272.0 | 423.1 |
| NARROWBAND TELECONFERENCING | | | |
| Image & Char. Mode Support | Neglig. | 0.2 | 0.4 |
| Freeze Frame TV | Neglig. | 0.6 | 1.9 |
| Total Narrowband Teleconf. | Neglig. | 0.8 | 2.3 |
| TOTAL DATA TRAFFIC DEMAND | 112 | 280 | 437 |

(1) 1980 Elect. Mail included in other traffic subcategories.

## SUMMARY OF DEMAND FORECASTS

Demand for Voice, Video and Data Services is summarized in Table 8.

TABLE 8. SUMMARY OF VOICE, VIDEO AND DATA TRAFFIC DEMAND IN THOUSANDS OF TERABITS PER YEAR
(Greater than 200 Miles)

| | 1980 | 1990 | 2000 |
|---|---|---|---|
| Voice | 559 | 1401 | 2893 |
| Video | 83 | 171 | 418 |
| Data | 112 | 280 | 437 |
| Total | 754 | 1852 | 3748 |

Throughout the forecast period voice service represents the largest component of demand with video and data demand being considerably lower and roughly comparable to each other. During the first decade of this forecast, total demand grows at an average annual rate of 9.4 percent, which moderates to 7.3 percent during the second decade. Over the two decades covered, demand grows by a factor of five, providing a clear signal that existing facilities will require considerable augmentation to handle the expected traffic.

## DISTANCE DISTRIBUTION OF TRAFFIC

The distance over which traffic is transferred depends on community of interest patterns that exist within the United States. Many of the communication traffic components considered in this study may be expected to follow distance distributions typical of long distance telephone traffic. MTS Voice traffic is clearly of this type, and so also are some components of Data traffic. Teleconferencing, however, may be expected to follow distance distribution patterns more like those pertaining to airline traffic and the message traffic distance distribution finds its parallel in the distribution of First Class Mail.

The following illustration shows the distance distribution for telephone toll traffic, airline trips, and first class mail for distances beyond 200 miles.

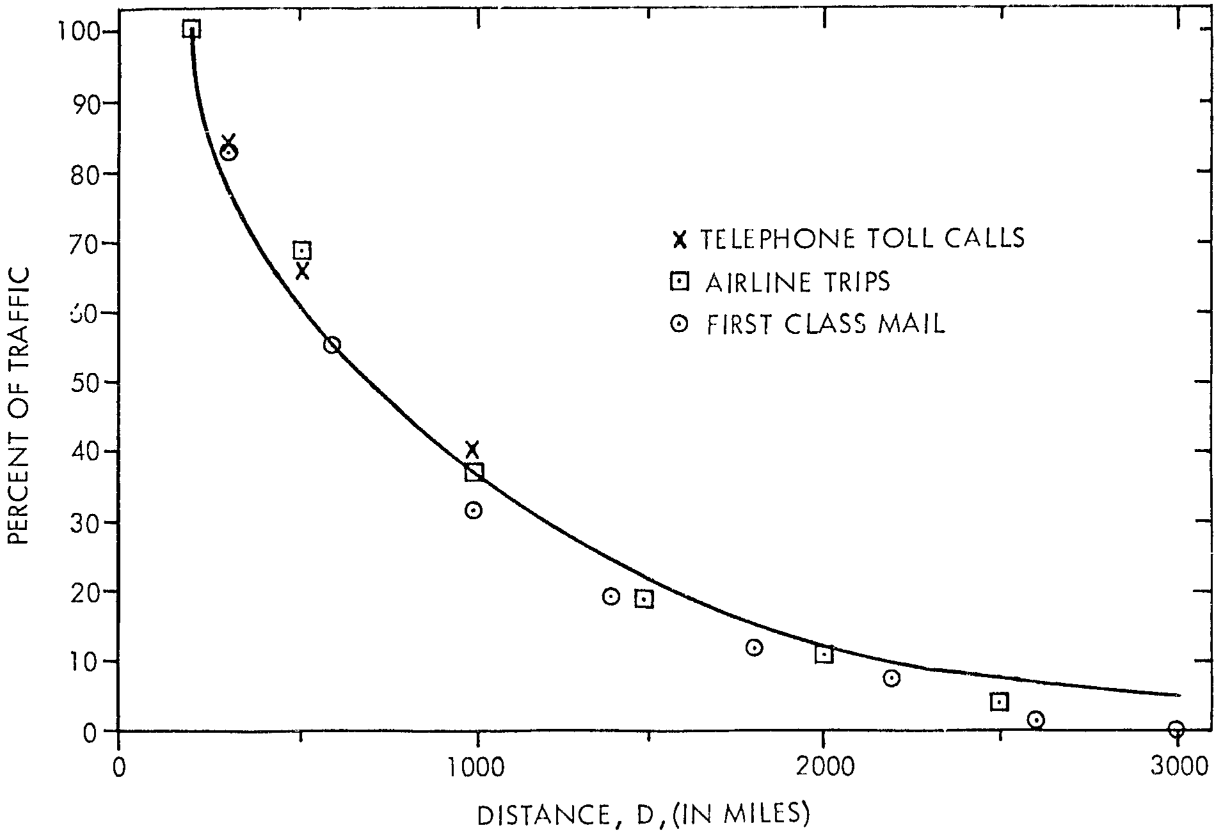

FIG.1. DISTANCE DISTRIBUTION BEYOND 200 MILES OF VARIOUS TYPES OF TRAFFIC

The three distributions plotted are remarkably similar considering the diversity of the communities of interest represented. The single curve illustrated provides a reasonable approximation to all three distributions. The equation of this curve is:

$$T = 100e^{-\frac{D}{1000}}$$

where T is the percent of traffic beyond 200 miles that travels D miles or more. Based on this empirical curve, 50 percent of the traffic most suitable for satellite transmission (i.e., that transmitted beyond 200 miles) travels more than 700 miles and 37 percent travels more than 1000 miles.

Since a single distribution provides a good approximation to the three communities of interest represented by toll telephone, air travel, and first class mail statistics, it is reasonable to assume that no significant difference will be found in the distances traveled by the various communications components that are logically related to these distributions.

Thus it may be concluded that, to a first approximation, voice and data traffic, and many of the subcategories of video traffic, follow roughly the same distance distribution. Furthermore, it appears that the distance distribution is relatively insensitive to future population shifts, and as a result will not change significantly over the time frame of this study.

Network TV, CATV, and some of the other components of video, however, depart from the distance distribution discussed above. These network-oriented subcomponents of the Video Services category require a relatively small number of wideband channels originating in specific major metropolitan areas. These channels are used in a broadcast mode to reach a widely dispersed set of users. While Network TV and CATV demand is of significance circa 1980, the rapid growth of Videoconferencing soon dominates video demand. As a result, with the possible exception of 1980, the bulk of video as well as voice and data traffic is predicted to follow the distance distribution described above.

TRAFFIC VOLUME AS A FUNCTION OF CITY SIZE

Cities throughout the U.S. vary widely in both size and in character so that two cities of the same size may present considerably different traffic requirements. However, when averaged over many cities, with a wide mix of characteristics, variations from city to city average out and population remains the basic determinant of traffic.

Figure 2 shows the distribution of population among cities in six population ranges from very small to very large. Under the assumption that the overall distribution of communications demand follows population patterns, the same chart provides a breakdown of total telecommunications demand by city size.

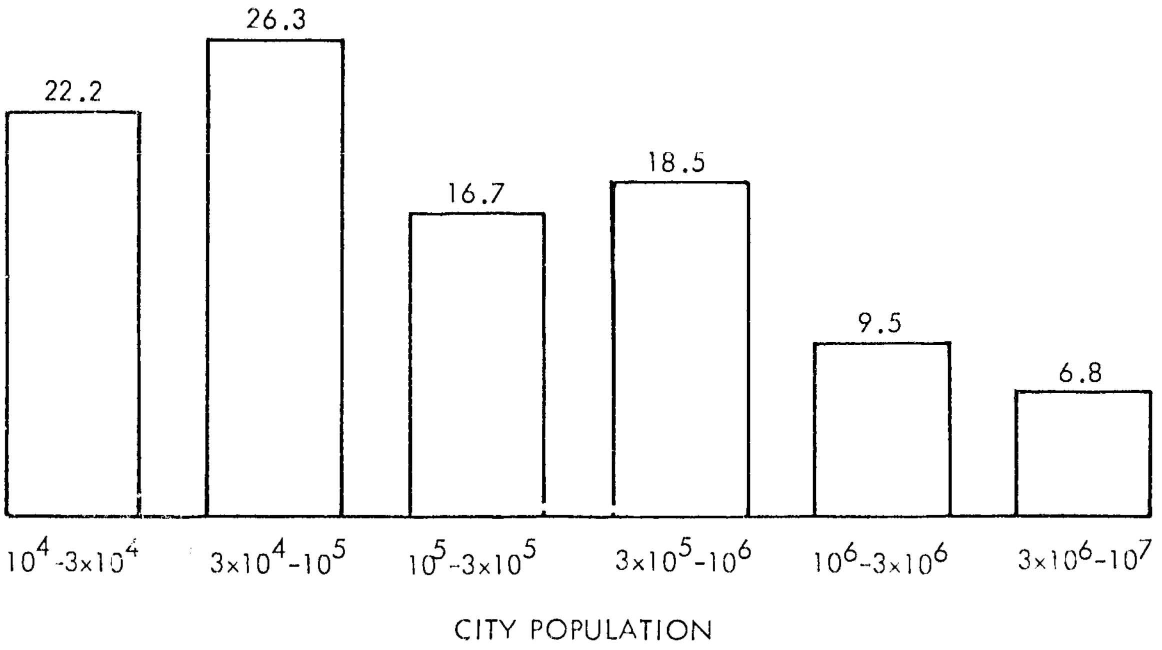

FIGURE 2. PERCENT OF POPULATION (OR TRAFFIC) BY CITY SIZE FOR CITIES WITH POPULATIONS ABOVE 10,000

Since the ratio of business traffic to residential traffic generally increases as a function of city size, it is also of interest to consider separately the distributions of traffic by city size for business and for residential traffic. This was accomplished by determining the relative number of business and residential telephones in cities of each size category and using the ratio to modify the total traffic demand shown in Figure 2. The resulting distributions for business and residential traffic are shown in Figures 3 and 4 respectively.

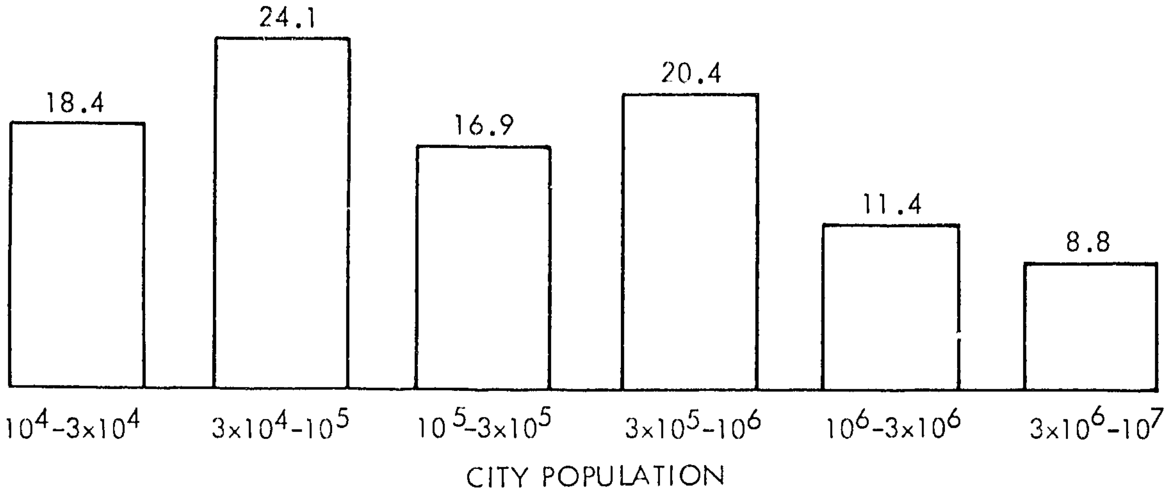

FIGURE 3. PERCENT OF BUSINESS TRAFFIC BY CITY SIZE

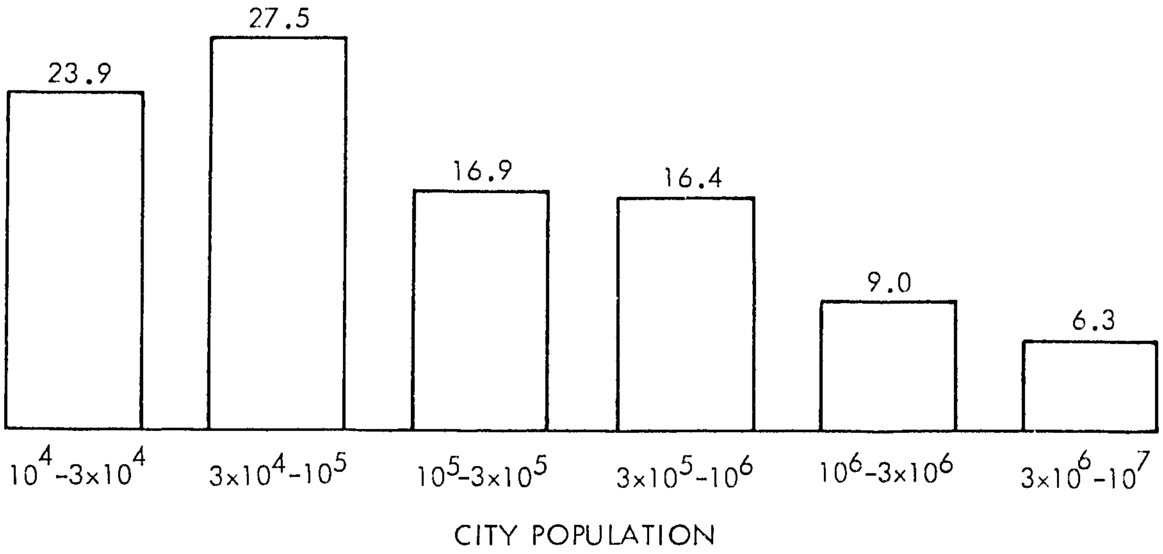

FIGURE 4. PERCENT OF RESIDENTIAL TRAFFIC BY CITY SIZE

The sorting of residential and business-oriented traffic by city size category, as shown in Figures 3 and 4, may be approximately correlated with the service categories of Voice, Video, and Data used elsewhere in this report. The business traffic distribution of Figure 3 serves as a model for almost all of the Data traffic and for most of the Video. It also serves as a model for the WATS, Private Line, and MTS Business components of Voice traffic. Thus Figure 3 describes the distribution with respect to city size of most of the service categories defined in this report. The major exceptions to this are MTS Residential traffic which can be expected to follow the residential distribution shown in Figure 4, and the network oriented portions of Video components which originate in a few specific metropolitan areas rather than being widely distributed over the United States.

## TRAFFIC DENSITY DISTRIBUTION

The study estimates the density of communications traffic per square mile throughout the United States. The basic telecommunications demand forecasts for the United States was organized for this purpose into three groupings as follows:

a. Residential (MTS Residential only)
b. Network TV
c. Business - all other subcategories of Table 1

To estimate the traffic per unit area over the United States, the Residential and Business traffic as defined above was distributed in proportion to the number of residential and business telephones existing in each state. Network TV traffic was assigned proportionately to the three metropolitan areas in which this traffic originates, i.e., New York, Los Angeles, and Washington, D.C. and is included in the associated states.

The total traffic for each geographic region was then divided by the land area of that region to obtain traffic density per unit area. Results are displayed in Figures 5, 6, and 7, for the years 1980, 1990, and 2000, respectively. The density ranges indicated on the maps are decade ranges defined as follows:

Very Low - .01 to 0.1 terabits per year per square mile
Low - 0.1 to 1.0
Medium - 1.0 to 10
High - 10 to 100

The results confirm expected patterns, with the higher traffic densities primarily concentrating in the Northeast. Figures 5, 6, and 7 show the overall increase in traffic density over the 1980 to 2000 time frame. In 1980 only three percent of the total U.S. area generates more than one terabit per square mile annually. By 1990, eighteen percent of the area generates more than one terabit per square mile annually, and by the year 2000 this level of traffic originates from almost a third of the area of the U.S.

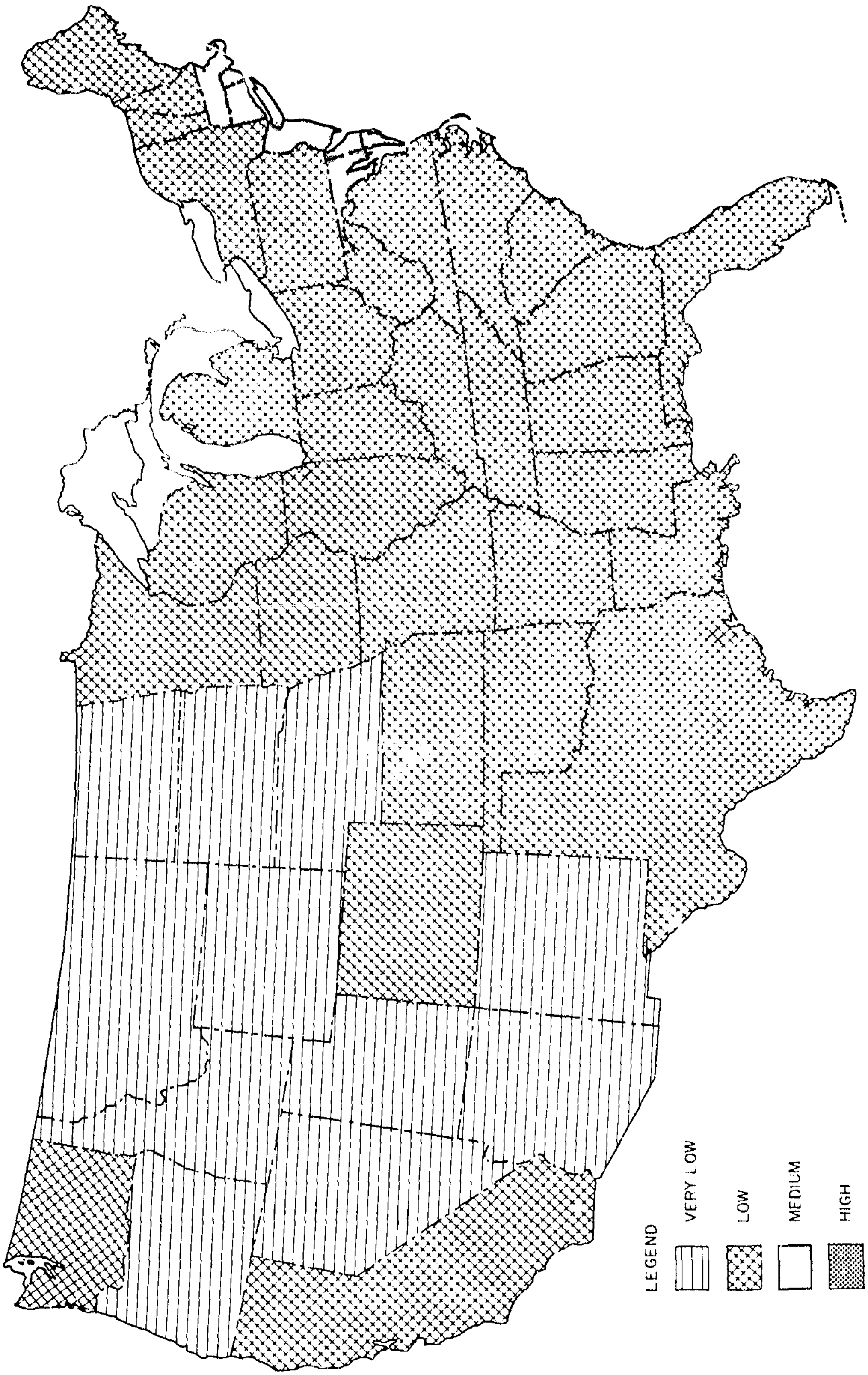

FIGURE 5. TRAFFIC DENSITY - 1980

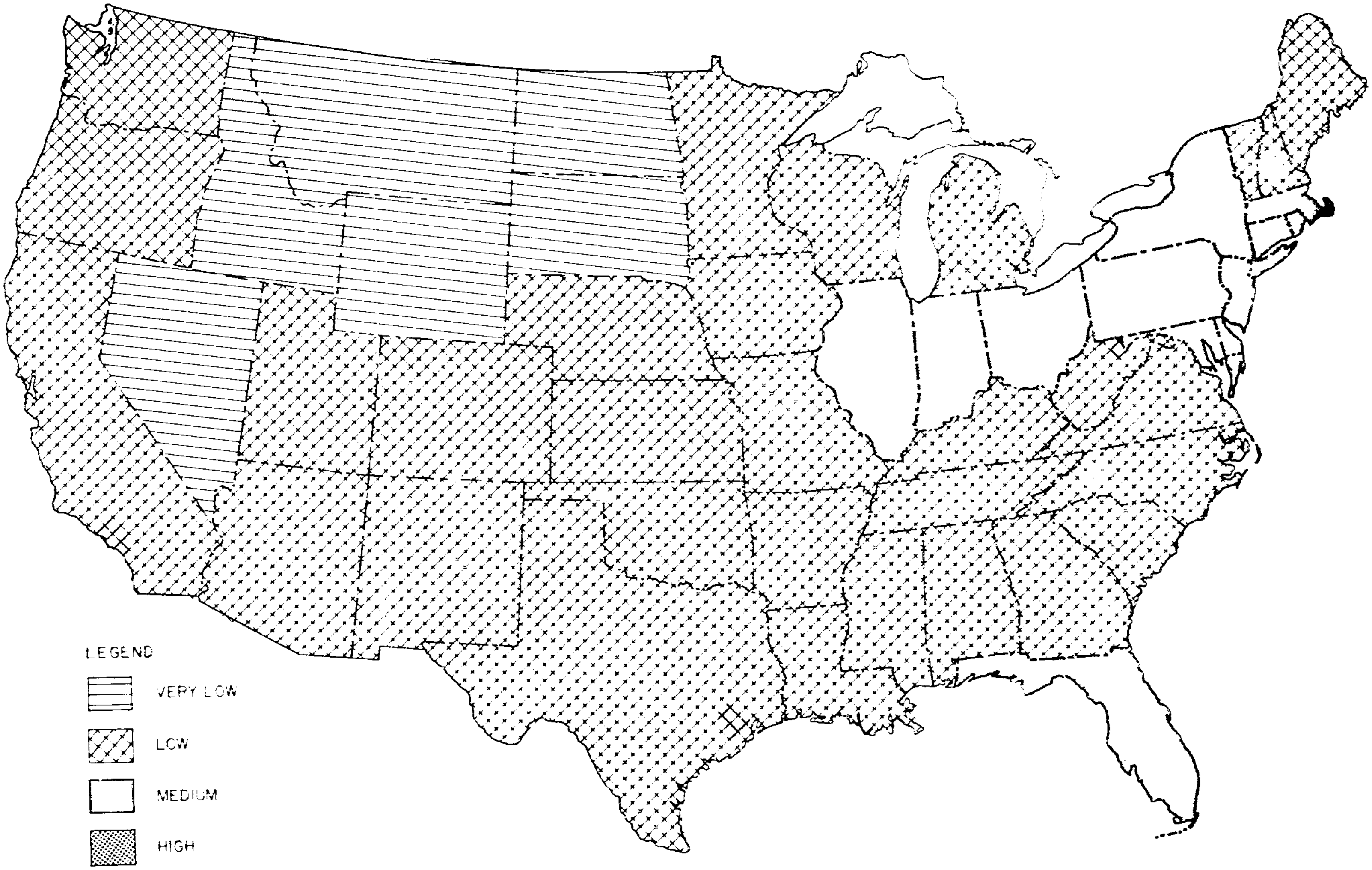

FIGURE 6. TRAFFIC DENSITY - 1990

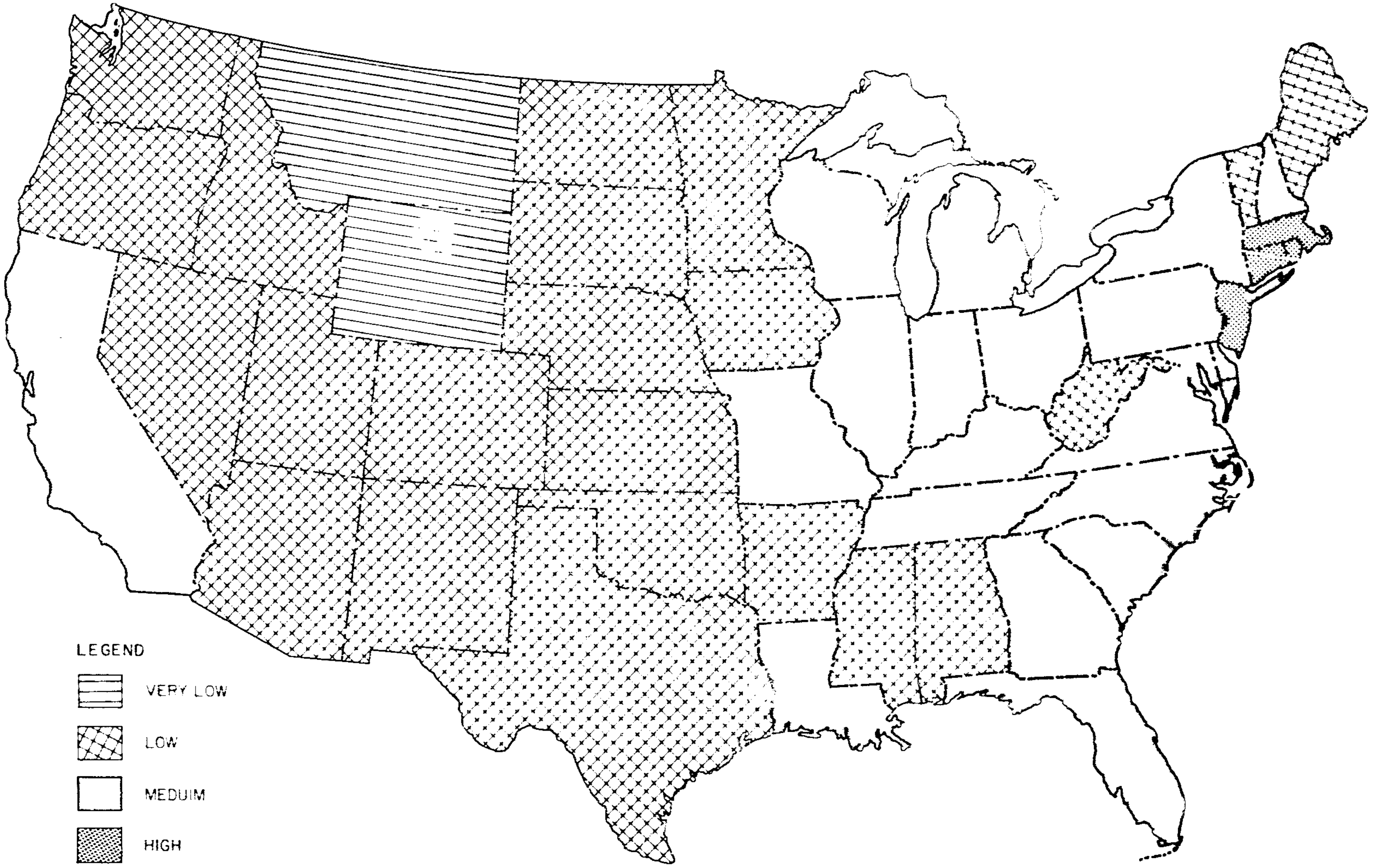

FIGURE 7. TRAFFIC DENSITY - 2000

## USER MARKET IDENTIFICATION

The study presents a breakdown of the traffic demand according to type of user. Table 9 shows traffic in thousands of terabits per year for each of the benchmark years separated into four user categories.

TABLE 9. DISTRIBUTION OF TRAFFIC BY USER CATEGORY
(thousands of terabits per year)

| | Private | Business | Govt. | Inst. | Total |
|---|---|---|---|---|---|
| Voice | | | | | |
| 1980 | 81 | 322 | 90 | 66 | 559 |
| 1990 | 196 | 812 | 224 | 168 | 1400 |
| 2000 | 376 | 1676 | 491 | 347 | 2890 |
| Video | | | | | |
| 1980 | - | 61 | - | 22 | 83 |
| 1990 | - | 120 | 5 | 46 | 171 |
| 2000 | 4 | 266 | 14 | 134 | 418 |
| Data | | | | | |
| 1980 | - | 75 | 21 | 16 | 112 |
| 1990 | 3 | 188 | 53 | 36 | 280 |
| 2000 | 4 | 293 | 83 | 57 | 437 |

## CASE STUDY OF A METROPOLITAN AREA

This study examines the characteristics of a large metropolitan area to identify the telecommunications demand likely to evolve in centers of this type. The Atlanta region was selected for this purpose since it represents the type of fast growing metropolitan area that offers a good potential market for both existing and innovative telecommunications services.

The geographic area investigated in the case study includes:

(a) The Atlanta Region, consisting of seven counties containing more than 90 percent of the Atlanta SMSA's population and employment.

(b) The North Georgia Area, covering the telephone numbering plan area 404, which is one of the two area codes assigned to Georgia.

The Atlanta region in 1975 included 0.8 percent of the nation's population and 0.9 percent of the nation's employed, civilian, non-agricultural labor force. Current annual population growth rate is about five percent per year as compared to 0.8 percent for the country as a whole.

The Atlanta region's consumption of telecommunications is also rapidly growing. The number of main telephones in the Atlanta region is currently growing at over eight percent per year while overall for the United States this rate is three percent. Similarly, the number of households with access to CATV cables is higher in Atlanta than the national average.

The Atlanta region was recently chosen by Bell Laboratories as the location for a study of the economics of an all-digital telephone exchange capable of serving a mix of innovative telecommunications services expected for the 1980s. Currently an eight-mile fiber optics link is being implemented by the Southern Bell Telephone Company to supply 45 Mbps capacity in the Atlanta region.

The Atlanta region also is served by a large and growing number of trunks linking it to other metropolitan areas throughout the country. Figure 8 shows this community of interst circa 1978. A total of 6904 interstate trunks connecting Atlanta with 39 other major SMSAs are shown. Projections for 1980, 1990, and the year 2000 indicate that the number of trunks will grow to 8700, 16,700, and 31,300 respectively.

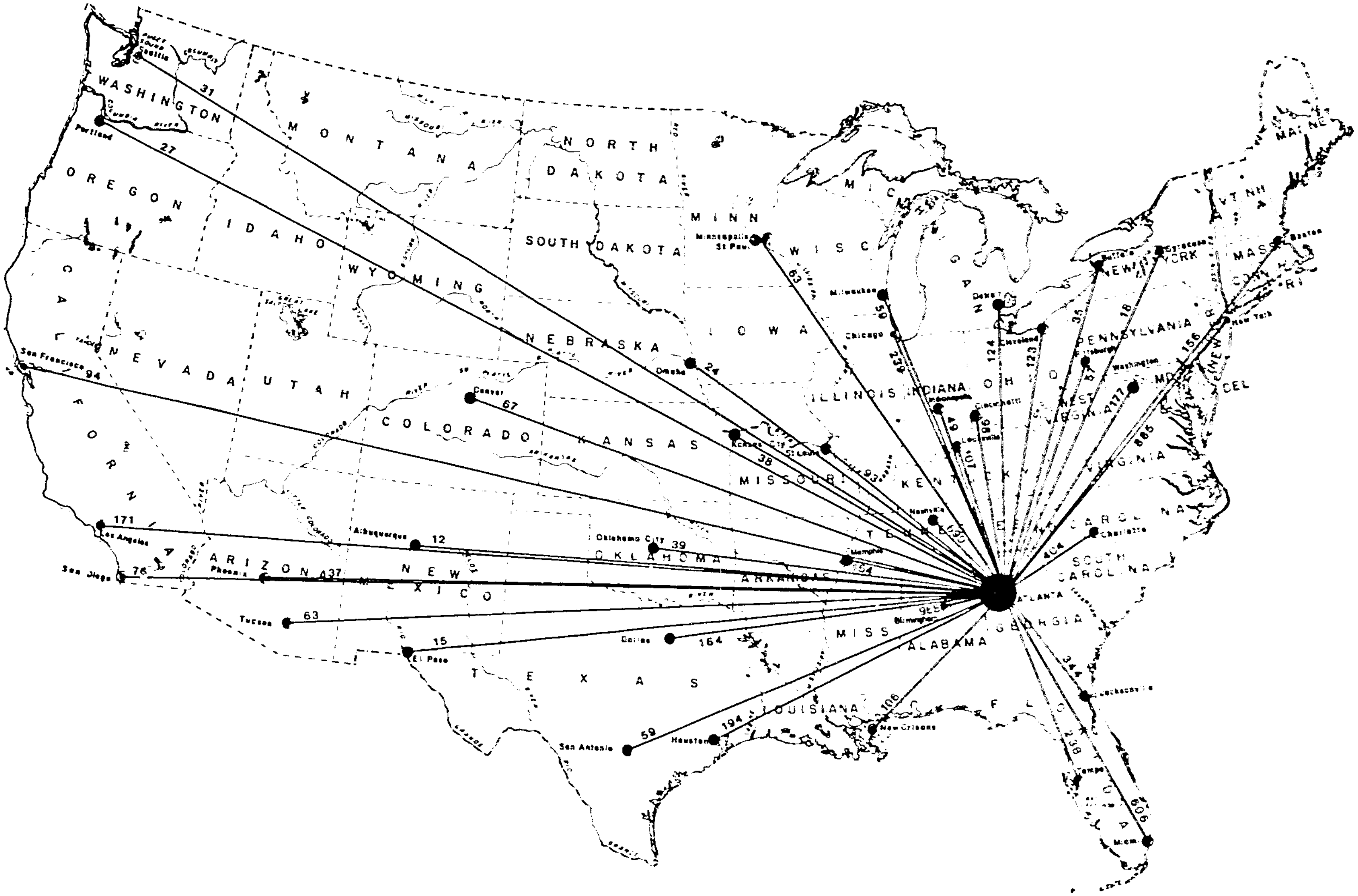

FIGURE 8. ATLANTA TELECOMMUNICATIONS COMMUNITY OF INTEREST, 1978
(Number of Trunks)

## TERRESTRIAL COMMUNICATIONS COSTS

The costs of long haul and short distance terrestrial communications facilities were estimated for the years 1980, 1990 and 2000. The terrestrial facilities considered are microwave radio relay, coaxial cable, and fiber optics cable. The first two media represent the bulk of the current terrestrial long haul plant, and the third, fiber optics, is anticipated to become an important constituent in the next two decades. All three terrestrial media are important competitors to a potential 30/20 GHz satellite system.

Table 10 summarizes terrestrial communications costs for all three media for the years 1976, 1980, 1990, and 2000. Costs are provided for both analog and digital systems and weighted averages are formed to arrive at composite costs. Projections for microwave radio relay and coaxial cable are determined by starting with 1976 as the base year since good data is available for this year from the FCC and common carrier sources. Fiber optics facilities, however, are insignificant for the base year since this new technology had almost no in-place plant in 1976. Projections for fiber optics, therefore, are based on estimates for the technology derived from current ITT planning information. It is anticipated that fiber optics will be important in satisfying new traffic requirements.

The requirements for short haul terrestrial communication links is different from that described above. Terrestrial links of up to 50 miles will be needed to support local distribution of a satellite trunking earth station as well as to provide interconnection between two space diversity earth station sites which are employed for reliability purposes. There is no inherent difference, however, in the type of equipment used for short haul transmission as compared to that used for long haul transmission. Table 11 summarizes the short haul transmission costs.

## TABLE 10. COMPOSITE TERRESTRIAL VIDEO CIRCUIT COSTS (1976-2000)

| YEAR | ITEM | CAPITAL COSTS |  |  |  |  | RECURRING COSTS |  |  |  |  | Total Costs Weighted | Per-cent In Mix | Total Composite |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Analog |  | Digital |  | Weighted | Analog |  | Digital |  | Weighted |  |  |  |
|  |  | $ | % | $ | % | $ | $ | % | $ | % | $ | $ | % | $ |
| 1976 | Microwave | 257 | 100 | N.A. | - | 257 | 278 | 100 | N.A. | - | 278 | 535 | 67 | 359 |
|  | Coax Cable | 309 | 100 | N.A. | - | 309 | 471 | 100 | N.A. | - | 471 | 780 | 33 | 257 |
|  | F.O. Cable | - | - | - | - | - | - | - | - | - | - | - | - | - |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | 616 |
| 1980 | Microwave | 254 | 95 | 200 | 5 | 251 | 275 | 95 | 220 | 5 | 272 | 523 | 67 | 350 |
|  | Coax Cable | 309 | 100 | N.A. | - | 309 | 453 | 100 | N.A. | - | 453 | 768 | 33 | 253 |
|  | F.O. Cable | 160 | 70 | 130 | 30 | 150 | 566 | 70 | 639 | 30 | 588 | 738 | - | 0 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | 603 |
| 1990 | Microwave | 250 | 50 | 190 | 50 | 220 | 264 | 50 | 210 | 50 | 237 | 457 | 55 | 251 |
|  | Coax Cable | 300 | 50 | 234 | 50 | 267 | 430 | 50 | 453 | 50 | 442 | 709 | 20 | 142 |
|  | F.O. Cable | 60 | 40 | 34 | 60 | 50 | 344 | 40 | 370 | 60 | 360 | 410 | 25 | 103 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | 496 |
| 2000 | Microwave | 245 | 40 | 200 | 60 | 219 | 264 | 40 | 216 | 60 | 236 | 455 | 50 | 228 |
|  | Coax Cable | 290 | 10 | 222 | 90 | 228 | 429 | 90 | 450 | 10 | 432 | 660 | 5 | 33 |
|  | F.O. Cable | 55 | 10 | 40 | 90 | 42 | 340 | 10 | 362 | 90 | 360 | 402 | 45 | 181 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | 442 |

Notes:
1. Costs are in constant 1976 dollars per video channel mile.
2. Cost estimates based on 500 mile circuit length.
3. Microwave in 1990: 30% AR6A, 20% conventional FDM/FM, 50% digital.
Microwave in 2000: 40% AR6A, 60% digital.

TABLE 11. TERRESTRIAL TAIL COST PROJECTIONS (1976-2000)

50 MILE LENGTH - VIDEO SERVICE

| YEAR | ITEM | CAPITAL COSTS | | | | | RECURRING COSTS | | | | | TOTAL COSTS WEIGHTED |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Analog | | Digital | | Weighted | Analog | | Digital | | Weighted | |
| | | $ | % | $ | % | $ | $ | % | $ | % | $ | |
| 1976 | Microwave | 354 | 100 | - | - | 354 | 703 | 100 | - | - | 703 | 1057 |
| | Coax Cable | 313 | 100 | - | - | 313 | 830 | 100 | - | - | 830 | 1143 |
| | F.O. Cable | - | - | - | - | - | - | - | - | - | - | -- |
| 1980 | Microwave | 350 | 95 | 276 | 5 | 346 | 695 | 95 | 556 | 5 | 688 | 1034 |
| | Coax Cable | 313 | 100 | - | - | 313 | 798 | 100 | - | - | 798 | 1111 |
| | F.O. Cable | 171 | 70 | 139 | 30 | 161 | 1247 | 70 | 1408 | 30 | 1295 | 1456 |
| 1990 | Microwave | 344 | 50 | 262 | 50 | 303 | 668 | 50 | 530 | 50 | 599 | 902 |
| | Coax Cable | 304 | 50 | 237 | 50 | 271 | 758 | 50 | 799 | 50 | 799 | 1050 |
| | F.O. Cable | 73 | 40 | 41 | 60 | 54 | 759 | 40 | 816 | 60 | 793 | 847 |
| 2000 | Microwave | 337 | 40 | 276 | 60 | 300 | 668 | 40 | 545 | 60 | 594 | 894 |
| | Coax Cable | 294 | 10 | 225 | 90 | 232 | 756 | 10 | 794 | 90 | 790 | 1022 |
| | F.O. Cable | 59 | 10 | 43 | 90 | 45 | 750 | 10 | 798 | 90 | 793 | 838 |

Notes:
1. Costs are in constant 1976 dollars per video channel mile.
2. Cost estimates based on 500 mile circuit length.
3. Microwave in 1990: 30% AR6A, 20% conventional FDM/FM, 50% digital.
Microwave in 2000: 40% AR6A, 60% digital.

## PRICE ELASTICITY OF DEMAND

Elasticity of demand for communications service with respect to price changes depends very strongly on the alternatives available to users. When the communications plant as a whole is considered, demand is relatively inelastic. Values of about -0.2 are suggested in some recent studies of the telephone plant indicating that a decrease in price of one percent is likely to cause an increase in traffic of only 0.2 percent.

However, when a limited segment of communications is considered (for example, satellite communications), price changes relative to the remainder of the communications plant have a much larger impact on demand. Clearly, if users can select an alternative medium offering comparable service at lesser cost, they will elect the less costly alternative. Demand in this case may therefore be expected to be much more elastic. Some limited studies indicate that price elasticity for a limited segment of the communications plant is about -1.6. While available data does not provide guidance in this respect, it appears likely that this value is most applicable to price decreases of the limited segment below the prevailing rates for the remainder of the communications plant. Under these circumstances, a limited segment of communications offering a price decrement of one percent might be expected to achieve a 1.6 percent increase in volume.

## DEMAND AS A FUNCTION OF RELIABILITY

The acceptability of various levels of reliability is evaluated for each of the communications categories introduced in this study. This assessment is carried out over the range of reliability performance that may be expected at various levels of design for 30/20 GHz satellite links.

A reliability measure commonly used to describe communications system performance is "Availability" which is defined as the percentage of time for which the transmission quality achieves some defined standard of performance. The study evaluates the acceptability to users of service at four levels of reliability, 99.99 percent, 99.9 percent, 99.5 percent, and 99.0 percent. An availability level of 99.9 percent is roughly equivalent to, or slightly better than, that achieved by most present day electronic communications systems. Thus, the four levels of availability investigated cover a range of performance from much better to much worse than the performance of typical existing services.

While availability is a valuable indicator of reliability performance, it does not fully define the reliability of the link in terms that permit the evaluation of user acceptance. Availability is dependent only on the total number of hours of outage and gives no indication of whether this total consists of frequent short outages, or infrequent outages of longer duration. To supplement availability considerations, therefore, reasonable assumptions were made (based on typical rainstorm-induced outage patterns) regarding the frequency and durations of outages characteristic of each of the four levels of availability under consideration. Together with the availability these define the typical reliability profiles summarized in Table 12.

TABLE 12. TYPICAL RELIABILITY PERFORMANCE

| Availability (Percent) | 99.99 | 99.9 | 99.5 | 99.0 |
|---|---|---|---|---|
| Aggregate Outage (Hours per Year) | 0.9 | 9 | 44 | 88 |
| Typical Frequency (Outages per Year) | 11 | 35 | 105 | 175 |
| Typical Duration (Minutes) | 5 | 15 | 25 | 30 |

The reliability profiles presented in Table 10 were used as a guide in estimating the degree of acceptability of each level of reliability with respect to each of the traffic subcategories identified earlier (Table 1). For each traffic subcategory, an acceptability percentage was assigned reflecting the estimated competitive rating of a satellite link (at each reliability level) relative to other transmission modes of equal costs but with reliability typical of the existing telecommunications plant.

For a traffic component with more or less stringent reliability requirements, only the highest reliability levels would be considered acceptable by most users and this was accounted for by assigning acceptability percentages considerably less than 100 percent to the lower reliability levels. Thus, for example, for the Facsimile subcategory of traffic, acceptability values of 100, 90, 20, and 10 percent were assigned respectively to the availability levels of 99.99, 99.9, 99.5, and 99.0 percent. This reflects an estimation that virtually all users of Facsimile are likely to find currently available levels of reliability acceptable, but that the two lower levels of reliability would find few buyers at costs comparable to other existing transmission modes.

Similar acceptability percentages were assigned to each traffic subcategory using the reliability profiles of Table 12 as a guide and taking into account the requirements of typical users of each type of traffic. The assigned percentages were then combined with the forecast demand (in terabits per year) to arrive at weighted average acceptability percentages for Voice, Video, and Data as well as for total traffic demand.

The results of this analysis are presented in Table 13 for each benchmark year. Implicit in the previous discussion is the assumption that the cost for service at each reliability level is comparable to that of existing competitive telecommunications services at reliability levels typical of most existing communications. The study used the previously described procedure to evaluate also the probable effectiveness of a substantial cost reduction (20 to 30 percent) in improving the degree of acceptance. These results also appear in Table 13.

The values presented in Table 13 are not strongly dependent on year. The greatest dependence in this respect is in the Video category, reflecting a trend toward less critical traffic as Video Teleconferencing grows relative to the highly critical Network TV component. Even for Video, however, variation from year to year is not of major significance.

## TABLE 13. SUMMARY PERCENT ACCEPTABLE VS. AVAILABILITY

| | DEMAND TERABITS/YR. | 99.99% | | 99.9% | | 99.5% | | 99.0% | |
|---|---|---|---|---|---|---|---|---|---|
| | | SAME COST | LESS COST | SAME COST | LESS COST | SAME COST | LESS COST | SAME COST | LESS COST |
| 1980 | | | | | | | | | |
| VOICE | 559,000 | 100 | 100 | 96 | 100 | 6 | 23 | 0 | 10 |
| VIDEO | 83,000 | 82 | 90 | 38 | 55 | 2 | 13 | 0 | 0 |
| DATA | 112,000 | 99 | 100 | 70 | 90 | 20 | 30 | 0 | 20 |
| TOTAL | 754,000 | 98 | 99 | 86 | 94 | 8 | 23 | 0 | 8 |
| 1990 | | | | | | | | | |
| VOICE | 1,401,000 | 100 | 100 | 96 | 100 | 6 | 23 | 0 | 10 |
| VIDEO | 171,000 | 91 | 94 | 57 | 69 | 2 | 14 | 0 | 0 |
| DATA | 280,000 | 100 | 100 | 71 | 90 | 21 | 31 | 2 | 21 |
| TOTAL | 1,852,000 | 99 | 99 | 89 | 96 | 8 | 23 | 3 | 11 |
| 2000 | | | | | | | | | |
| VOICE | 2,893,000 | 100 | 100 | 95 | 100 | 5 | 22 | 0 | 10 |
| VIDEO | 418,000 | 97 | 98 | 65 | 76 | 3 | 16 | 0 | 0 |
| DATA | 437,000 | 99 | 100 | 71 | 90 | 20 | 30 | 1 | 20 |
| TOTAL | 3,748,000 | 99.5 | 99.8 | 89 | 96 | 7 | 22 | 1 | 10 |

The following conclusions may be drawn from Table 13.

1. High Availability (99.99 percent)
   - Acceptable to virtually all candidate traffic.
   - Cost reduction and/or further improvement in availability produces negligible increase in acceptability.

2. Medium Availability (99.9 percent)
   - Acceptable to most, but not all, of the candidate traffic.
   - Cost reduction can improve acceptability, but not to the levels achieved with high availability above.

3. Low Availability (99.5 percent and 99.0 percent)
   - Acceptable to only a minor fraction of the candidate traffic.
   - Cost reduction has a significant impact on acceptability and results in the satisfaction of nearly one-quarter of the potential traffic at 99.9 percent availability.

As a general conclusion, it appears that the improvement of availability has greater significance than the lowering costs.

## REAL-TIME VS DEFERRED TRAFFIC DEMAND

An important factor in the design of a communications system is the degree to which real-time response is required. Real-time transmissions intensify the inefficiencies inherent in designing for peak hour demands, while deferred traffic allows greater efficiency by permitting use of the facilities provided during off-peak hours.

Real-time usage implies immediate transmission of the signal from user to user. In practice, however, some delays are induced by propagation time, or by the transmission mode (for example, packetized voice). These are generally accepted within the definition of real time as long as the delays remain a fraction of a second or less. The major contributor to real-time traffic is Voice, but other important traffic segments with real-time demands exist in the Video and Data categories as well.

Systems for deferred traffic may be designed for a wide range of delays. For convenience in estimating demand, deferred traffic was considered under three categories corresponding to delays in the order of minutes, hours, or one day.

Delays in the order of minutes do not allow much latitude in reassigning traffic to less busy hours, but nevertheless permit some design economies in the form of packet transmission or other forms of dense packing of bits. Many applications of facsimile service fall in this category as does some of the inquiry mode data traffic, and the more urgent components of electronic mail.

User tolerance for delays of several hours results in substantial system economy by off-loading peak hour traffic. Many communications applications can profitably use, and in some cases may even require, such delays (for example, store and forward traffic to an office which, because of time zone differences, will not open for some hours). Much of the electronic mail and computer type traffic such as that used in Electronic Funds Transfer applications is in this category. In addition, some transmissions to off-line storage media (such as magnetic tape) for later replay can profitably tolerate several hours of delay, and candidate traffic of this type will be found in the Video area.

The last category of deferred traffic (delays up to one day) permits overnight transmission and, in many respects, is similar to the "Express Mail" service currently offered by the U.S. Postal Service. Candidates for this type of service include the less urgent segments of electronic mail and the various video signals transmitted to storage media for later replay.

The overall methodology followed in estimating user requirements for real-time vs deferred traffic is similar to that used in the previous discussion of service demand vs availability. Estimates of user requirements for each of the subcategories of traffic included under Voice, Video, and Data were formed by considering the types of communications applications contributing to the traffic and their typical requirements. Weighted averages were then formed to obtain estimates for the percentage of traffic for which real-time response is needed and the percentages for which delays in the order of minutes, hours, and one day are suitable. An underlying assumption in arriving at these figures is that the longer the delay, the less costly the service, and that consequently a strong economic motivation is offered to users able to accept progressively greater delays.

Table 14 summarizes the percent of traffic demand falling in each range of delay.

Most of the traffic categories included in Table 14 change only slightly with time. The major exception is Video traffic which, because of the growth of Video Teleconferencing, moves moderately toward a greater percentage of real-time demand as time progresses.

For all components of traffic, the major requirement is for real-time service. Data traffic provides the highest overall demand for deferred traffic amounting to roughly 40 percent of the volume, but most of this is in the minutes to hours delay categories. Video traffic has a lower proporation of deferred traffic, but much of its demand for deferred traffic falls in the hours to one-day delay categories, allowing convenient use of off-peak nighttime capacity.

Total traffic, which tends to be dominated by the large component of real-time voice traffic, presents approximately 90 percent of its demand in the real-time category and has relatively small demands for service in each of the deferred delay categories.

## TABLE 14. SUMMARY
## PERCENT REAL-TIME VS DEFERRED TRAFFIC DEMAND

| | DEMAND TERABITS/YR. | REAL TIME | DEFERRED | | |
|---|---|---|---|---|---|
| | | | MINUTES | HOURS | ONE-DAY |
| 1980 | | | | | |
| VOICE | 559,000 | 100 | 0 | 0 | 0 |
| VIDEO | 83,000 | 53 | 0 | 14 | 33 |
| DATA | 112,000 | 60 | 20 | 20 | 0 |
| TOTAL | 754,000 | 89 | 3 | 5 | 4 |
| 1990 | | | | | |
| VOICE | 1,401,000 | 100 | 0 | 0 | 0 |
| VIDEO | 171,000 | 76 | 0 | 8 | 16 |
| DATA | 280,000 | 59 | 20 | 20 | 1 |
| TOTAL | 1,852,000 | 91 | 3 | 4 | 2 |
| 2000 | | | | | |
| VOICE | 2,893,000 | 100 | 0 | 0 | 0 |
| VIDEO | 418,000 | 80 | 0 | 7 | 13 |
| DATA | 437,000 | 58 | 20 | 20 | 2 |
| TOTAL | 3,748,000 | 93 | 2 | 3 | 2 |

COSTS DECREASE →

## BUSY HOUR TRAFFIC RATES

Traffic demand, as expressed earlier in this report, is indicative of the total annual flow of traffic that must be supported by the long distance communications plant. However, in exploring the capacity for which the communications plant must be designed, it is necessary to take into account the fact that demand fluctuates from day to day and from hour to hour, with heavy cocentrations of traffic resulting at particular times. Common engineering practice is to design the communications plant to accommodate the traffic levels occurring in the busy hour of a typical day. This is generally approached by applying a peak hour to average hour factor as appropriate to each category of traffic. The result converts traffic demand, as expressed in terabits per year, into the number of megabits per second carried by the communications plant during the busy hour.

Table 15 summarizes the projected traffic rates during both the average and busy hours for each of the benchmark years of this study. While the ratio of peak hour to busy hour traffic rate varies from traffic component to component, the overall peak factor remains relatively constant at about 2.2 to 2.3 for all three years.

TABLE 15. SUMMARY OF BUSY HOUR TRAFFIC

1980

| | Annual Traffic (Thousands of Terabits/Year) | Traffic Rate During Avg.Hr. (Megabits/Sec.) | Traffic Rate During Busy Hr. (Megabits/Sec.) |
|---|---|---|---|
| Voice | 559 | 21,300 | 44,000 |
| Video | 84 | 2,700 | 2,900 |
| Data | 112 | 5,200 | 20,600 |
| Total | 755 | 29,200 | 67,500 |

1990

| | Annual Traffic (Thousands of Terabits/Year) | Traffic Rate During Avg.Hr. (Megabits/Sec.) | Traffic Rate During Busy Hr. (Megabits/Sec.) |
|---|---|---|---|
| Voice | 1,401 | 53,200 | 107,900 |
| Video | 171 | 6,700 | 13,200 |
| Data | 280 | 13,000 | 51,100 |
| Total | 1,852 | 72,900 | 172,200 |

2000

| | Annual Traffic (Thousands of Terabits/Year) | Traffic Rate During Avg.Hr. (Megabits/Sec.) | Traffic Rate During Busy Hr. (Megabits/Sec.) |
|---|---|---|---|
| Voice | 2,893 | 107,400 | 205,100 |
| Video | 417 | 17,200 | 37,900 |
| Data | 437 | 20,200 | 78,800 |
| Total | 3,747 | 144,800 | 321,800 |

The values provided in the first two columns pertain to total traffic volumes and therefor are roughly related to potential revenues associated with the various services. This relationship, however, is not necessarily a close one since the mix of facilities (i.e., dial-up, private line, WATS, packet, etc.),and thus costs, varies from service to service.

The last column of Table 15 shows the Busy Hour Traffic. These values relate more closely to required communications plant facilities which must generally be sized to handle the busy hour of a typical day. Those traffic components, such as many of the important data service applications which concentrate in a limited time span during the business day receive extra emphasis in terms of facilities needed. Thus, compared with voice services whose combined residential and business components present a more evenly distributed traffic load, data services calls for a larger fraction of the required facilities than might ordinarily be expected.

## SATELLITE COMPONENT OF DEMAND

The annual demand, and busy hour traffic rates, discussed earlier represent total demand for long distance communications in the United States. Resultant communications loads will be handled by a wide variety of communications organizations and will involve many types of terrestrial and satellite facilities. The following discussion presents those factors that encourage or discourage the use of satellite facilities and provide estimates of the amount of traffic likely to be carried by satellites.

The assumption is made that cost and reliability factors for satellite communications are excellent and as good as or better than those of other available modes of communications. If particular system designs fall short of this assumption, the tradeoffs between reliability and demand, discussed earlier, may be used to explore the impact of lesser performance levels.

Among the factors that generally tend to slow the widespread acceptance of satellite communications is the large investment in existing terrestrial plant facilities. Considerable resistance to change is expected because of this on the part of both the common carriers and the users. Equally powerful pressures in the opposite direction, however, will be exerted by the projected rapid expansion of demand. As indicated by the traffic projections summarized in Table 15, communications demand over the next two decades will grow by almost five to one. It is difficult to see how the existing facilities can economically expand to five times their present size without making substantial use of the high capacity potential available through satellites. Furthermore, of the "new" technologies capable of providing the needed high capacity, satellite communications is the most mature. In comparison to other new technologies such as fiber optics, satellite communications is almost two decades further along on the path from early R&D to practical widespread usage.

Two other general characteristics of the satellite medium are worth noting from the particular viewpoint of the carriers who may own and operate the facilities. The first is that satellite installations are relatively flexible compared to most of the terrestrial communications plant. Capacity can be rapidly added or removed in response to emerging demand by reassigning transponders and relocating earth stations. Satellite transmission costs also tend to be distance nonsensitive, a fact which opens the possibility of pricing strategies very attractive to certain classes of users.

From a very broad viewpoint, the items discussed above generally encourage satellite transmission and favor increased capture of communications traffic by this transmission mode. However, with respect to each of the services discussed in this report, the satellite medium presents special characteristics, both favorable and unfavorable, which influence the fraction of total traffic likely to be sent over satellite facilities. These special characteristics are taken into account in arriving at the capture ratios estimated in Table 16.

TABLE 16. PERCENT CAPTURE BY SATELLITE

| | 1980 | 1990 | 2000 |
|---|---|---|---|
| Voice | 2 | 15 | 25 |
| Video | 50 | 60 | 60 |
| Data | 1 | 50 | 60 |

## FORECAST OF REQUIRED SATELLITE CAPACITY

Table 17 presents estimates for the capacity needed to support that portion of the Voice, Video, and Data Traffic forecast for satellite transmission. The first column of the table is obtained by combining the total annual traffic (as presented in Table 16) with the percentage of total traffic expected to be captured by satellites (from Table 17 ). This results in estimates of the annual traffic in thousands of terabits per year projected for satellite transmission for each year.

TABLE 17. REQUIRED SATELLITE CAPACITY

| | Annual Satellite Traffic (Thous. of Terabits/ Year) (1) | Satellite Traffic Rate During Busy Hour (Megabits/ Sec. (2) | Transponder Throughput Capacity (Megabits/ Sec.) (3) | Required Number of Advanced Transponders |
|---|---|---|---|---|
| | | 1980 | | |
| Voice | 11 | 880 | 42 | 21.0 |
| Video | 42 | 1,450 | 42 | 34.5 |
| Data | 1 | 210 | 42 | 5.0 |
| TOTAL | 54 | 2,540 | 42 | 60.5 |
| | | 1990 | | |
| Voice | 210 | 16,190 | 72 | 224.9 |
| Video | 103 | 7,920 | 72 | 110.0 |
| Data | 140 | 25,550 | 72 | 354.9 |
| TOTAL | 453 | 49,660 | 72 | 689.8 |
| | | 2000 | | |
| Voice | 723 | 51,280 | 108 | 474.8 |
| Video | 250 | 22,740 | 108 | 210.6 |
| Data | 262 | 47,280 | 108 | 437.8 |
| TOTAL | 1235 | 121,300 | 108 | 1123.2 |

(1) Annual traffic from Table 15 times percent capture by satellite times percent capture by satellite from Table 16.
(2) Busy Hour traffic rate from Table 15 times percent capture by satellite from Table 16.
(3) Digital throughput rate forecast for equivalent 36 MHz transponders.

The second column in Table 17 shows the satellite throughput capacity required during the busy hour. This is similarly obtained by combining values taken from Tables 15 and 16 and is presented in units of megabits per second.

The number of satellite transponders necessary to handle the projected busy hour traffic is readily derived from the busy hour traffic rate shown in Table 17, once the traffic handling capabilities of typical transponders are defined. A digital capacity of 42 megabits per second is generally accepted as the equivalent of present day 36 MHz satellite transponders. It is likely, however, that over the next decades considerable improvement in this rate will occur as a result of technology advances. Table 17 postulates that the current 42 Mbps digital rate equivalent to a 36 MHz transponder will grow to 72 Mbps and 108 Mbps by the years 1990 and 2000 respectively. The last column in this table uses these values to predict the number of transponders that will be needed for each year of the forecast.

The number of transponders needed is also shown graphically in Figure 9. The 23 transponders shown as a dotted line extension curve representing the total is based on historical data for the year 1976. Growth rate is rapid in the first decade, with some signs of saturation occurring during the second decade. It should be noted, however, that a substantial portion of this apparent saturation is the result of postulated technologic improvements in transponder capacity rather than a lessening of the growth rate of underlying demand. The latter growth rates are represented in the totals for annual traffic, and/or busy hour traffic rates shown in the first two columns of Table 17.

In terms of busy hour demand the average annual growth rate over the twenty year period is 21 percent, while in terms of the number of advanced transponders needed to serve this demand, the average annual growth rate is 16 percent.

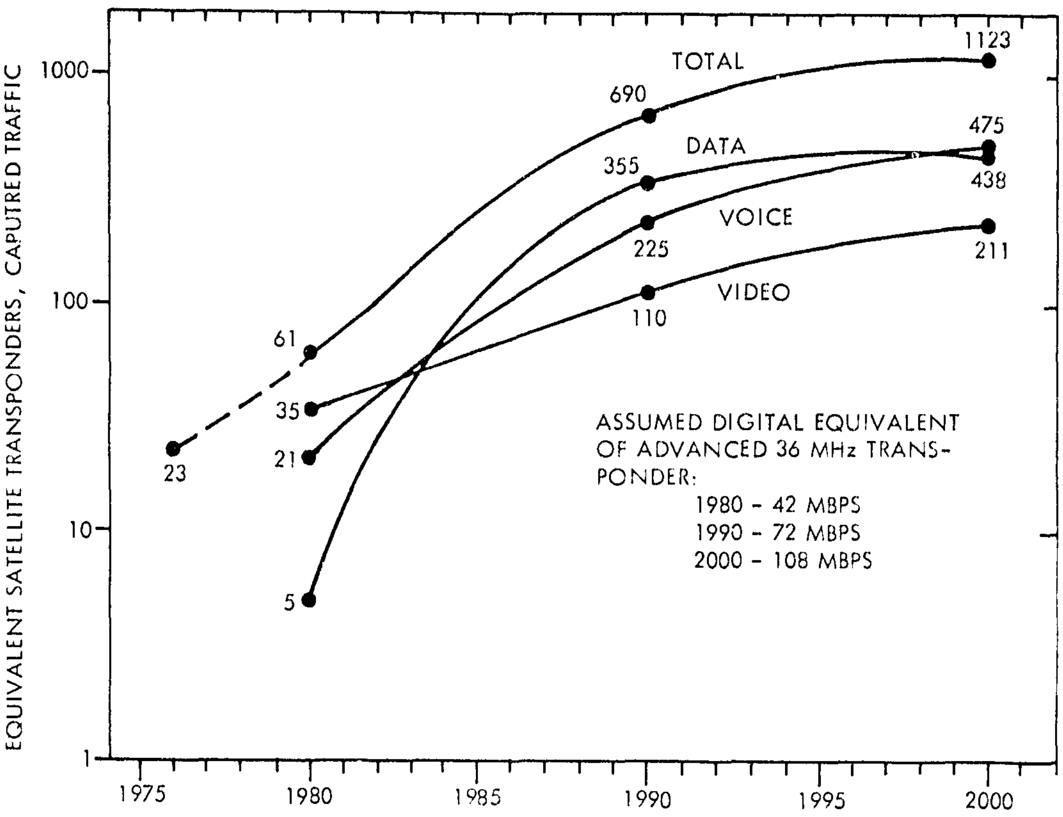

FIGURE 9. PROJECTED NUMBER OF TRANSPONDERS

## CAPACITY OF C AND KU BAND SATELLITES

The following discussion estimates the capacity of C and Ku band satellites for supporting communications within the Continental United States (CONUS). Three orbital configurations for synchronous satellites are considered in determining the maximum number of transponders that can be provided by these two frequency bands. The lowest capacity configuration assumes the use of a 4.5 degree orbital spacing, and the highest capacity configuration requires a three degree orbital spacing. The intermediate configuration assumes a four degree spacing. The calculation of applicable orbital slots for CONUS is based on use of the 70 degree equatorial arc from 65 to 135 degrees west longitude and the minimum look angle of the earth station antennas.

Table 18 summarizes satellite communication capacity in terms of the maximum number of transponders that can be supported by C and Ku band satellites considering the three orbital configurations of 4.5, four and three degree slot spacings. A capacity of 24 transponders per satellite is used uniformly to determine the cumulative transponder number presented. The columns marked "Total" give the total capacity of the 70 degree orbital arc from 65 to 135 degrees west longitude, and the columns marked "U.S." give the cumulative number of transponders based on the satellite slots deemed assignable to domestic carriers. In each band, seven slots of the total are allocated for use by other Western Hemisphere nations.

TABLE 18. TRANSPONDER CAPACITY VS. ORBITAL SPACING
(Number of Transponders)

| Spacing | C Band | | Ku Band | | C and Ku Band | |
|---|---|---|---|---|---|---|
| | Total | U.S. | Total | U.S. | Total | U.S. |
| 4.5° | 384 | 216 | 384 | 216 | 768 | 432 |
| 4.0° | 432 | 264 | 432 | 264 | 864 | 528 |
| 3.0° | 552 | 384 | 552 | 384 | 1104 | 768 |

Figure 10 presents, in graphical form, the saturation limits estimated for the domestic C and Ku band. The values shown to the left of the vertical line at 1981 indicate the absence of Ku band satellites prior to that year and, therefore, saturation of only C band transponders is indicated. For the years subsequent to 1981, both C and Ku band satellite saturation limits are considered. Based on estimates of the technology and, more important, regulatory actions stemming from international agreements, the most probable satellite spacings are four degrees for C band and three degrees for Ku. This spacing is reflected in the solid curve of Figure 10 showing 648 as the most probable number of transponders for years subsequent to 1981.

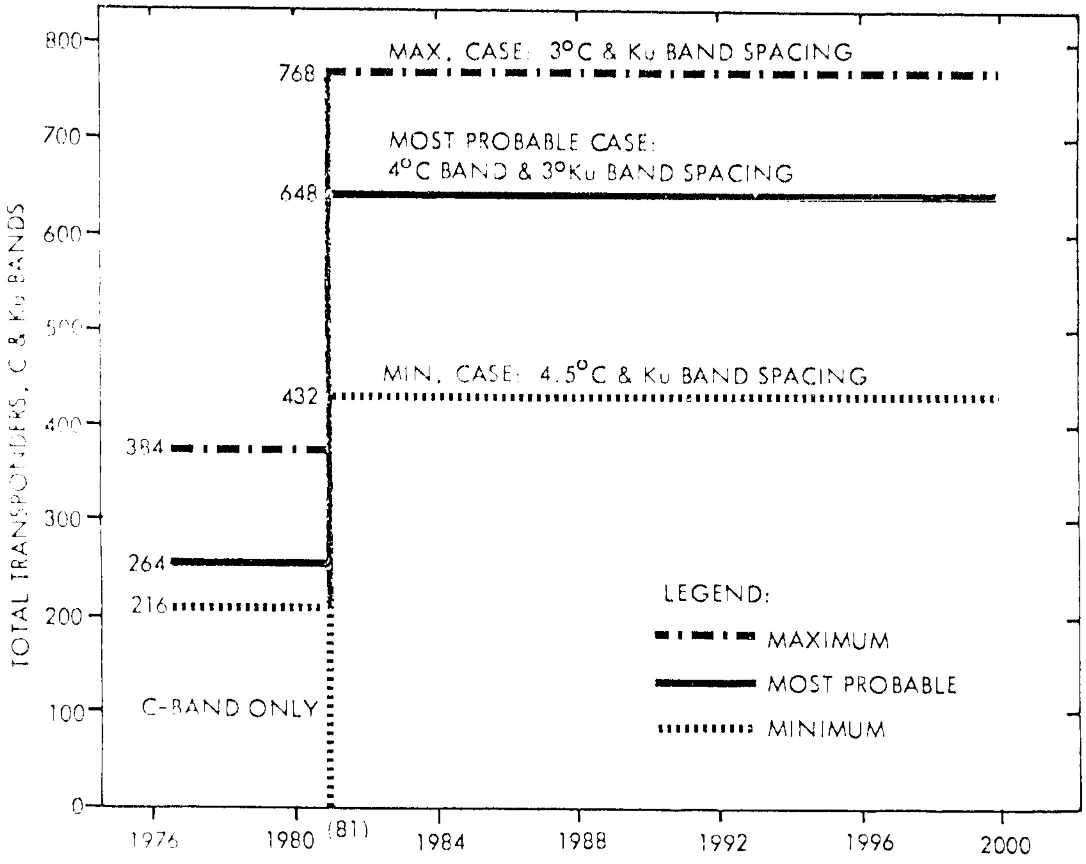

FIGURE 10. PROJECTED CAPACITY OF C AND KU BAND SATELLITES

## COMPARISON OF TRANSPONDER DEMAND WITH C AND KU BAND CAPACITY

The number of C and Ku band satellite transponders that are likely to be in orbit over the time frame of this study may be compared with total demand for transponders. The comparison permits an estimate of the time at which C and Ku capacity, in the absence of new satellite technology, will become saturated.

Figure 11 shows total demand for satellite transponders overlaid on the estimated capacity of C and Ku band satellites. The curve labeled "Increasing Capacity Transponders" refers to advanced transponder design with digital capacity increasing with time as discussed earlier. A most probable target year for saturation of C and Ku band capacity is 1989. The curve labeled "Constant Capacity Transponders" refers to the case in which the digital capacity of nominal 36 MHz transponders remains fixed at 42 MHz. As may be seen from the curves, if technologic advances fail to achieve the projected improvements in transponder digital capacity, the most probable year in which C and Ku systems will become saturated advances to 1987. In either event, the need for new satellite technology prior to the decade of the 1990s is evident.

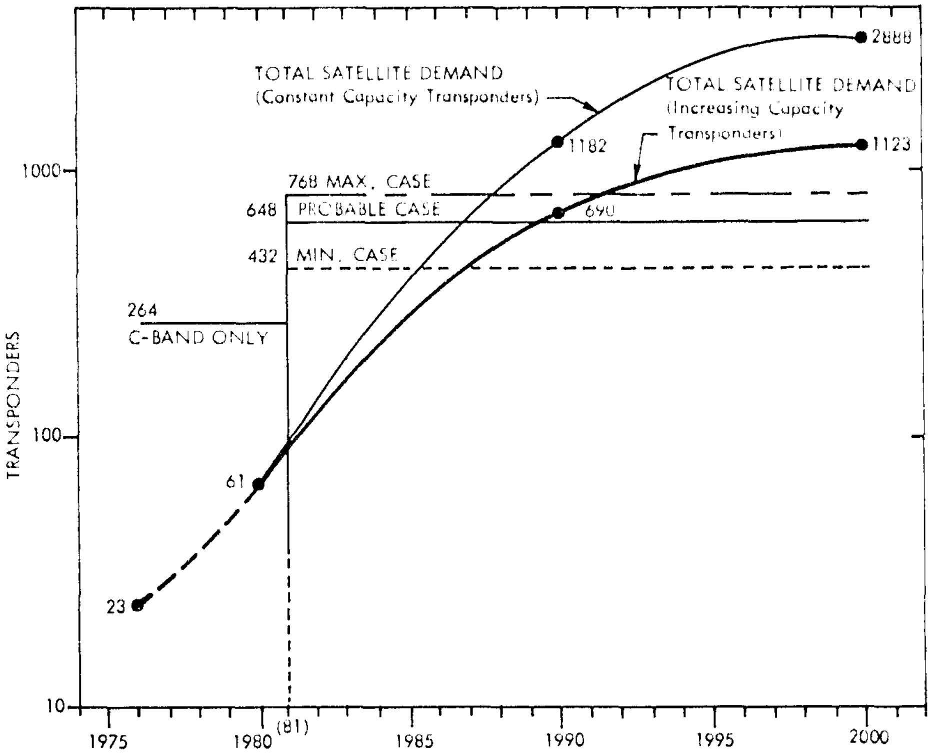

FIGURE 11. REQUIRED TRANSPONDERS VS C AND KU CAPACITY

# 4. CONCLUSIONS

It is clear that demand for telecommunications in general, and for satellite communications in particular, will increase by substantial factors over the next two decades. Voice services over this period will continue, by wide margins, to account for the largest part of overall demand for telecommunications services. However, due to economic and technical factors, the satellite captured demand for voice, video, and data services will all be of similar magnitude in the 1980 to 2000 time frame.

New communications facilities should be designed to achieve levels of reliability at least equal to typical terrestrial facilities, but need not be appreciably better in order to be effective. While some traffic can be deferred to off-peak hours, the bulk of the traffic projected will require real-time transmission capabilities and future designs should reflect this division of traffic.

The distances over which traffic is projected to be transmitted are relatively large, a factor which is generally favorable to competition for traffic by satellite facilities. Substantial markets exist in urban areas of all sizes and a decision to serve cities down to a particular size category rests on the economics of distributing service down to that level rather than to a lack of total demand among these cities.

The capacity of the C and Ku satellite bands to handle the projected demand is limited and is likely to be exceeded prior to the decade of the 1990s. Steps necessary to introduce new satellite technology, and to develop the 30/20 GHz band for commercial transmission, should be taken in time to respond to the emerging demand forecast in this study.