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ADVANCED TECHNOLOGY SATELLITES IN THE COMMERCIAL ENVIRONMENT

Volume 2: Final Report

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Future Systems Incorporated

4 Professional Drive, Suite 141

Gaithersburg, Maryland 20879 U.S.A.

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Prepared for

NASA-LEWIS Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Prepared by

Future Systems Incorporated
7640 Standish Place
Rockville, Maryland 20855

Telephone: (301) 294-9117

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16. Abstract

It is now possible to place relatively large communications satellites in geostationary orbit, using the Shuttle. Other advanced technoloy, such as the use of 30/20 GHz (Ka) band has reached or is near the point of commercial use. The satellite industry, however, is in a state of transition from the early state with few operators, to a later state with many diverse operators and correspondingly many satellites. It is not clear if or how advanced technology will be incorporated into this enviroment.

This report postulates one set of scenarios, based on a set of traffic demand forecasts derived from previous contracts performed by Western Union and ITT. The scenarios use a demand-driven model to launch new satellites, with other limits on the available (and economical) technology. The results using a Low Traffic Forecast show a continuing oversupply of transponders. However, the scenarios using a High Traffic Forecast show that considerable advanced technology including the use of 30/20GHz will be needed to satisfy demand.

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

SECTION 1
INTRODUCTION: TASK 1

The basic aim of Task 1 is to utilize the forecasts provided by Western Union and ITT in order to obtain a forecast of transponder requirements including various factors. The WU and ITT forecasts are of satellite addressable traffic. This merely postulates the fraction of total traffic that is susceptible to satellite carriage. The end product of Task 1 is a forecast of traffic that actually will be carried by satellite. Certain assumptions about system configurations are also implicit in this process.

The factors that we included in Task 1 are, in order: interpolation of the WU and ITT baseline year values to produce yearly figures; estimation of satellite capture; effects of peak-hours and the time-zone staggering of peak hours; circuit requirements for acceptable grade of service; capacity of satellite transponders, including various compression methods where applicable; and requirements for spare transponders in orbit. As part of Task 1, we also estimated the geographical distribution of traffic requirements. These items are explained below.

The Process

The factors noted above were applied sequentially to transform the forecasts of raw demand into transponder requirements. The first step was to interpolate between the baseline years of 1980, 1990, and 2000. This we did graphically, using the simplest curves that fit the three points reasonably well. The result was two year-by-year forecasts of satellite addressable traffic. This process was simple for voice and data, and for the video distribution and video conferencing forecasts of ITT. For the WU video forecasts, somewhat more manipulation was needed. This involved a separation between the so-called "full-motion" and "limited-motion" forms of conferencing. The limited-motion conferencing (LMVC) was considered to be compressed video of the sort used by AT&T PMS (for example) while the full-motion conferencing (FMVC) was considered as equivalent to broadcast video channels. This distinction was prompted by WU's own specifications for the required bandwidths of these two forms. The FMVC was stated to require 22 MHz in 1980, with a 2:1 compression in 1990 and 3:1 in 2000 (note that these are average values). The LMVC was stated to use an average of 1/12 transponder in 1980, with a 2:1 compression in 1990 and 3:1 in 2000. The video conferencing forecasts were translated into half-circuits using the information supplied by WU and ITT. Interpolation between the baseline years was made as simple as possible for these calculations.

Satellite Capture

This term has been the source of some confusion. As we use it in this (and previous) studies, satellite capture is simply the fraction of the traffic under consideration that is actually carried by satellite. Since we are dealing here only with a base of satellite addressable traffic, the satellite capture is the fraction of satellite addressable traffic that is actually carried. In some instances, this causes the capture fraction to be higher than seems appropriate. For example, in 1980, we estimate a voice traffic capture of 20 percent. This is high only because the addressable portion of the total market is relatively small in 1980: 10.9 percent according to ITT. This means that the satellite capture of the total voice market in 1980 is only 2.2 percent, a much more reasonable figure. As a further example, in 2000, the addressable portion is 33.5 percent of the total, and this combined with a capture fraction of 34 percent of addressable yields an 11.4 percent capture of the total voice market.

The satellite capture was estimated using whatever data we were able to find. In the case of voice, the result was a reasonable estimate; however, from there on out the figures are more speculative, with the exception of TV distribution which is carried almost exclusively via satellite. The capture fractions were then applied to the interpolated forecasts to produce a set of raw satellite traffic forecasts, expressed in the same units as the basic forecasts.

Peaking

The next step was to estimate the effects of busy-hour staggering on the peak traffic demand. The contractors had already included allowances of 5 percent and 8 percent in the forecasts for grade-of-service considerations, and these allowances were removed at this stage. Next, the peak factors included by WU and ITT were also removed, since we had peak factors of our own to apply. In some cases, the peak-hour factors we used were close to those of the contractors; in others, there were substantial differences. To some extent, this involved substituting our own judgment for that of the contractors.

Peaking during the busy hour is not uniform across the CONUS, but varies because of the time zone differences. For local traffic, this has no effect, but because a significant portion of the long-haul traffic goes between time zones, the staggering of busy hours has an averaging effect on a facility such as a satellite that serves all time zones at once. We used data from AT&T filings before the FCC to estimate the busy-hour peaking. The division of traffic among the time zones we estimated from the population distribution. In effect, we took the basic forecasts of satellite traffic, which had the contractors' peak factors in them, "un-peaked" the forecasts, and then "re-peaked" them, using our factors and the time-zone staggering.

Grade-of-Service Calculations

In order to provide service to users without extensive waiting or a high proportion of busy signals, additional circuits must be included in the system over and above those needed to carry the peak traffic if fully loaded. The number of additional circuits needed is a strong function of such factors as the traffic on the link, the desired grade-of-service, and the existance (or absence) of demand assignment. We simulated real conditions to some extent by using the results of Western Union's Market Distribution Model (MDM) to size the traffic among the cities served. Three networks were postulated using the MDM data for 10 SMSAs, 20 SMSAs and 97 SMSAs. Since the 20 SMSA model included the 10 SMSA traffic distribution values, these were subtracted from the 20 SMSA figures before the calculations were done. Traffic along each link in the networks was sized, and demand assignment was used if the link was too thin to be efficient. A grade-of-service of 1 percent was used for voice, 5 percent for data (to reflect the deferrability of some data) and 20 percent for video conferencing (to reflect to some extent the existence of scheduling for this service). The resulting circuit requirements were then used as input to the next steps in the process.

Satellite Transponder Capacity

We estimated transponder capacities for various types of traffic in order to convert the circuit requirements into transponder requirements. The reference transponder of 36 MHz bandwidth and the equivalent of 33 - 35 dBW EIRP (at C-band) was used for this. EIRPs will be higher at higher frequencies to accommodate the larger margin requirements. We made our estimated based on 1) likely modulation/access methods, 2) cost/technology tradeoffs, especially for CPS applications, and 3) the estimates of WU and ITT in their reports to NASA. Technology advances in several areas were also incorporated. The results of applying these capacity estimates to the circuit requirements were the net, operational transponder forecasts.

Requirements for Spare Transponders

Because there is a finite probability that one or more transponders or even an entire satellite will fail in orbit, and because there is a need to handle sun outages and system re-configurations without significant loss of service, there is a need for spare transponders in orbit. Some or all of these spares may be used for preemptible services, if enough such customers can be found, and the portion of the total so used will depend on the traffic type.

We estimated the sparing requirements from a number of sources: statements by the satellite operators and users, both publicly and in FCC filings; known sparing strategies in existing systems such as INTELSAT; financial data on the cost of protected versus unprotected versus preemptible transponders; and estimates of the required availability of service over the satellite lifetime for various types of traffic. These sparing estimates were then added to the net transponder requirements to yield a gross, in-orbit transponder forecast.

Summary

Table 1-1 illustrates the effect that various processes in Task 1 have had on the base forecasts. We have illustrated this with the low traffic forecast for 1990. The basic satellite-addressable forecast is considered to be the normalized value of 1.0. The table shows the relative value after processing through the indicated stage. Thus, the combined effects of previous stages are included in these figures. In general, the capture fraction calculation had the most effect.

Table 1-1
Normalized Effects on the
Low Forecast - 1990

Stage	Voice	Data	Video Conferencing	TV
Base Forecast (satellite-addressable)	1.0	1.0	1.0	1.0
After Satellite Capture	0.21	0.37	0.90	1.0
Includes Time Zone Effects	0.144	0.546	0.84	1.0
Includes Grade-of-Service Factors	0.165	0.546	1.074	1.0
Includes Transponder Spares	0.205	0.682	1.15	1.07

SECTION 2
VOICE TRAFFIC DEMAND FORECAST

2.1 Satellite-Addressable Voice Traffic Forecasts

Recent studies by Western Union and ITT have produced updated estimates of future traffic in the U.S. A certain portion of the long-haul traffic is susceptible to being carried by domestic satellite communications systems. This portion is called "satellite addressable traffic." The fraction of the addressable portion that actually is carried by satellite is the satellite capture fraction.

Table 2-1 shows the ITT and WU forecasts for voice traffic. Included under the heading of voice traffic are the following services: WATS, MTS and private line. WU has included several categories of traffic explicitly that don't seem to be in the ITT traffic. However, these don't account for much of the total, so we have ignored this particular difference. These forecasts include peak factors to account for the unevenness of traffic during the day and allowances of five percent and eight percent for WU and ITT, respectively, for grade-of-service considerations.

Table 2-1
WU & ITT Forecasts
Satellite-Addressable Voice Traffic
(thousands of half-circuits)

	1980	1990	2000
Western Union	227	1,781	8,843
ITT	253	1,319	4,482

Interpolation between the benchmark years given in the forecasts was done by the simple means of drawing a smooth curve across the three points. The results are shown in Figure 2-1. Yearly values taken from Figure 2-1 are shown in Table 2-2. Unfortunately, the two forecasts intersect around 1983, thus confusing the issue of high and low forecasts. However, since they are quite close to each other from 1980 to the intersection, we have used the average of the two forecasts between 1980 and 1983. After that time, the WU forecast is used for the high, and the ITT forecast for the low.

Table 2-2
Satellite-Addressable Voice Traffic
(thousands of half-circuits)

Year	Low	High
1980	240	240
1981	310	310
1982	380	380
1983	470	470
1984	550	590
1985	650	720
1986	760	870
1987	880	1,030
1988	1,010	1,230
1989	1,150	1,450
1990	1,319	1,781
1991	1,500	2,100
1992	1,700	2,450
1993	1,950	2,900
1994	2,230	3,430
1995	2,500	4,000
1996	2,830	4,700
1997	3,200	5,550
1998	3,550	6,500
1999	4,000	7,600
2000	4,482	8,843

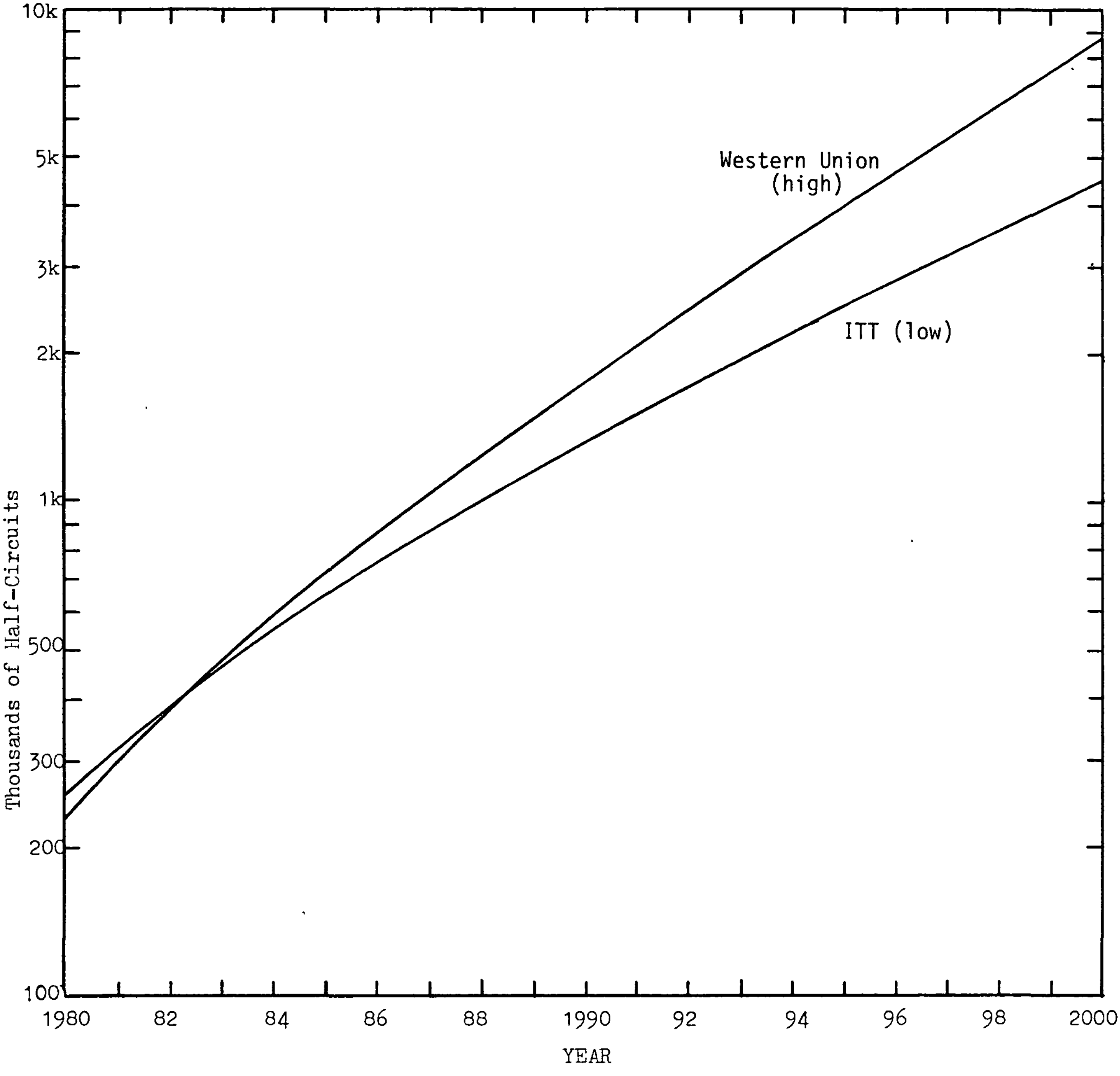


Figure 2-1

Forecasts of Satellite-Addressable Voice Traffic

2.2 Satellite Voice Capture Fractions

The decision to place a portion of voice traffic on satellite circuits depends on several factors. Primary in most thinking is the economic savings which can accrue from the distance-insensitivity of the satellite link. In a simple cost comparison, for a point-to-point link or relatively sparse network, this advantage is easily seen. However, for most of the long-haul traffic in a well-developed telephone system this comparison will not hold. Traffic is accumulated and delivered at many points along the way. In a satellite system, earth stations must be installed for such access. In a terrestrial network, such access is readily available at virtually every repeater site. For switched service, moreover, circuits are shared among calls of various length from one moment to the next, providing more efficient loading of the system. For private line service, however, there will be a savings available at some distance or beyond, and a certain fraction of circuits can be carried by satellite economically.

Given the developing competitive environment after the AT&T divestiture, some of the original reasons for using satellite (or other dedicated facilities) may disappear. For example, MCI, then known as Microwave Communications Incorporated, began by proposing a dedicated microwave link between Chicago and St. Louis, which would be used for shared private-line service. At this time, the private-line rate offered by AT&T was well above the competitive price (that is, the price in a competitive market) and volume discounts were offered (via the Telpak C and D tariffs) only to users of more than 60 circuits. MCI was able to offer private-line service to small users at considerable savings.

This situation existed because AT&T was a de facto — rather than de jure — monopoly, but had been accustomed to maintaining this situation by a combination of strategies. Rather than using the natural monopolist's barriers to entry of setting prices low in accord with the economies of scale available, AT&T used nationwide average pricing, and relied on the existance of the FCC to set up regulatory barriers to entry. The Telpak tariff was an example of a barrier which was erected in response to an entry threat which promised to overcome the regulatory barrier. By adopting this mixed strategy, AT&T left open the possibility that a sufficiently determined competitor — which MCI certainly was and is — would be attracted by the entry possibilities and be tenacious enough to overcome the regulatory obstacles.

In a completely competitive long-haul market, the price should decline to the competitive level, thus reducing the incentive for additional competitors to enter, despite the reduced barriers. This will probably lead to a more consolidated position for the established long-haul carriers, who can use the economies of scale along their existing routes. New opportunities may open up for service to lower-traffic regions, however. These will be charged higher prices under true allocation, and this will offer incentive to alternative transmission systems operating at a lower cost.

Another source of incentive for satellite use is the offering of new services, or "old" services no longer offered by existing carriers. A new entrant seeking to offer such services might choose satellite carriage because of the speed with which earth stations can be installed, compared to the lengthy process of constructing a terrestrial link over a distance.

An example of new service offering that has made several attempts at the market is switched digital service. First offered (via terrestrial microwave) by the now-defunct Datran system, this service has its latest incarnation using DTS microwave and satellite inter-city links, as originally proposed by XTEN. Demand for such services has grown somewhat each time it has been introduced. With increasing emphasis on various digital systems, and aggressive marketing of office automation by firms such as Wang and Xerox, we have probably reached the point at which switched digital networks will become economical and widespread.

New service need not take such a completely different form; MCI's shared private line service was, after all, simply private line voice. The newness was the ability of users to share in the cost savings resulting from traffic aggregation. A value-added service for voice is even possible. "Voice mail" can be added to private line service, and voice mail systems already exist. Thus, new services can range from relatively simple money saving offerings up to value-added networks and the provision of service to areas not already covered by other carriers.

Estimating the Voice Capture

Because information about the actual usage of satellite circuits is rather hard to come by, we have had to estimate the capture fraction on the basis of reasonable scenarios. Of the common carriers with significant voice traffic, either switched or private line, AT&T, Western Union, RCA Americom, GTE/SP Communications, and MCI either have or will soon have their own satellite capacity. We have used available information about some of these carriers to provide guidance in making our estimates.

Table 2-3 summarizes the information about the carriers. AT&T Long Lines is, of course, the largest, and of the SCCs, MCI carries the most traffic. Of particular interest are the growth rates for the SCCs. These, coupled with the overall market growth rates estimated by WU and ITT, can be used to calculate the approximate market shares for the SCCs in the future, assuming growth as shown in Figure 2-2. These shares are shown in Table 2-4.

Table 2-3
Toll Carrier Statistics
Interstate Circuits
(thousands)

Carrier	1978	1980	1981	1982	Carrier Annual Growth, %
AT&T Long Lines	491	592	622	660 (est)	5
MCI	4	49	95	129	36
GTE/SPCC	9	14	21	26	23
USTS	7	30	47	66	40

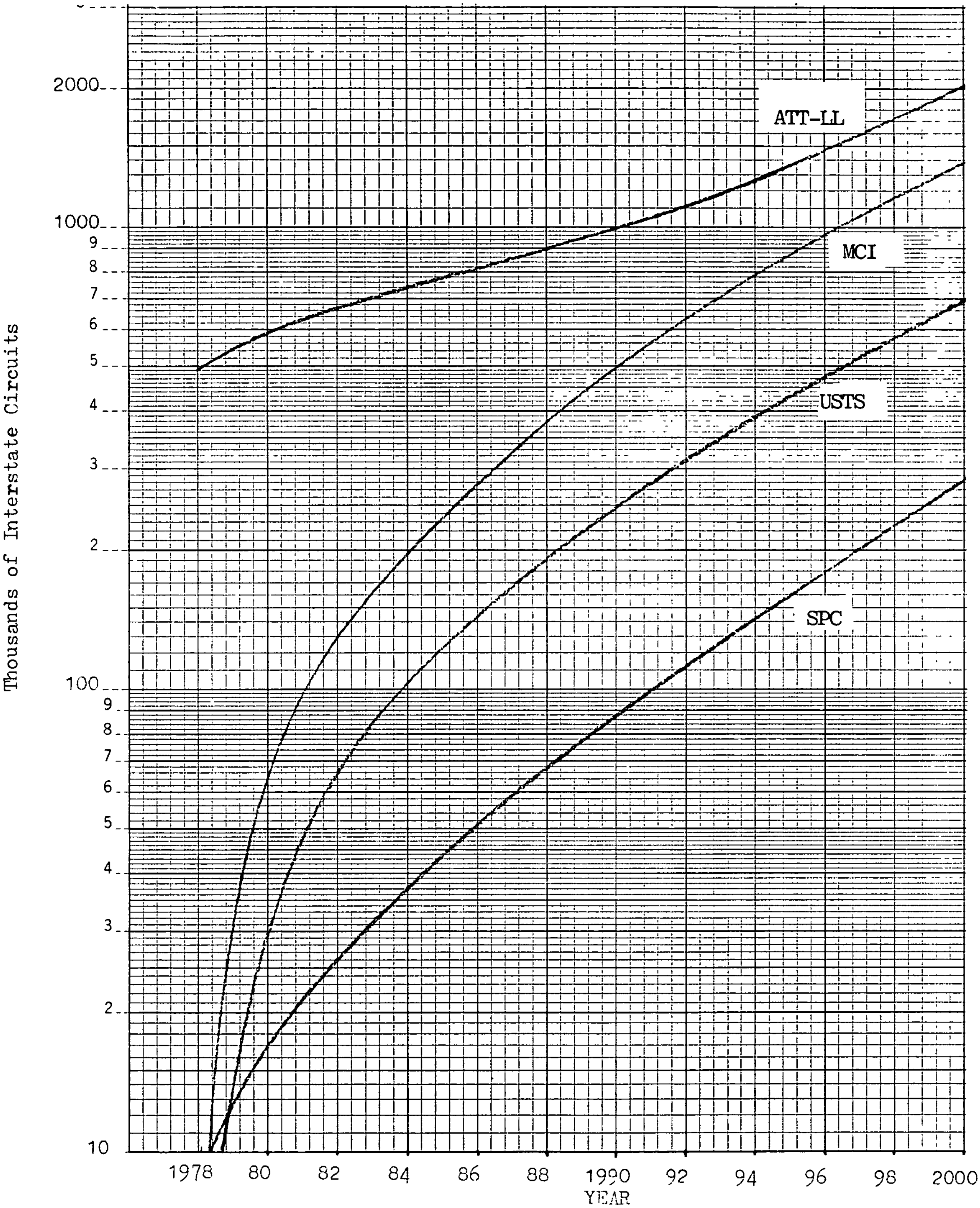


Figure 2-2

TRAFFIC ASSUMPTIONS FOR SOME TOLL CARRIERS
(Interstate Circuits)

Table 2-4

Estimated Market Shares of

Various Interstate Toll Carriers

(percent)

Carrier	1978	1980	1985	1990	2000
AT&T Long Lines	96	86	66	55	46
MCI	0.8	7.2	20	27	31
GTE/SPCC	1.8	2.0	3.7	4.7	6.5
USTS	1.4	4.4	10.3	13	16

Taking MCI as a paradigm of the other SCCs, we can examine the logic by which we estimated the satellite capture. MCI has purchased 24 C-band transponders from Hughes, which they are intending to use in their network. These are primarily intended for two purposes: offloading and overflow handling in the existing system, and extension of the system to areas not now covered. Since the standard Hughes contract includes a certain amount of protection for the transponders, we can assume that all 24 could be used if needed.

Because their main interest lies in relatively heavy traffic, MCI is unlikely to use these transponders for thin-route traffic. The modulation/access method chosen will probably be one which permits a very high capacity per transponder and multiple access. One possibility is Companded Single Sideband (CSSB). With reasonable earth station sizes, this is capable of 4,200 channels (2,100 circuits) per 36 MHz transponder at 2 degree spacing. (These figures are taken from the filing of AT&T on the 2 degree spacing docket, and are computed using a 12-meter antenna.) This results in a total of 50,400 circuits.

Clearly, it will not be feasible for MCI to have 24 transponders in operation immediately. The Hughes satellites are scheduled to be launched in late 1983 and mid-1984, using the Delta 3920. If an average of 1,000 circuits per earth station is assumed, resulting in 50 earth stations, then a reasonable construction schedule might result in full operation around 1988. At that time, the situation should be stable, with all transponders loaded.

The fraction of total long-haul traffic that is considered satellite addressable varies with time. Based on ITT estimates, that fraction will be about 20 percent in 1988. Since we have no special reason to think otherwise, we should assume that this same proportion of MCI's total traffic (which is by definition all long-haul) is satellite addressable. In 1988, this will be approximately 139,000 circuits. Combined with the total satellite traffic of 50,400 circuits, this gives a capture fraction of 36 percent for MCI in 1988. Similar figures can be derived for other SCCs and are shown in Table 2-5. You should keep in mind that these figures are derived using total long-haul traffic. This is computed from the estimated interstate traffic figures shown in Figure 2-2, based on the assumption (from the ITT report) that interstate traffic comprises 54 percent of the total long-haul. Thus, the 139,000 circuits mentioned above is equal to the 1988 figure of approximately 375,000 interstate circuits (of MCI) from Figure 2-2, divided by 0.54, multiplied by the 20 percent satellite addressable factor.

Table 2-5
Estimates of Satellite Capture

Carrier	Year	Satellite Circuits	Satellite Capture of Addressable**
ATT-LL	1981	28,500	20.7%
ATT-LL	1983	22,500	12.8%
MCI	1988	50,400	36 %
GTE/SPCC	1988	13,000	52 %
Industry*	1988	78,400	13.8%

*assumes 4.5% for ATT-LL

**Note that the addressable traffic includes intrastate as well as interstate circuits. Interstate always assumed at 54% of total.

It's clear that these estimates involve a lot of approximation, and that they therefore offer only an indication. However, given that the SCCs have more incentive to use satellites than does AT&T, because of their less extensive terrestrial networks, the figures are reasonable. Figure 2-3 shows some information used in the development of the capture fraction. The lower set of isolated points show the fraction of the total addressable market carried by satellite for each of several carriers. These values are a reliable lower bound on the capture. The curves show three different estimates of capture fractions. The curve marked FSI79* is the capture estimate published in FSI report #106. This curve was applied to the total long-haul market. The line marked FSI 79** shows these same values after adjustment to reflect the fraction of the total market that is satellite-addressable, resulting in much higher numbers. The ITT 79 curve is drawn from numbers taken from the 1979 ITT traffic study.

The points marked "I" are estimates for the entire industry derived from the estimates for the individual carriers. Finally, the estimates for the carriers as a fraction of their own addressable traffic are shown labelled with the carriers' initials.

One point here deserves added clarification. The estimated capture fraction for 1980 and the next few years seems rather high. However, this results from the fact that the satellite-addressable traffic at that time was only a small fraction of the total long-haul traffic. For example, in 1980, satellite addressable traffic made up only about 11 percent of the total. Thus, even though we estimate that the satellite capture was about 21 percent of the addressable, it was only about 2 percent of the total.

Figure 2-4 shows our final estimate of the capture fraction versus time. This curve flattens out at about 30%. The reason we have assumed such a flattening for the capture fraction is that the addressable part of the total traffic, as defined by WU and ITT, is growing with time for some of the same reasons that would normally be incentives to switch from terrestrial to satellite. Thus, the two concepts overlap somewhat. Therefore, we have included less growth in the capture fraction because of the growth in the addressable portion.

Table 2-6 contains the high and low satellite voice traffic forecasts. This table incorporates only the capture fractions developed thus far.

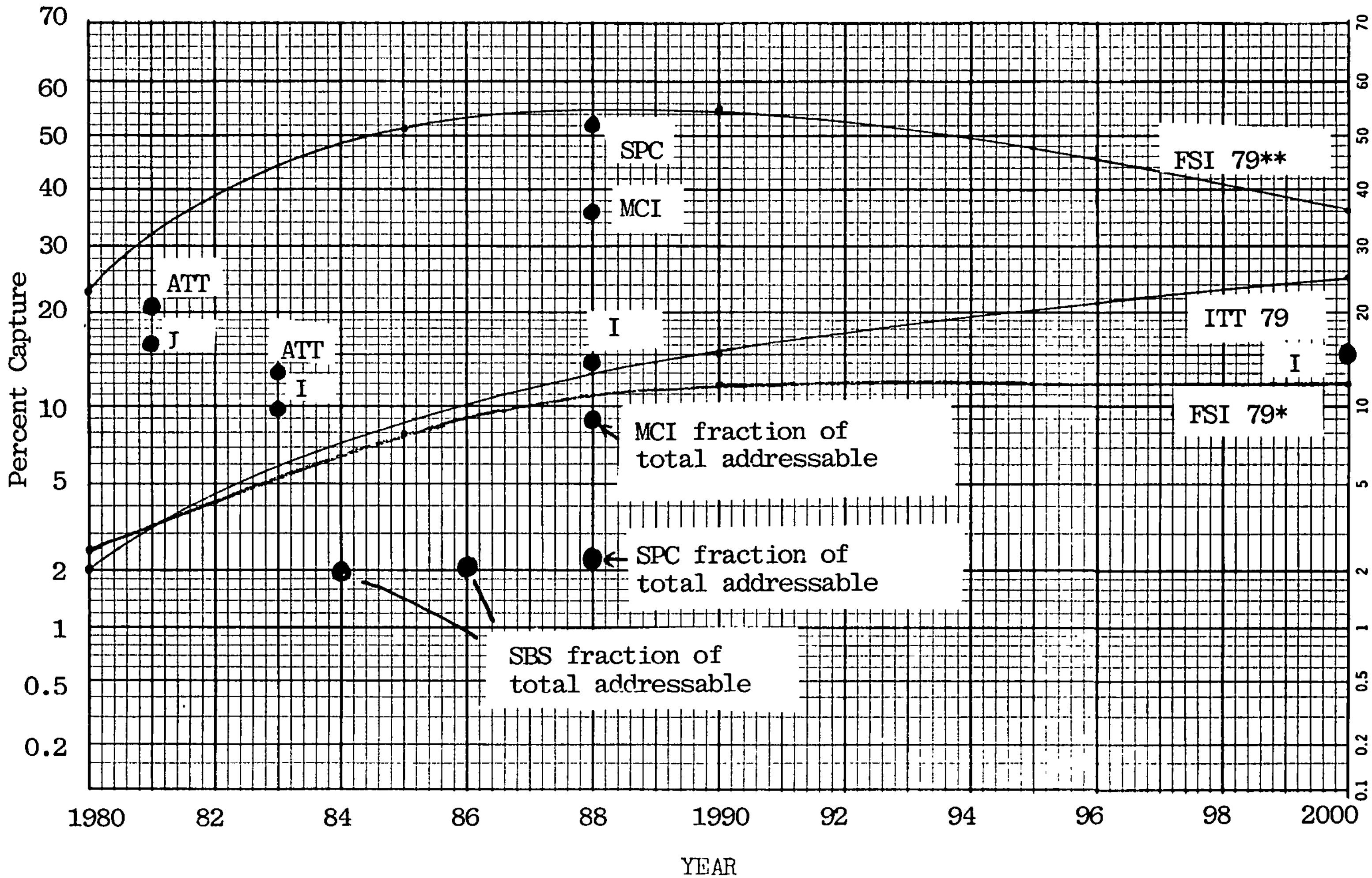


Figure 2-3

Estimates of Voice Traffic Capture
By Various Satellite Systems

* FSI 79 figures from FSI report #106
** FSI 79 figures after adjustment by addressable traffic fraction

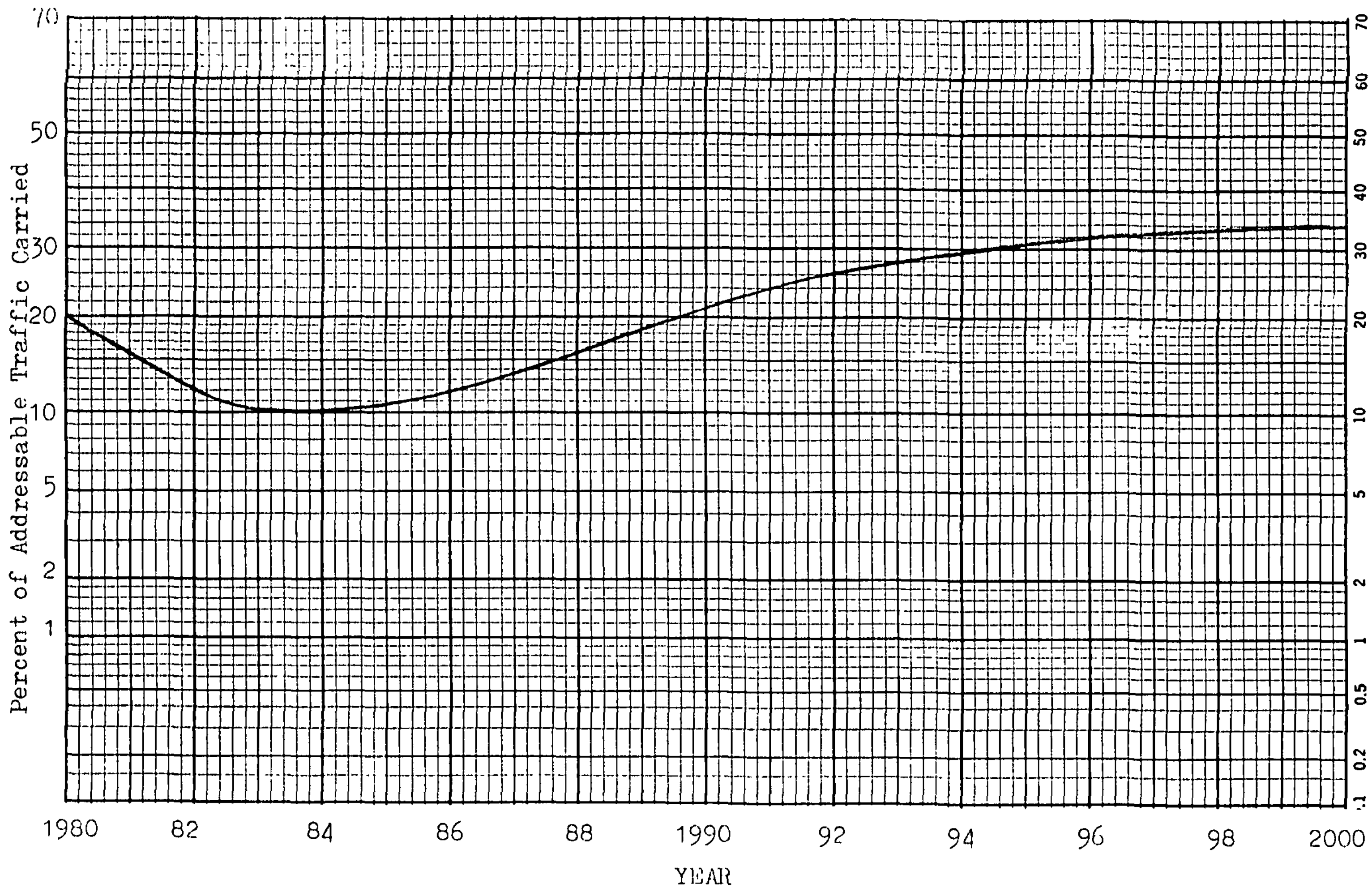


Figure 2-4

Satellite Capture Fraction vs Time

Table 2-6

Satellite Voice Traffic Forecast

(thousands of half-circuits)

Year	Low	High
1980	47	47
1981	48	48
1982	45	45
1983	46	46
1984	54	59
1985	69	77
1986	91	100
1987	120	140
1988	160	190
1989	210	270
1990	280	370
1991	360	500
1992	440	640
1993	550	810
1994	660	1,000
1995	770	1,200
1996	900	1,500
1997	1,000	1,800
1998	1,200	2,200
1999	1,400	2,600
2000	1,500	3,000

2.3 Geographical Distributions and Facilities Loading

The geographical distribution of traffic is important for several reasons. Aside from the obvious concern of manufacturers and planners who wish to allocate service facilities and personnel appropriately, frequency coordination, frequency band segmentation and satellite loading all depend to some degree on the distribution of traffic.

Frequency coordination among earth stations is not generally a problem at this time, but it could become one if the density of stations increased sufficiently. This could occur in areas such as New York and Los Angeles. However, frequency coordination with terrestrial microwave systems is likely to remain the limiting factor. The coordination criteria are based on an average number of interference entries along the so-called reference path. In spite of this, there is a tendency for system planners to regard the coordination criteria as something which can be used again and again as long as it is not exceeded. This is not the case, and in areas supporting both dense microwave and dense satellite use, consideration of the number of entries will certainly be needed. This will complicate the coordination task and requires additional advance planning. Congestion at one frequency band clearly affects the division of traffic among bands.

Regions of high traffic density will experience frequency coordination problems (at C-band for example) that will drive users to the other available bands. In systems using spot-beam satellites, the beam capacity at the lower bands will also saturate sooner in these high traffic areas, again resulting in pressure to use the higher bands. Another factor arises from the coincidence of high traffic density and high population density, with attendent urbanization. This makes the smaller antennas associated with higher frequencies desirable for zoning and esthetic reasons.

In a system using multiple spot beams with interconnection onboard the spacecraft, traffic concentrations will cause the system to saturate the satellite at less than 100 percent utilization of the theoretical capacity. This phenomenon occurs because in general connectivity is required for all traffic. This means that as the traffic grows, some of the incremental traffic originating from all other beams must be connected to the largest beam (most traffic, that is, not physically largest). Therefore, when the largest beam is saturated, no more traffic can be added to the system. If the traffic is distributed in a very uneven manner, considerable unused capacity will exist when saturation occurs.

Of course, this is to some extent an oversimplification, since it is possible to fine-tune the system slightly. Traffic that does not require access to the saturated beam(s) can be added. In fact, INTELSAT optimizes their traffic plan in a similar manner, trying to extract the maximum from each satellite before requiring additional antennas to access other satellites. However, the amount of such fine-tuning is limited and cannot be determined beforehand. Therefore, for system planning purposes, saturation can be assumed to happen as described above.

Basis for Traffic Distribution

The most straightforward basis for traffic distribution determination is the population distribution. While other factors can be used, and have been included in the Western Union Market Distribution Model, for instance, population seems to provide an adequate approximation. We have used data from the 1980 Census as the basis for the population distribution. In order to provide a useful model, we considered other factors as well. These were: population shifts with time, and the granularity with which the information should be presented.

Population Projections

During the past decade, the pace of population growth in the United States slowed to its lowest rate since the 1930 - 1940 decade.

A total of 225.2 million mainland Americans were tallied in the 1980 census, an 11.4 percent increase since 1970. The Census Bureau expects a decreasing rate of population growth - less than ten percent - in this decade, and about seven percent by the end of the century.

Statistics tabulated thus far show that about 90 percent of the country's net population growth since 1970 occurred in the South and West. Those regions grew by 21.4 percent, while the Northeast and North Central regions grew by a little more than two percent. More than half the population - 52.3 percent - now lives in the South and West.

Assuming that the 1965 to 1975 migration patterns continue, and using the results of the 1980 census as a baseline, Tables 2-7 and 2-8 were developed showing the national population projections segmented by region and time zone, respectively.

Since the largest shift over the 1980 to 2000 period is about five percent, we decided to ignore the effect of population shifts.

Granularity

The Census data is available to a very fine degree of resolution. The smallest geographical division that we felt appropriate was the county, of which there are about 3000 in the CONUS. Using county-level data, we divided states into several smaller areas where appropriate. Since the most we would expect in this study period would be about 20 to 30 beams on a single satellite, this should prove sufficient resolution.

The map foldout (Figure 2-5) shows the regions totaled, the time-zone boundaries, and within each region, the percent of the total U.S. population contained therein.

Table 2-7

Population Projections - Region: 1980 - 2000

	Population (millions)			% of CONUS		
	1980	1990	2000	1980	1990	2000
New England	12.35	13.70	14.62	5.48	5.67	5.66
Middle Atlantic	36.80	39.14	40.24	16.34	16.21	15.58
E. North Central	41.68	44.85	47.01	18.51	18.57	18.20
W. North Central	17.22	18.02	18.78	7.56	7.46	7.27
South Atlantic	36.95	41.18	45.40	16.41	17.05	17.58
E. South Central	14.66	15.06	15.92	6.51	6.24	6.16
W. South Central	23.75	24.79	27.02	10.55	10.27	10.46
Mountain	11.38	12.08	13.35	5.05	5.00	5.17
Pacific	30.45	32.68	35.91	13.52	13.53	13.90
TOTAL	225.2	241.5	258.3			

Table 2-8

Population Projections - Time Zone: 1980 - 2000

	Population (millions)			% of CONUS		
	1980	1990	2000	1980	1990	2000
Pacific	31.46	33.66	37.00	13.97	13.94	14.33
Mountain	11.59	12.33	13.57	5.15	5.10	5.25
Central	66.55	69.82	74.17	29.55	28.91	28.72
Eastern	115.64	125.73	133.51	51.34	52.05	51.70
TOTAL	225.2	241.5	258.3			

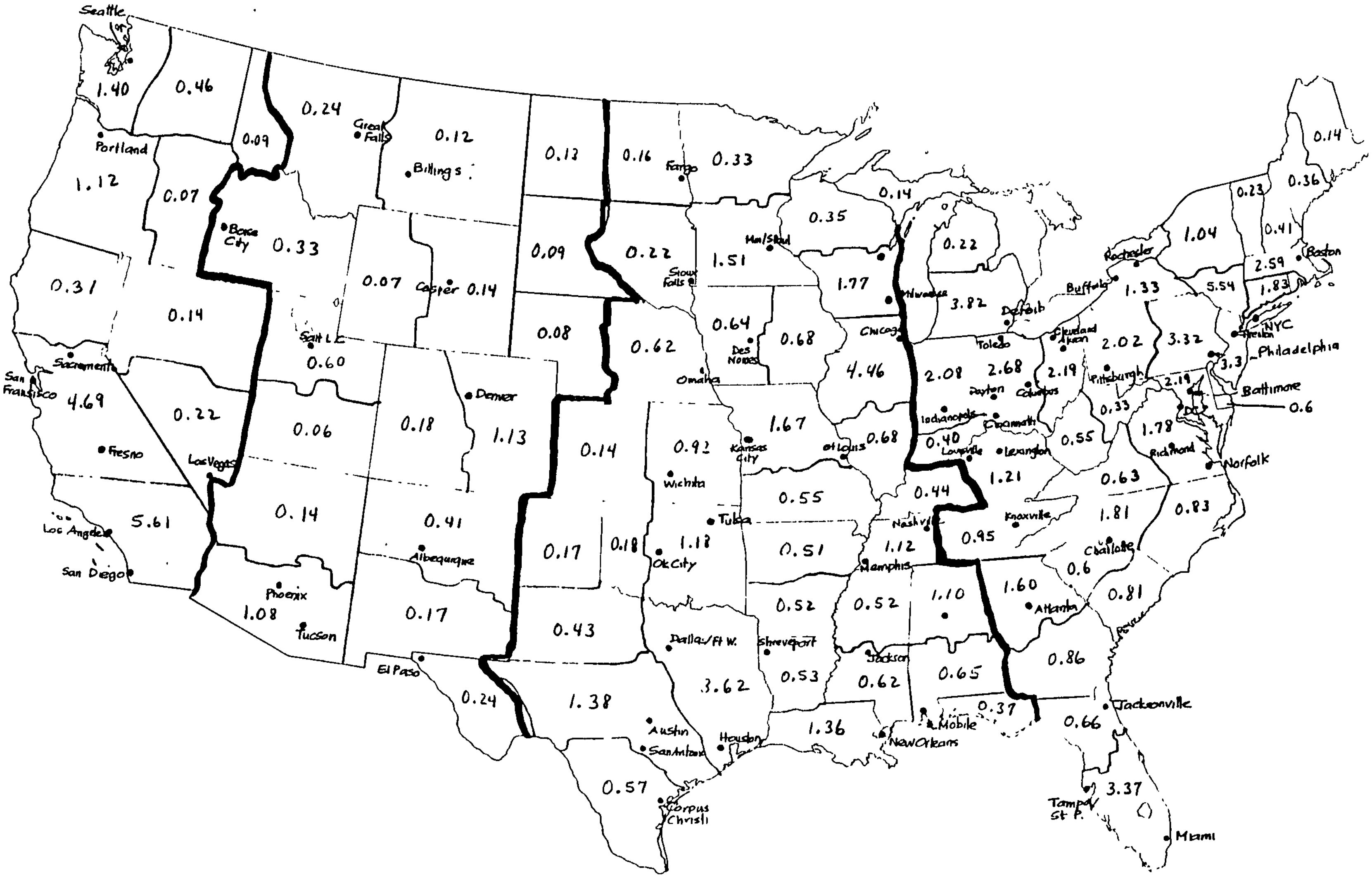


Figure 2-5

PERCENT BREAKDOWN OF TOTAL U.S. POPULATION
(1980 Census)

2.4 Busy-Hour Averaging and Peaking

An understanding of the nature of traffic, whether it be voice, video or data, and its distribution with respect to time and destination is essential in determining the transmission facilities required. For example, the distribution of telephone traffic varies greatly from one period to another, not in any uniform manner but according to the stochastic needs of the subscriber. In addition, traffic volumes often deviate from season to season, from month to month, from day to day, and from hour to hour.

Busy-hour traffic patterns vary in both amplitude and time duration as one crosses the time zones spanning the contiguous United States. These variations are caused by many factors, the most important of which are the concentrations of population and business.

The telephony traffic intensity on which the satellite facilities are calculated should represent the normal busy hour. Occasionally, however, the traffic will exceed that level (some unusual peaks can be expected on such days as Mother's Day and Christmas, while other peaks are unexpected). To engineer the transmission facilities for all such eventualities would be very costly and inefficient. As a result, there will be peak periods when the traffic exceeds the volume which has been assumed.

Within the week, traffic volume usually forms a fairly consistent pattern, such as high on Mondays and Fridays, and low on Wednesdays. The greatest degree of traffic variation over any period occurs between the hours of the day. Volume ratios of the busiest hour to the least busy hour, for example, can be as high as 100:1. In offices serving the business community, peak traffic can be expected in the late morning and early afternoon.

Sometimes expressed as a percentage of the traffic occurring during a 24-hour period, the busy hour traffic usually varies from 10 to 14 percent. Figures 2-6 through 2-8 provide the traffic profiles of MTS DDD, 800 Service and Outward WATS, respectively, for AT&T Long Lines in the year 1981.

Of the three traffic components examined by both Western Union and ITT (MTS, WATS and Private Line), the latter two are employed by the business sector and therefore follow the general business day usage profile, that is, peak hours occurring from 10 a.m. to noon and from 1 p.m. to 3 p.m.. MTS, however, is divisible into two components: residential and business. Since neither component is negligible and both have different hourly traffic distributions, the residential and business MTS peak hour must be calculated separately in order to determine the worst case situation. As might be expected, the MTS business profile is identical to that of Outward WATS appearing in Figure 2-8.

Although nearly all residential traffic occurs in the 16 hours from 8 a.m. to midnight, the peak hours occur between 7 p.m. and 11 p.m. partly because of the lower tariffs at those times and partly because that is the period during which most members of the household are home. It is the residential traffic which accounts for the second peak in the MTS profile of Figure 2-6.

Busy-Hour Staggering

To begin the analysis of busy-hour staggering, the traffic flow between time zones and within time zones must be identified. While many factors can be used to develop the time-zone matrix mix, we have opted for what we believe is the most straightforward - population distribution.

As an example, we will develop the time-zone distribution mix for the year 1990. From Table 2-8, the percent breakdown of population by time zone is 13.94, 5.10, 28.91, and 52.05 for the Pacific, Mountain, Central, and Eastern Time Zones, respectively. Based on the premise that the flow of traffic is proportional to the time-zone population, Table 2-9 can be developed. The first row in the table is calculated as follows - 52.05 percent of the total traffic orginates in the ETZ. Out of this fraction, 52.05 flows back into the ETZ, 28.91 percent to the CTZ, 5.10 percent to the MTZ, and 13.94 percent to the PTZ.

The first row of entries in the matrix results from simply multiplying the above fractional values together as follows:

Eastern-Eastern = 0.5205 x 0.5205 = 0.271

Eastern-Central = 0.5205 x 0.2891 = 0.150

Eastern-Mountain = 0.5205 x 0.0510 = 0.0265

Eastern-Pacific = 0.5205 x 0.1394 = 0.0726

In effect, 27 percent of the total traffic will remain within the ETZ, with 15, 3, and 7 percent flowing from the ETZ to the CTZ, MTZ, and PTZ, respectively.

Table 2-9
Traffic Flow Between and Within the Time Zones
(percent)

	Eastern	Central	Mountain	Pacific
Eastern	27.1	15.0	2.65	7.26
Central	15.0	8.36	1.47	4.03
Mountain	2.65	1.47	0.26	0.71
Pacific	7.26	4.03	0.71	1.94

By coupling the results of Table 2-9 with the MTS and Outward WATS usage profiles of Figures 2-6 and 2-8, the percent capture of both MTS and WATS can be determined on an hour-by-hour basis for each time zone. The procedure will be demonstrated with an example.

On examination of Table 2-9, the first column may be interpreted as the flow from (source) the Eastern, Central, Mountain, and Pacific Time Zones to (sink) the Eastern Time Zone. In order to ascertain the fraction of WATS or MTS telephony traffic flowing into the ETZ, say at 5 p.m. (Eastern Standard Time), one must determine the fraction of WATS or MTS traffic flowing within the ETZ at 5 p.m., from the CTZ to the ETZ at 4 p.m., from the MTZ to the ETZ at 3 p.m., and finally the traffic flowing from the PTZ to the ETZ at 2 p.m.

For Outward WATS, 8.6, 11.1, 11.3, and 10.0 percent of the traffic flows during the hours of 5 p.m., 4 p.m., 3 p.m., and 2 p.m., respectively, during the course of day as shown in Figure 2-8. These percentages can be conveniently expressed in a (1 x 4) matrix - (8.6, 11.1, 11.3, 10.0).

In like manner, the percent of total traffic flowing within and into the ETZ can be expressed as a (4 x 1) matrix -

$$\begin{pmatrix} 27.1 \\ 15.0 \\ 2.65 \\ 7.26 \end{pmatrix}$$

where the uppermost element corresponds to the total traffic within the ETZ and in decending order the flow of traffic from the Central, Mountain, and Pacific Time Zones into the Eastern Time Zone.

To determine the percentage of WATS traffic flowing into the ETZ at 5 p.m. (EST) the two matrices (1 x 4) (4 x 1) are multiplied together resulting in a single output (1 x 1). For example, when the above matrices are multiplied together we find that 5.02 percent of the total WATS traffic flows into the ETZ at 5 p.m. (EST). Similar calculations can be made for the remainder of the day and for the other three time zones. Figures 2-9 and 2-10 display the percent capture of MTS and Outward WATS by each of the time zones on an hour-by-hour basis.

Figure 2-6

MTS DDD
1981 TIME-OF-DAY
TOTAL WEEK

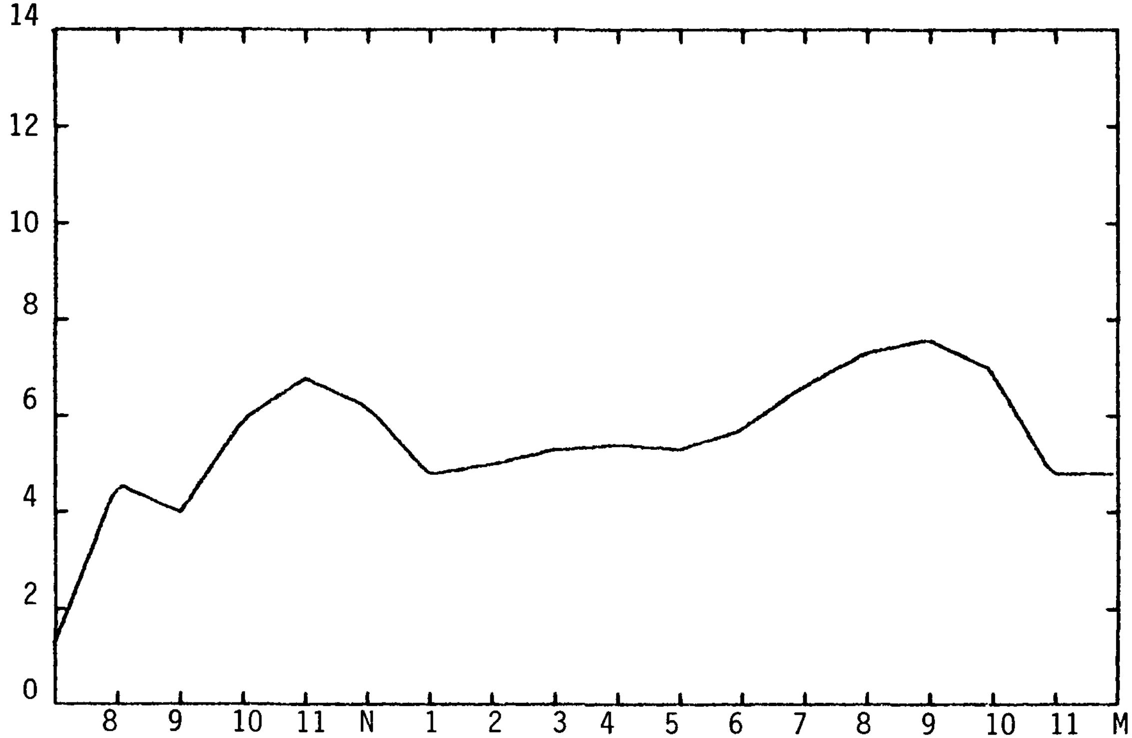


Figure 2-7

800 SERVICE
1981 TIME-OF-DAY
TOTAL WEEK

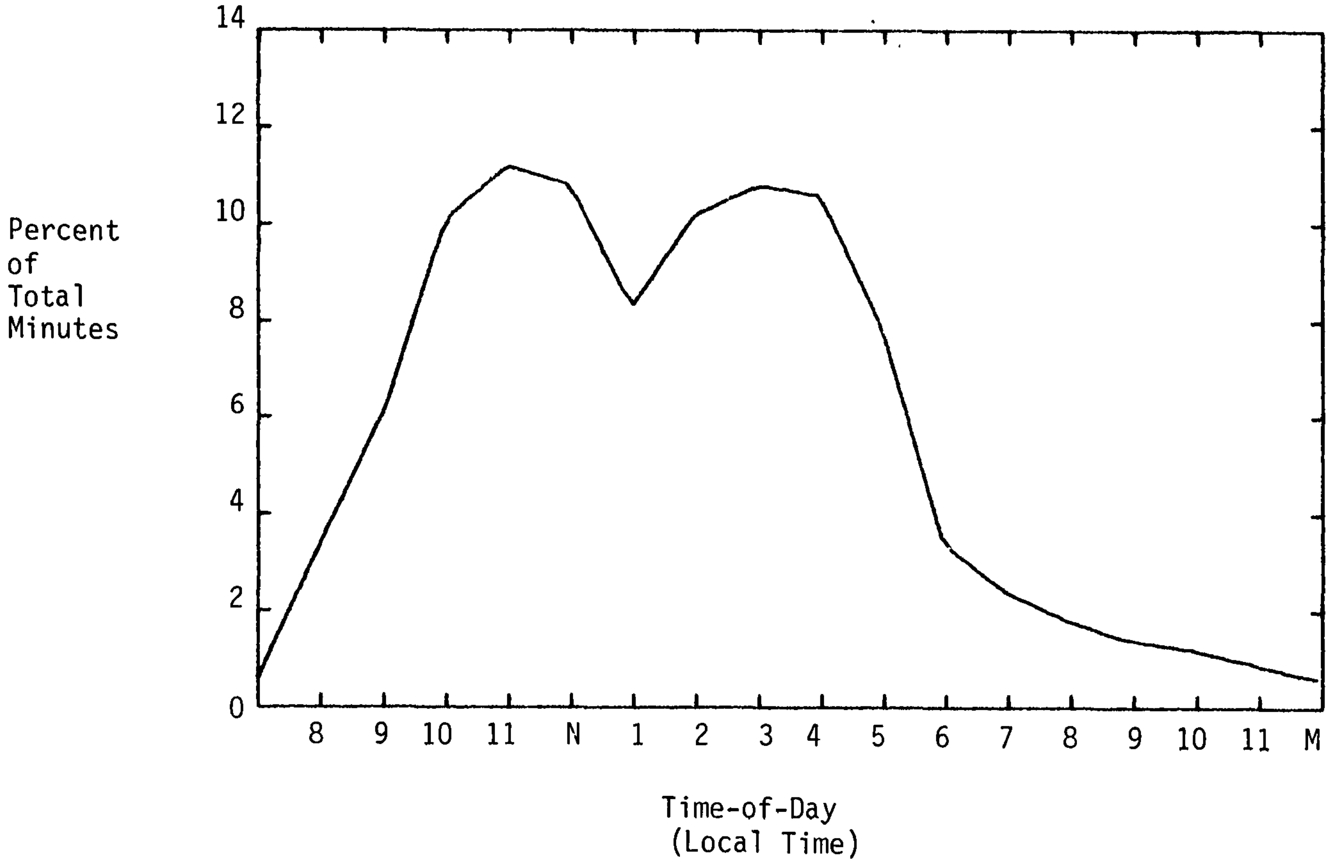


Figure 2-8

OUTWARD WATS
1981 TIME-OF-DAY
TOTAL WEEK

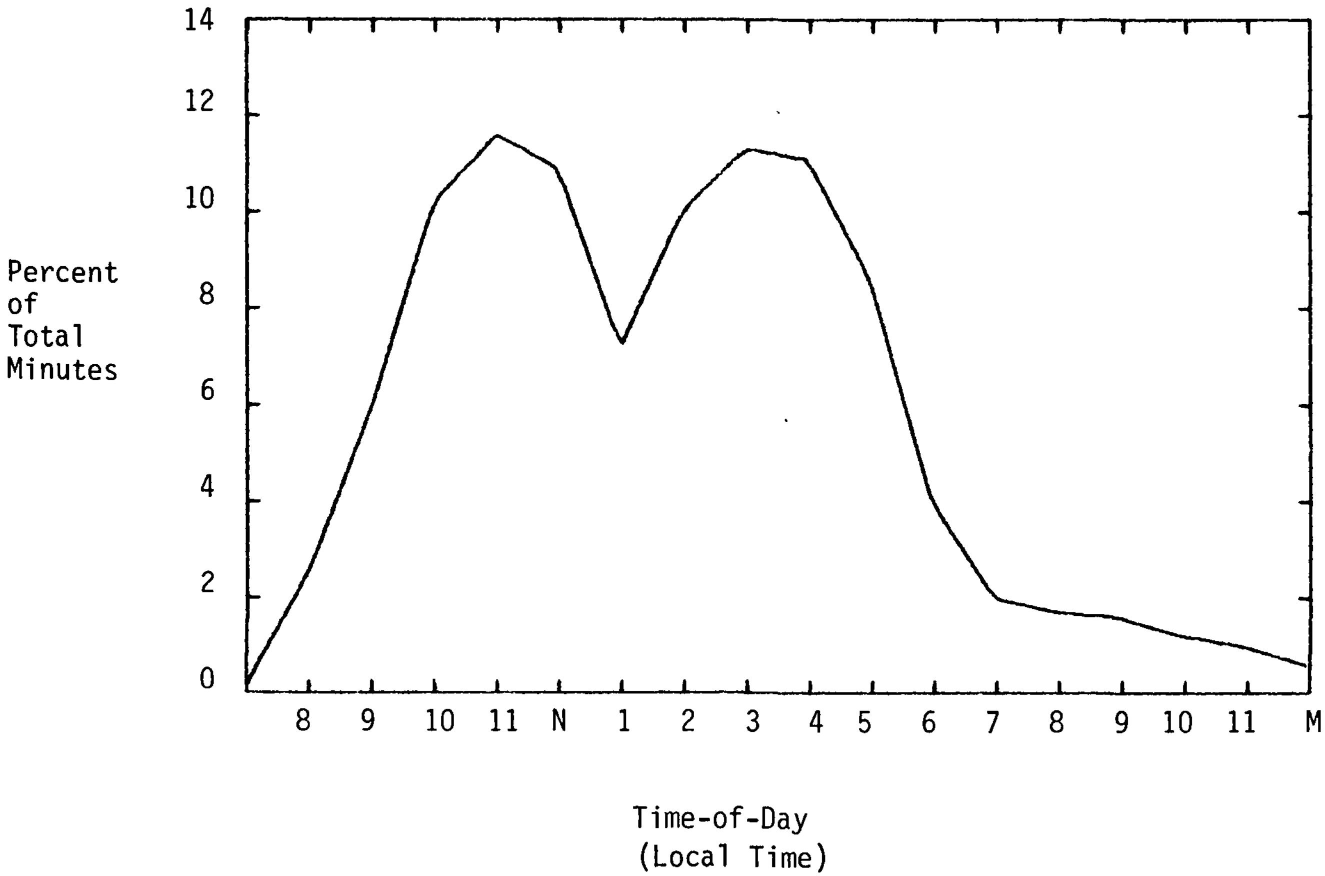


Figure 2-9

MTS PERCENT CAPTURE

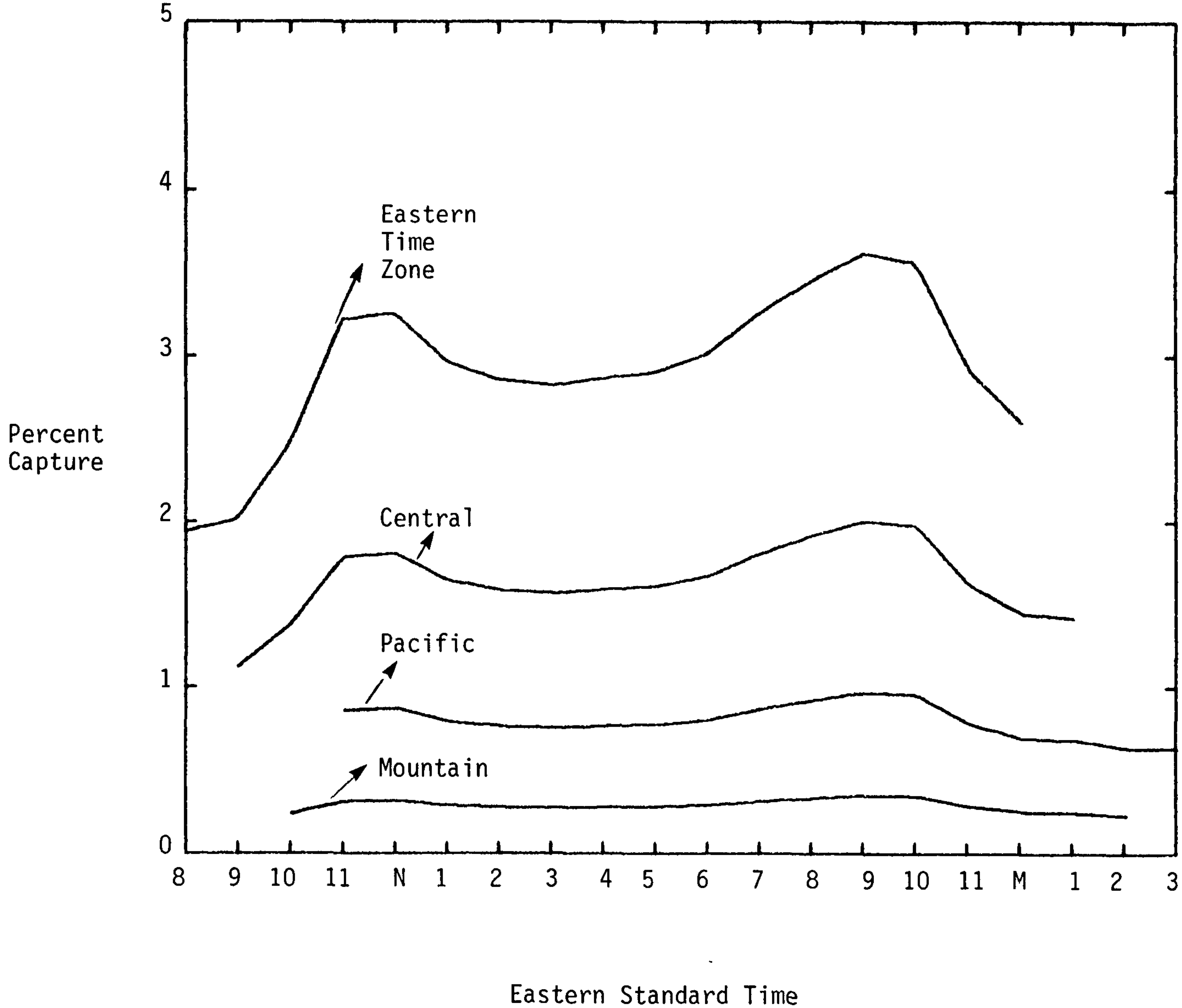


Figure 2-10

WATS PERCENT CAPTURE

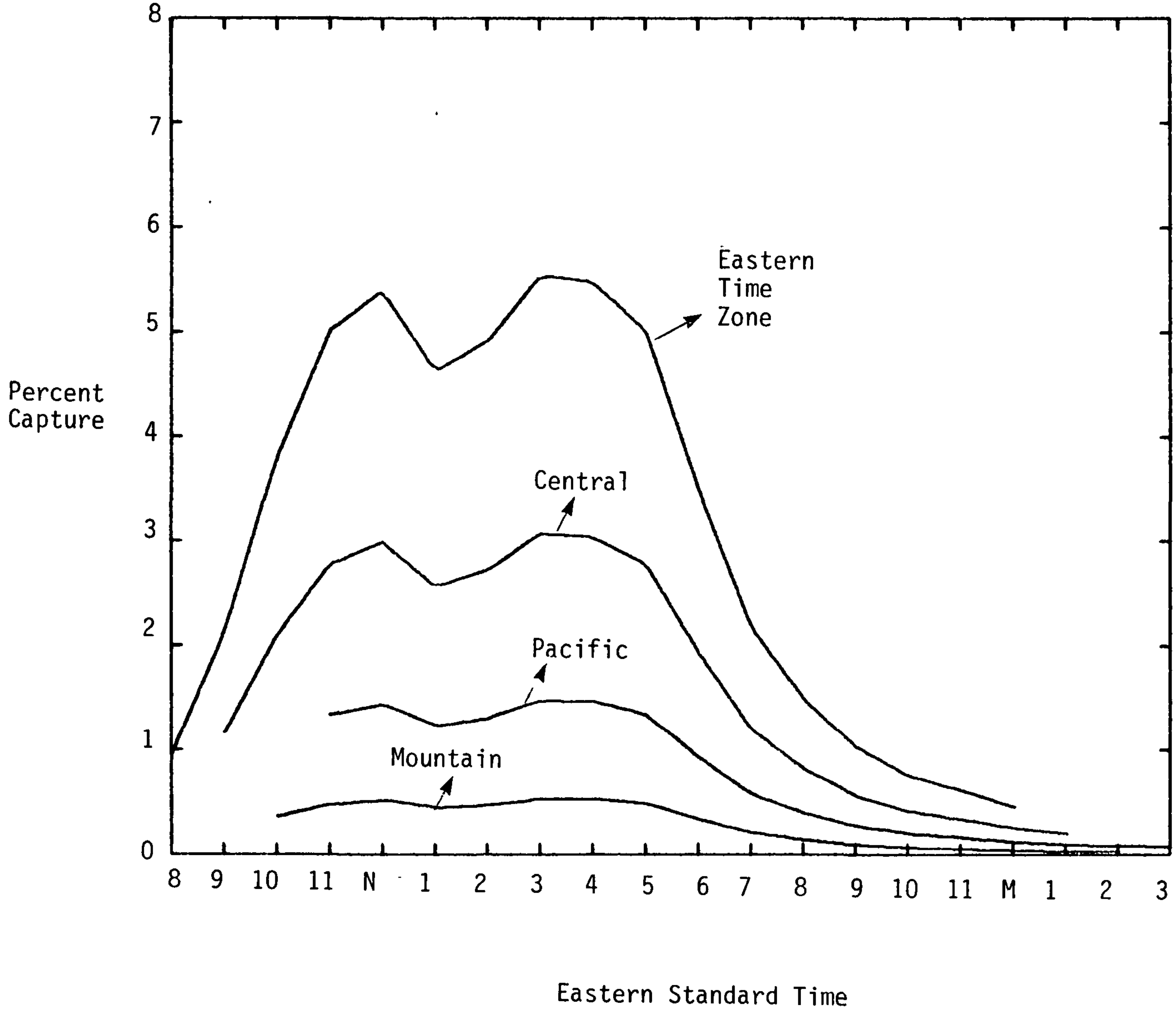


Table 2-10 shows the percent breakdown of voice into MTS, WATS, and Private Line during the average hour. These figures are derived from the recent ITT study.

Table 2-10
Average Hour Voice Traffic
(percent)

	MTS	WATS	Private Line
1980	34.6	17.6	47.8
1990	29.0	14.1	56.8
2000	20.9	19.3	59.8

Using these data together with the satellite-addressable voice traffic forecasts, the satellite voice capture percentages, and the ITT composite peak factors, the number of circuits in an average hour can be determined. Table 2-11 displays the average number of circuits needed for the low forecast of Section 2.1 for the years 1980, 1990, and 2000.

Table 2-11
Average Hour Voice Traffic
(half-voice circuits)

	MTS	WATS	Private Line
1980	8,390	4,270	11,600
1990	44,400	21,600	86,900
2000	197,000	182,000	563,000

The MTS entry for 1980 is determined as follows—the satellite addressable voice traffic for the year 1980 totals 240,000 half-voice circuits. In order to extract the average number of satellite-addressable circuits, this figure must be reduced by the peaking factor. In the work performed by ITT, a composite satellite addressable peak factor of 1.98 was used for the year 1980 and later reduced to 1.81 and 1.62 for the years 1990 and 2000. Dividing 240,000 half-voice circuits by a peak factor of 1.98 results in 121,212 satellite-addressable half-voice circuits. This figure is then multiplied by the estimated satellite capture (20%) and the fraction of MTS satellite addressable traffic (34.6%) from Table 2-10.

That is, the average hourly MTS voice traffic is equal to—

$= 240{,}000/1.98 \times 0.20 \times 0.346$

$= 8{,}390$ half-voice circuits

In order to determine the peak voice traffic on an hour-by-hour basis for one standard time (for example Eastern Standard Time), MTS and WATS peak factors derived from Figures 2-6 and 2-8 are applied to the average hourly voice traffic in Table 2-11.

In a format similar to Table 2-6, which forecast the high and low satellite voice traffic, Table 2-12 lists the year-by-year satellite traffic forecast integrating the effects of the staggered busy hours. As shown in Table 2-12, the staggering of busy hours has an averaging effect on a facility that serves all the time zones simultaneously. This averaging process results in a reduction of the satellite voice facilities required amounting to 30 percent in the early years, and slowly dropping to 20 percent by the year 2000.

Table 2-12

Satellite Voice Traffic Forecast

Adjusted to Include Effects of Busy-Hour Staggering

(thousands of half-circuits)

Year	Low	High
1980	32.2	32.2
1981	32.2	32.2
1982	30.5	30.5
1983	31.5	31.5
1984	37.0	36.7
1985	47.0	49.0
1986	61.9	68.0
1987	81.1	94.5
1988	109	135
1989	147	192
1990	192	268
1991	251	376
1992	313	495
1993	393	648
1994	480	825
1995	574	1,040
1996	679	1,270
1997	791	1,520
1998	920	1,840
1999	1,070	2,150
2000	1,210	2,470

2.5 Grade of Service Calculations

2.5.1 Traffic Engineering

If calls are to be handled without delay or loss, it would be necessary to provide as many circuits as there are subscribers. Assuming that each call involves two subscribers, it would perhaps be sufficient to provide half as many circuits as there are subscribers. This is the ideal case, but for economical reasons it is impractical.

To reduce the number of circuits to a reasonable amount, it is necessary to give up the ideal concept for nonblocking service. Subscribers have to realize that some of their calls cannot be handled immediately when the circuits are being used by other subscribers and that such calls have to be delayed or renewed. The term "grade of service" is given as the proportion of these unsuccessful calls relative to the total number of calls. The grade of service is defined as the measure of service given from the point of view of insufficiency of plant equipment.

For example, when transatlantic cables were first introduced the cost per channel over these cables was very high. It was then the practice of telephone administrations to queue up all traffic, so that it was practically never possible to obtain a channel when desired. Instead, a telephone subscriber desiring to place a call had to register his intention with the telephone company, and he was advised of the approximate waiting time, always in the order to several hours. This resulted in very high line utilization but a very poor grade of service.

We are now use to a very good grade of service. It is the standard practice of the Bell Operating System to design links for grades of service ranging from 1 in 100 to 1 in 1,000.

Traffic engineering can be defined as the process of determining adequate quantities of the correct type of equipment and trunks. All traffic engineering is based on a calculated grade of service. When used in accordance with accepted operating procedures, the desired balance of quality and cost of service will result.

2.5.2 Demand Assignment

Satellite links can be established on a preassigned or on a demand-assigned basis. Earth stations having continuous traffic over a given number of channels use preassigned channels. However, many channel requirements are of a short-term nature, so a channel and terminal equipment economy technique known as demand assignment is used.

Increased space segment efficiency in a fully variable demand assignment network arises from the fact that all channels are pooled and may be used by any station, according to its instantaneous traffic load. This may be contrasted with a system using preassignment in which all channels are dedicated, that is, both ends of the channel are fixed. With this system, when traffic to a particular destination is light, the utilization is poor. Also, for a given system traffic load, the blocking probability for a system employing preassignment is higher than for a system employing demand assignment. This occurs because some number of channels are "locked in" to a particular link. In a system employing demand assignment, unused channels may be made available to other users. Conversely, for a given blocking probability, the number of channels required to pass a given amount of traffic in a preassigned system is greater than in a demand assignment system. The lighter the traffic per destination, the greater the advantage of the demand assignment system.

Figure 2-11 shows the general relationship between the number of channels required as a function of the traffic in Erlangs for grades of service of 1 in 20, 1 in 100, and 1 in 1,000.

The relationship between traffic density, channels per link, and grade of service is defined by the Erlang equations.

The most commonly used equation is the Erlang B equation which assumes an infinite number of sources and a lost-calls-cleared situation. The Poisson equation applies for the lost-calls-held case. For the limited sources condition, the Engset and Binominal equations apply. The Erlang B equation has been standardized by the CCITT and is shown below:

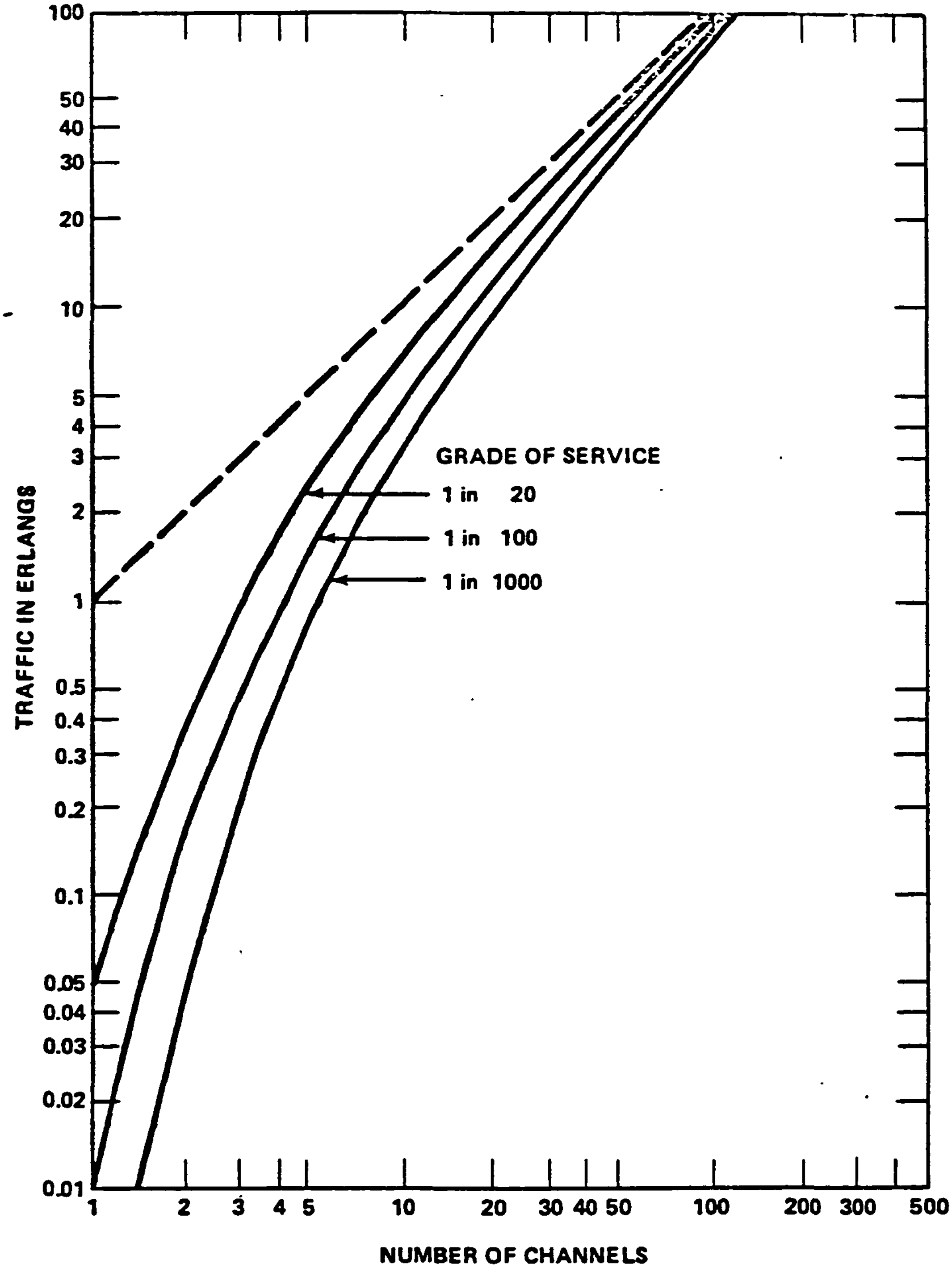


Figure 2-11

ERLANG LOAD VERSUS NUMBER OF CHANNELS

$$P = \frac{A^N/N!}{\sum_{x=0}^{N} A^x/x!}$$

where

P	=	Probability of blocking.
A	=	Total traffic offered in erlangs.
N	=	Number of channels.

2.5.3 Circuit Loading Calculations

Additional circuits are needed to ensure the required grade of service, which we have taken to be one percent of calls busy. However, the number of extra circuits required depends on the trunk group size and by the Erlang (or similar traffic engineering) function. Therefore, in order to estimate the number of circuits needed for an acceptable grade of service, we must first estimate the size of the trunk groups involved.

Since the Erlang B function is rather nonlinear, we felt that an approach based strictly on the average number of trunks per link would be inaccurate, especially for the thinner-route traffic carried by CPS and smaller SCCs. So, we looked for a way to approximate the actual trunk group size, even without knowing the actual system configuration. The method that we chose makes use of the Western Union market distribution information developed under their Task 2.0.

We assumed that the traffic was carried by three "systems," one comprising the top ten SMSAs as defined for an established common carrier, and carrying 42.5 percent of the traffic; a second comprising the top twenty SMSAs as defined for an established carrier, and carrying 32.5 percent of the traffic, and a third comprising the "most efficient network" for a specialized common carrier. See Tables 2-13 through 2-15. CPS links would be generally thinner than even the SCC links, but because CPS will be shared among voice, data and videoconferencing, we estimate that the overall efficiency for CPS will be similar to that for the SCCs. Given these assumptions, we then proceed as follows.

Table 2-13

Established Common Carrier—10 Earth Station Model

		NO. SMSA'S	GROUP MARKET VALUE	CUM GROUP MARKET VALUE
1	NEW YORK NY-NJ	42	10.02	10.02
2	FORT WAYNE IN	33	8.09	18.11
3	LYNCHBURG VA	19	4.69	22.80
4	ERIE PA	15	4.18	26.97
5	ROCKFORD IL	20	3.31	30.29
6	ATHENS GE	15	3.34	33.62
7	BRYAN-COLLEGE STATION TX	12	2.35	35.98
8	LAKELAND-WINTER HAVEN FL	13	2.25	38.23
9	PORTLAND ME	12	2.19	40.42
10	EVANSVILLE IN-KY	7	2.11	42.53

Table 2-14

Established Common Carrier-20 Earth Station Model

		No. SMSA's	Group Market Value	Cum Group Market Value
1	New York, NY-NJ	42	3.12	3.12
2	Fort Wayne, IN	33	2.94	6.06
3	Lynchburg, VA	19	1.13	7.19
4	Erie, PA	15	1.02	8.21
5	Rockford, IL	20	1.22	9.43
6	Athens, GA	15	0.94	10.37
7	Bryan-College Station, TX	12	1.24	11.61
8	Lakeland-Winter Haven, FL	13	0.73	12.34
9	Portland, ME	12	0.54	12.88
10	Evansville, IN-KY	7	0.69	13.57
11	Visulia-Tulare-Porterville, CA	11	3.07	16.64
12	Lawrence, KS	10	2.67	19.31
13	Jackson, MS	10	2.39	21.70
14	Eau Claire, WI	6	1.93	23.63
15	Montgomery, AL	6	1.50	25.13
16	Chico, CA	8	1.59	26.72
17	Yakima, WA	9	1.53	28.25
18	Oklahoma City, OK	6	1.45	29.70
19	Fort Collins, CO	6	1.39	31.09
20	Little Rock-North Little Rock, AR	5	1.37	32.46

Note: Market values for the first 10 (of the above 20) SMSAs were reduced from the Western Union figure to account for traffic in the 20 city model.

Table 2-15

Specialized Common Carrier Summary—Most Efficient Model

		NO. SMSA'S	GROUP MARKET VALUE	CUM GROUP MARKET VALUE
1	NEW YORK NY-NJ	20	9.64	9.64
2	CANTON OH	9	3.82	13.46
3	RACINE WI	5	3.96	17.41
4	JACKSON MI	6	2.72	20.13
5	SPRINGFIELD-CHICOPEE-HOLYOKE CT-MA	12	3.13	23.27
6	HAGERSTOWN MD	8	3.52	26.79
7	MUNCIE IN	6	1.86	28.65
8	GREENSBORO-WINSTON-SALEM-HIGH NC	7	2.31	30.96
9	ANNISTON AL	5	2.13	33.09
10	SPRINGFIELD IL	5	1.97	35.06
11	DUBUQUE IA	6	1.45	36.52
12	OXNARD-SIMI VALLEY-VENTURA CA	4	2.74	39.26
13	STOCKTON CA	6	1.84	41.10
14	PETERSBURG-COLONIAL HEIGHTS-HO VA	5	1.62	42.72
15	LAKELAND-WINTER HAVEN FL	4	1.19	43.91
16	ELMIRA NY	6	1.66	45.57
17	LEXINGTON-FAYETTE KY	3	1.58	47.15
18	ROCHESTER MN	4	1.65	48.80
19	ASHEVILLE NC	5	1.40	50.21
20	LIMA OH	4	1.45	51.66
21	BEAUMONT-PORT ARTHUR-ORANGE TX	4	1.68	53.34
22	KANSAS CITY MO-KS	4	1.34	54.68
23	BENTON HARBOR MI	5	1.23	55.91
24	BILOXI-GULFPORT MS	4	1.24	57.14
25	JACKSONVILLE NC	4	1.06	58.21
26	PARKERSBURG-MARIETTA WV-OH	4	1.06	59.27
27	COLUMBIA SC	4	1.06	60.33
28	DENVER-BOULDER CO	4	1.28	61.61
29	FORT LAUDERDALE-HOLLYWOOD FL	3	1.19	62.81
30	OCALA FL	4	1.01	63.82
31	COLUMBUS GA-AL	4	0.97	64.79
32	DALLAS-FORT WORTH TX	2	1.11	65.90
33	PROVIDENCE-WARWICK-PAWTUCKET RI-MA	4	0.91	66.81
34	TERRE HAUTE IN	4	0.90	67.71
35	BUFFALO NY	2	0.87	68.58
36	GLENS FALLS NY	4	0.87	69.45
37	APPLETON-OSHKOSH WI	4	0.86	70.31
38	BREMERTON WA	4	0.83	71.13
39	VINELAND-MILLVILLE-BRIDGETON NJ	4	0.84	71.97
40	LONGVIEW TX	4	0.85	72.83
41	LAWTON OK	3	0.87	73.70
42	AUSTIN TX	3	0.88	74.58
43	CLARKSVILLE-HOPKINSVILLE TN-KY	2	0.77	75.35
44	BAY CITY MI	3	0.75	76.09
45	JOPLIN MO	3	0.69	76.78
46	LAFAYETTE LA	3	0.72	77.50
47	FORT WALTON BEACH FL	3	0.65	78.15
48	LINCOLN NE	2	0.66	78.80
49	SALEM OR	3	0.64	79.45
50	BRADENTON FL	3	0.55	80.00
51	CHARLESTON-NORTH CHARLESTON SC	2	0.55	80.55
52	LITTLE ROCK-NORTH LITTLE ROCK AR	2	0.55	81.10
53	EVANSVILLE IN-KY	2	0.52	81.63

Table 2-15 (continued)

Specialized Common Carrier Summary—Most Efficient Model

		NO. SMSA'S	GROUP MARKET VALUE	CUM GROUP MARKET VALUE
54	MEMPHIS TN-AR	1	0.53	82.16
55	PROVO-OREM UT	2	0.52	82.68
56	VISALIA-TULARE-PORTERVILLE CA	3	0.47	83.16
57	PHOENIX AZ	1	0.49	83.65
58	CEDAR RAPIDS IA	2	0.42	84.07
59	LEWISTON-AUBURN ME	2	0.41	84.48
60	YUBA CITY CA	3	0.42	84.90
61	SAN DIEGO CA	1	0.45	85.35
62	SIOUX CITY NE-IA	2	0.41	85.76
63	BANGOR ME	2	0.39	86.14
64	TULSA OK	1	0.41	86.56
65	EL PASO TX	2	0.40	86.96
66	FARGO-MOORHEAD ND-MN	2	0.37	87.33
67	MIDLAND TX	2	0.37	87.70
68	CORPUS CHRISTI TX	2	0.37	88.06
69	ALTOONA PA	2	0.36	88.42
70	BROWNSVILLE-HARLINGEN-SAN BENI TX	2	0.36	88.78
71	BRYAN-COLLEGE STATION TX	2	0.36	89.14
72	ABILENE TX	2	0.35	89.49
73	CHATTANOOGA TN-GA	1	0.34	89.82
74	DES MOINES IA	1	0.34	90.17
75	WICHITA KS	1	0.32	90.48
76	JACKSON MS	1	0.30	90.78
77	SALINAS-SEASIDE-MONTEREY CA	2	0.29	91.07
78	DULUTH-SUPERIOR MN-WI	1	0.27	91.34
79	RICHLAND-KENNEWICK WA	2	0.27	91.61
80	ALBUQUERQUE NM	1	0.27	91.88
81	RIVERSIDE-SAN BERNARDINO-ONTAR CA	1	0.27	92.14
82	HAMILTON-MIDDLETOWN OH	1	0.25	92.40
83	LORAIN-ELYRIA OH	1	0.25	92.64
84	LYNCHBURG VA	1	0.24	92.89
85	LAS VEGAS NV	1	0.25	93.13
86	TUCSON AZ	1	0.25	93.38
87	FORT SMITH AR-OK	1	0.24	93.62
88	ATHENS GE	1	0.23	93.86
89	FLORENCE AL	1	0.23	94.08
90	TALLAHASSEE FL	1	0.23	94.31
91	LUBBOCK TX	1	0.22	94.53
92	TUSCALOOSA AL	1	0.22	94.75
93	COLUMBIA MO	1	0.22	94.97
94	MONROE LA	1	0.22	95.19
95	AMARILLO TX	1	0.22	95.40
96	ST CLOUD MN	1	0.21	95.61
97	KANKAKEE IL	1	0.19	95.80

Traffic is apportioned to the various SMSA stations by their "Group Market Value." Thus, for example, in Table 2-13, the New York SMSA would be originating 10.02 percent of the total traffic. This traffic is apportioned among the nine links to the other nine stations (still referring to Table 2-13) according to their share of the total 42.53 percent of the traffic carried by this network. An appropriate adjustment is included so that: 1) the traffic along each link is reciprocal, that is, if 200 circuits originate in New York and go to Lynchburg, Virginia, then 200 circuits originate in Lynchburg and terminate in New York; and 2) the total traffic still sums to 42.53 percent of the nationwide traffic; and 3) no traffic flows from a station back to itself.

At this point, we have the traffic along each link, in both directions, for all the links in the network. For Table 2-13 this comprises 90 numbers. This traffic is expressed in peak loaded channels, or Erlangs. We then consult the Erlang table for the appropriate grade of service (0.01) to find the number of circuits along each link in each direction needed to give that service. Because in a satellite system, carriers originate at a particular earth station, the trunks between any two stations are assumed to be available for service in two groups: one-half in one direction and one-half in the other. For large trunk groups, there is a negligible difference between this case and considering the total group as one aggregate, available to either station independently.

After the number of circuits for each link is determined, the numbers are totalled up to give the total number of circuits needed for this network.

Demand Assignment

In the 20 and 97 station networks, many of the links will have very few Erlangs of traffic. If these links were served on a pre-assigned basis, as we assumed the heavier trunk groups were, the result would be a very inefficient system. For the links in these networks, we have assumed a variable-destination demand assignment system, with a threshold traffic level equivalent to 50 circuits.

The traffic originating at each station is tested. If it exceeds 50 circuits (37 Erlangs at 0.01) then the links are broken out as noted above. If the traffic is less than 37 Erlangs then the entire traffic load is assumed to be demand-assigned, and the number of circuits is computed on the basis of the total traffic. For example, a station might be the source of 20 Erl. of traffic. Since this is less than 37 Erl., the entire 20 Erl. are assumed to be carried on a variable-destination demand assignment system, originating at that station, but terminating at any other station, as needed. This would result in a requirement for 30 circuits at 0.01. If the links were pre-assigned, and even if there were only 20 other stations, each with 1 Erl. of traffic, between 80 and 100 circuits would be needed.

Assuming that the station originates more than 37 Erl. of traffic, and each link is examined individually, a further test is conducted. If the traffic on any one link is less than 37 Erl., then that link is combined with other(s), until the total exceeds 37 Erl. Again, variable destination is assumed. This results in similar savings in circuit requirements.

We did this for each year in the twenty-one year scenario, but in order to avoid too many sets of lengthy tables we will simply show the results for 1980, 1990, and 2000. As you can see from Table 2-16, the later years, having more traffic and thus denser links, show more efficient use of the circuits. These calculations are included in the year-by-year values for total transponder requirements that are shown further on in the report.

2.6 Transponder Capacity for Voice

The satellite voice traffic forecasts consider only the source of demand. In order to transform them into a forecast of transponder requirements, we have to determine the capacity of a transponder for voice. This capacity will in general be a time-varying function. Our calculations here don't imply a particular transponder configuration, but are based on the common 36 MHz transponder bandwidth.

Table 2-17 shows the WU estimates of voice circuit capacity versus time. Rather than use these directly, we developed our own estimates and used the Western Union figures as a check. We consider three "kinds" of voice traffic: analog voice, carried on FDM/FM carriers or as Companded Single Sideband (CSSB); digital voice carried on large TDM or TDMA carriers; CPS voice, carried

Table 2-16

Grade-of-Service Results for Voice

(traffic in thousands of half circuits)

		Year				
		1980	1990		2000	
			Low	High	Low	High
TOTAL TRAFFIC		32.2	192	268	1,210	2,470
10 SMSAs:	Traffic	13.7	81.7	114	515	1,050
	Capacity	16.1	86.6	119	519	1,050
	Efficiency	85%	94%	96%	99%	100%
20 SMSAs:	Traffic	10.4	62.3	87.0	393	802
	Capacity	13.5	73.0	99.7	416	826
	Efficiency	77%	85%	87%	95%	97%
97 SMSAs:	Traffic	8.06	48.0	67.1	303	618
	Capacity	10.7	60.2	83.5	359	708
	Efficiency	75%	80%	80%	84%	87%
TOTAL:	Capacity	40.3	220	302	1,290	2,580
	Efficiency	80%	87%	89%	94%	96%

digitally on carriers of 3.088 Mbps each, eight per transponder. The bit rate per half-voice circuit varies with time as shown in the WU figures. Large carriers are assumed to use DSI if carried digitally, and companding if analog (except in 1980). Other assumptions are described below.

Our approach was to use the market distributions shown in Table 2-4 (reproduced for convenience as Table 2-18) to divide the total satellite market among the carriers, after extracting the CPS traffic fractions also shown in Table 2-18. We then estimated the transmission method and parameters for each carrier for 1980, 1990 and 2000. These figures are shown in Table 2-19. The resulting average half-circuits per transponder are also shown.

Table 2-17

Western Union Estimates of Transponder Capacity

	1980	1990	2000
Half-Voice Circuits:			
Estimate 1	1,200	3,600	7,200
Estimate 2	1,200	2,400	4,800
Digital	937	2,812	3,750
Composite:			
Estimate 1	1,200	3,364	4,931
Estimate 2	1,200	2,491	4,210

Table 2-18

Estimated Market Shares of Various Interstate Toll Carriers

(percent)

Carrier	1978	1980	1985	1990	2000
	Year				
AT&T Long Lines	96	86	66	55	46
MCI	0.8	7.2	20	27	31
GTE/SPCC	1.8	2.0	3.7	4.7	6.5
USTS	1.4	4.4	10.3	13	16
CPS - WU	—	0.25	—	1.57	2.47
CPS - ITT	—	5.8	—	10.6	14.9

Table 2-19

Transponder Capacity Estimates

(Except CPS)

Year	
1980	All 1,500 half-circuits per transponder
1990	AT&T - All digital, half of transponders at 90 Mbps, half at 60 Mbps rate 7/8 FEC, DSI, 32 kbps per half-voice circuit
	MCI - All CSSB, 4,200 half-voice circuits per transponder
	Other SCCS - All digital, 60 Mbps rate 7/8 FEC, DSI, 32 kbps
	1990 Composite = 3,949 half-circuits per transponder
2000	AT&T - All digital, same as 1990 except no FEC, 24 kbps per half-circuit
	MCI - All CSSB, 6,000 half-voice circuits per transponder
	Other SCCs - All digital, same as 1990 except no FEC, 24 kbps per half-circuit
	2000 Composite = 5,839 half-circuits per transponder

CPS Transponder Loading

We assumed that all or most CPS traffic would be carried using small earth stations, and relatively inefficient utilization of the space segment would result. For example, a 36 MHz transponder operated in the multicarrier mode has significantly less capacity than would be the case for single carrier operation. Operation into small stations can be enhanced by the use of carrier spacing plans designed to reduce intermod. Such sequences have been described in the literature by Babcock and Fang and Sandrin. Figure 2-12 shows typical variations in the transponder capacity as a function of earth station figure of merit and required carrier to noise ratio. Based on this and probable system configurations, we assume that a typical CPS transponder would support eight carriers of 3.088 Mbps each for a total of 24.7 Mbps.

The bit rate for a half-voice circuit was assumed to vary from 64 kbps in 1980 to 24 kbps in 2000. This gives a CPS transponder of 386 half-voice circuits in 1980, 772 half-voice circuits in 1990, and 1,029 half-voice circuits in 2000. The capacity of a CPS transponder, combined with the fraction of the addressable traffic denoted as CPS and the capture fraction then gives the number of CPS transponders. The non-CPS portion of the traffic is used with the previously-developed loading factors to get the number of non-CPS transponders.

Composite Transponder Capacities

Figures 2-13 and 2-14 show the time-varying information needed to convert transmission requirements into active transponders. Figure 2-13 shows the portion of voice traffic carried through CPS stations; the CPS portion of data is also shown for comparison. Figure 2-14 shows the capacity of one 36 MHz transponder in half-voice circuits as a function of time; this curve applies to the non-CPS portion of the total voice traffic.

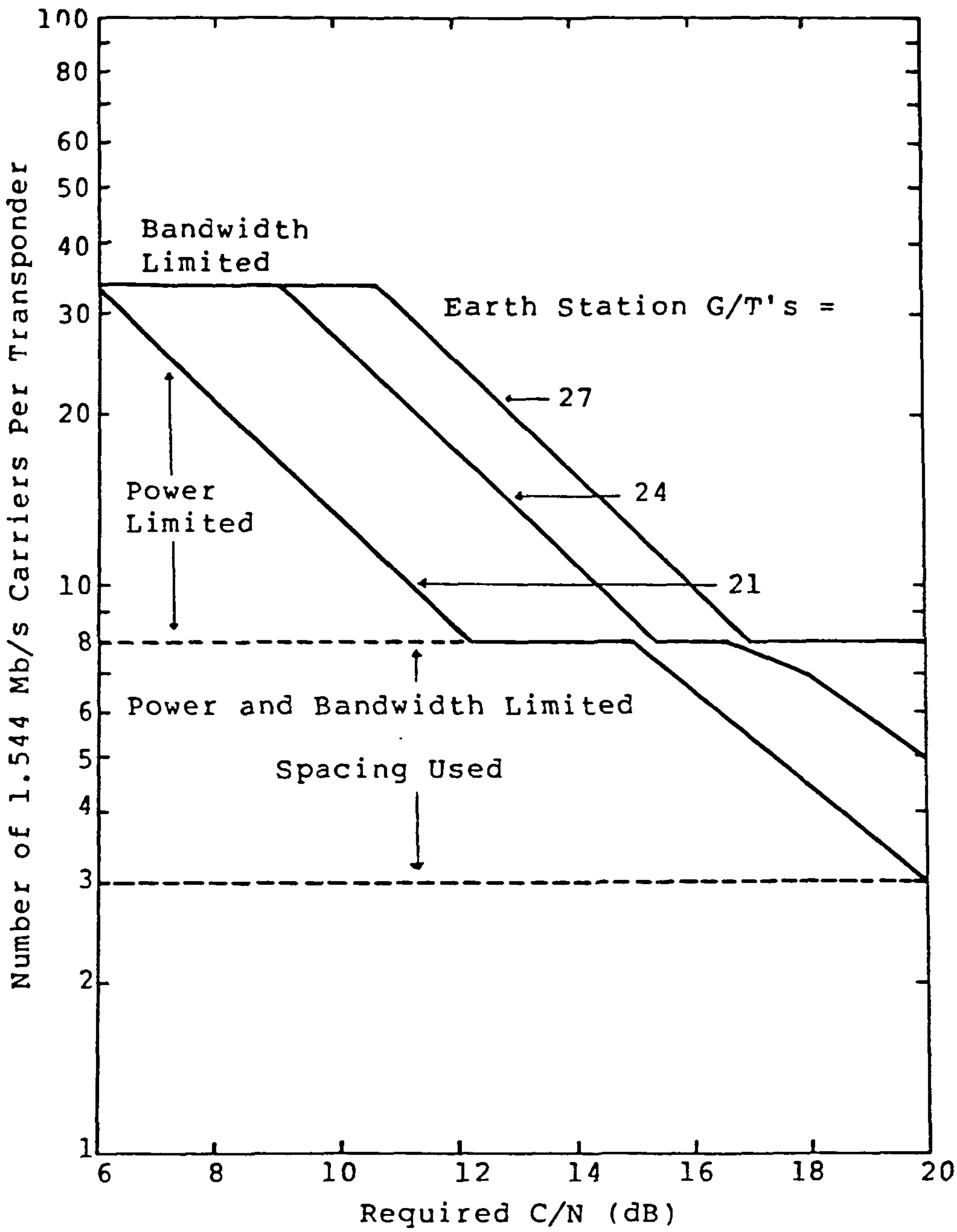


Figure 2-12

MULTI-CARRIER CAPACITY FOR A TYPICAL DOMSAT TRANSPONDER

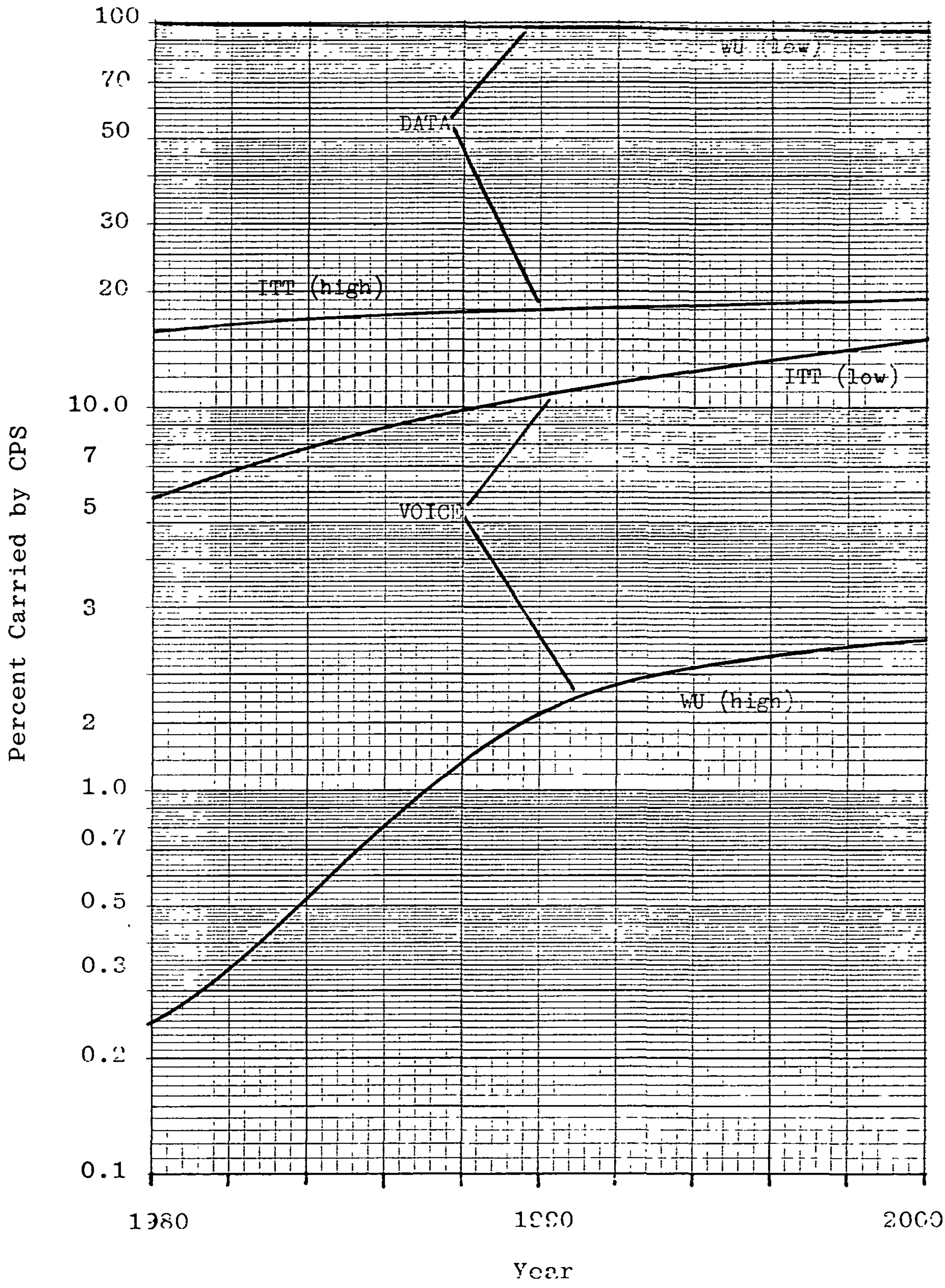


Figure 2-13

FRACTION OF TRAFFIC CARRIED BY CPS

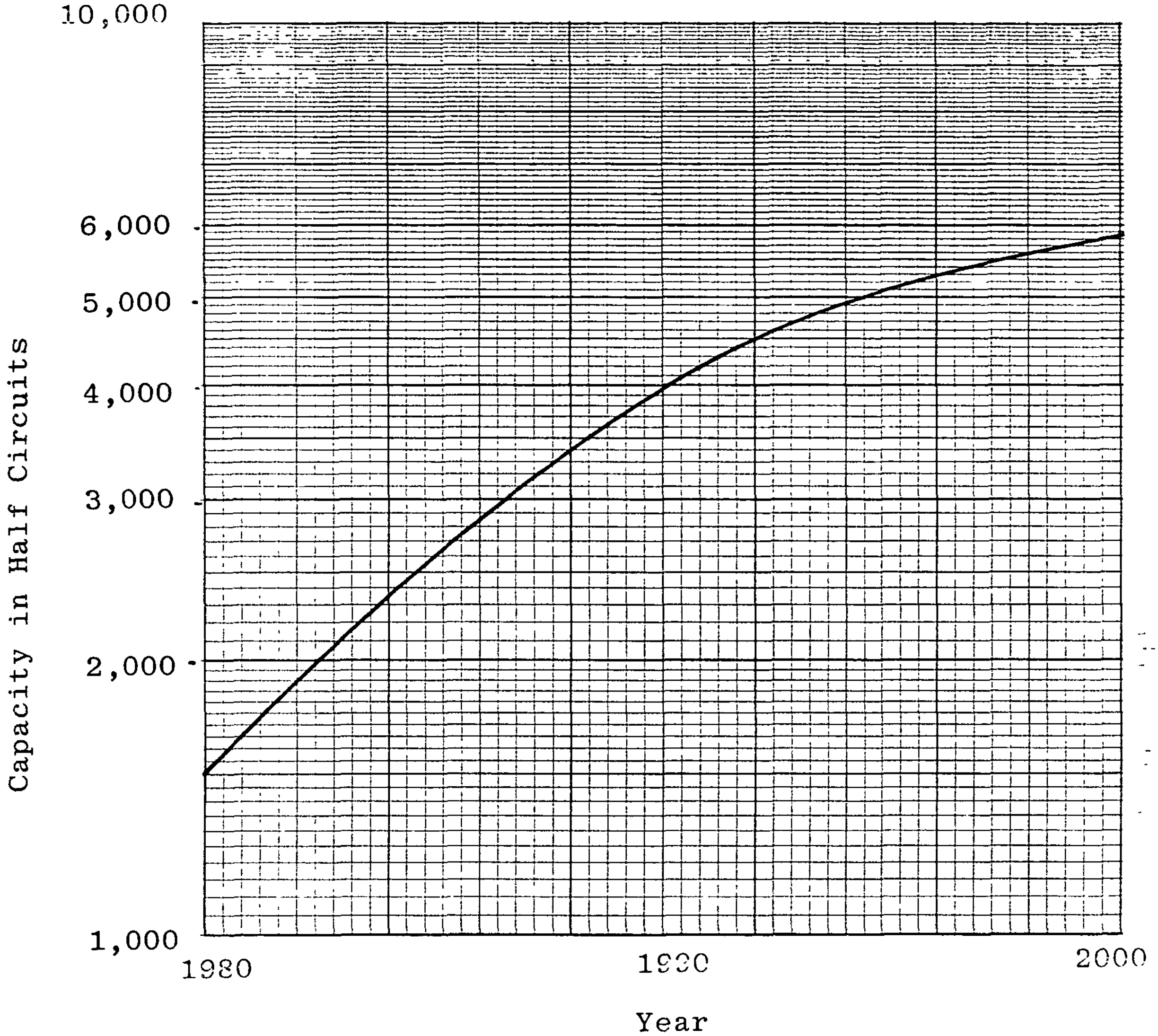


Figure 2-14

NUMBER OF HALF VOICE CIRCUITS
PER 36 MHz TRANSPONDER
(non-CPS traffic)

2.7 Transponder Requirements Forecasts for Voice

The satellite voice traffic forecasts of Section 2.5, Table 2-16 can now be integrated with the time-varying transponder capacity for voice appearing in Section 2.6, Figure 2-14 resulting in an operational transponder requirements forecast, that is without spare transponders included. Table 2-20 shows the result of this calculation for both the high and low traffic forecasts.

Table 2-20

Operational Transponder Requirements Forecast - Voice

Year	Low	High
1980	27	30
1981	24	27
1982	20	23
1983	19	23
1984	20	25
1985	23	31
1986	27	39
1987	32	49
1988	39	64
1989	49	84
1990	59	110
1991	72	144
1992	84	181
1993	100	227
1994	118	280
1995	134	343
1996	153	410
1997	173	479
1998	196	573
1999	222	657
2000	247	753

SECTION 3
DATA TRAFFIC DEMAND FORECAST

3.1 Satellite-Addressable Data Traffic Forecasts

Table 3-1 shows the WU and ITT forecasts for data traffic that is satellite-addressable. Interpolation was again done by a simple smooth curve. This is shown in Figure 3-1. Yearly values are shown in Table 3-2. It is interesting that in this case the ITT forecast is the higher of the pair, in contrast to the voice traffic forecast.

Table 3-1
WU & ITT Forecasts
Satellite-Addressable Data Traffic
(thousands of megabits per second)

	1980	1990	2000
Western Union	0.8	10.8	28.9
ITT	3.2	27.1	103.6

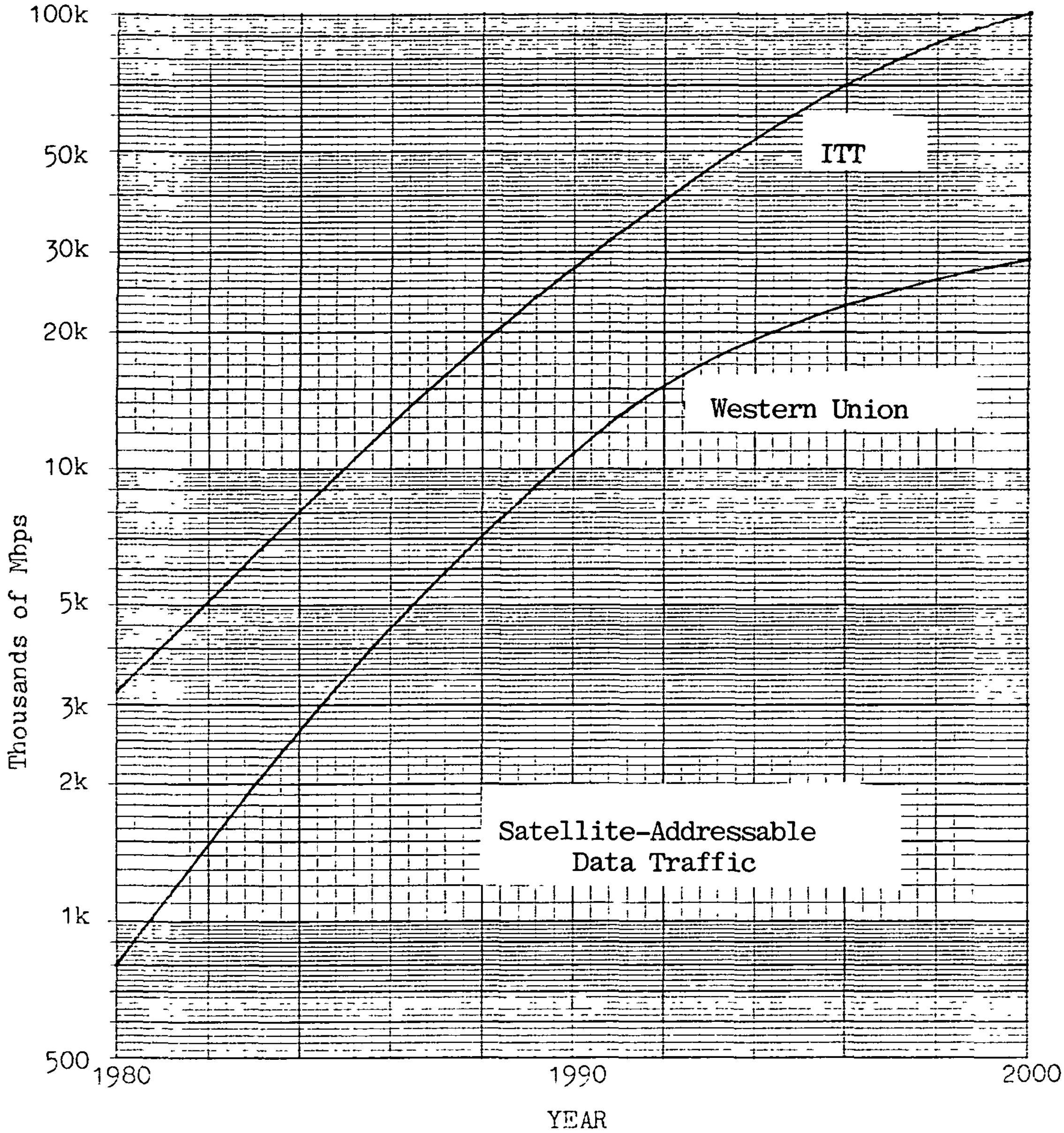


Figure 3-1

Forecasts of Satellite-Addressable Data Traffic

Table 3-2

Satellite-Addressable Data Traffic

(thousands of Mbps)

Year	Low	High
1980	0.8	3.2
1981	1.1	4.0
1982	1.5	5.1
1983	2.0	6.4
1984	2.6	8.0
1985	3.4	10.0
1986	4.4	12.5
1987	5.6	15.5
1988	7.1	19.0
1989	8.8	23.0
1990	10.8	27.1
1991	13.0	33.0
1992	15.0	39.0
1993	17.3	46.0
1994	19.1	53.5
1995	21.0	61.5
1996	23.0	70.0
1997	24.5	79.0
1998	26.0	87.0
1999	27.5	94.0
2000	28.9	103.6

3.2 Data Capture by Satellite

According to the distribution of data transmission speeds in the Western Union study, voiceband* data accounts for 91 percent of the total data traffic. Thus, even if there were no other mechanisms working, data capture by satellite should be at least 91 percent of the voice capture. However, the analog nature of the communications plant (most of it, anyway) in the U.S. more or less ensures that the economics of data transmission will compare unfavorably with those for voice. Therefore, even in a competitive environment, we would expect a higher data capture. This should increase as the data rate increases, with a rather sharp jump once we leave the realm of voiceband data.

*data rate $\leq$ 9.6 kbps

At one time, we made the bold statement that data circuits as short as 20 miles could be considered good candidates for satellite carriage, because of networking considerations. That, however, was before two data communications developments had begun to look significant: institutional cable (B-cable) and local area networks. As a result of these (and related technologies) it now seems unlikely that any data communications within a metropolitan area will be carried by satellite. However, because these networks have the potential to aggregate data traffic, thereby lowering the cost of the earth station per kbps, the potential for inter-city satellite data has actually been increased.

The prime market for satellite capture of data communications will be the growth portion of the total market. In the early years, this will be the case because much of the growth will come from new, higher-speed services that were not economical terrestrially. In later years, the situation will be more stable with regard to the satellite/terrestrial trade-off, and in general, users of existing services will have made their decisions. In addition, the gradual digital conversion of the terrestrial plant will allow terrestrial facilities to remain competitive. This will be aided by the increasing density of data communications. It is generally more economical to serve dense routes by terrestrial means (assuming no physical obstacles) and thinner routes by satellite. This is another reason for focussing attention on the growth segment, since it is there that innovative services will be found. Users of innovative services are almost always widely scattered at first, making them more likely to use satellite facilities.

Of course, there will always be a certain amount of capture of existing services, for a variety of reasons. However, this will be counterbalanced to some extent by losses in existing services (for similar but contrary reasons) and by increasing competitiveness of terrestrial facilities for the growth portion of non-innovative services. Therefore, given the crude knowledge that we have to work with, we think that a reasonable approximation to the capture can be derived by working with the incremental growth portion of the market.

Figure 3-2 shows the approach we have chosen. The lower curve is the capture fraction versus time for voice traffic. This is taken as the lower limit, and in the early years of the period, as the actual fraction for data as well. The uppermost curve shows the average capture fraction computed by assuming capture of 50 percent of the growth portion of the data traffic. The curve is the average of that growth figure for ITT and Western Union forecasts. In an environment with constant growth, this will of course approach 50 percent capture eventually. The central curve is the capture fraction pattern we have selected. It begins at the voice capture level, and gradually reaches the growth capture level.

3.3 Busy-Hour Averaging and Peaking

The approach used to determine the effects of busy-hour staggering of the peak voice traffic demand is again repeated for the satellite data traffic. As previously stated, the satellite facilities should be engineered to handle the normal busy hour. Unfortunately, no information is readily available which gives the data traffic profile as a function of the time-of-day. Therefore, we have postulated that the data has a profile similar to that of Outward WATS (Figure 2-8).

Table 3-3 displays the high and low satellite data traffic forecasts. In order to proceed with the staggered busy-hour analysis, the peak factors included by WU and ITT were removed. For the low scenario (WU), peak factors of 1.91, 1.73 and 1.58 were used for the years 1980, 1990 and 2000. ITT, on the other hand, used peak values of 1.40, 2.00 and 3.91 for the same years. The year-by-year peak factors were then obtained by interpolating between the above values.

With the removal of the contractors' peak factors, the analysis could then proceed. Table 3-4 shows the forecast of satellite data traffic, adjusted to include the effects of busy-hour staggering.

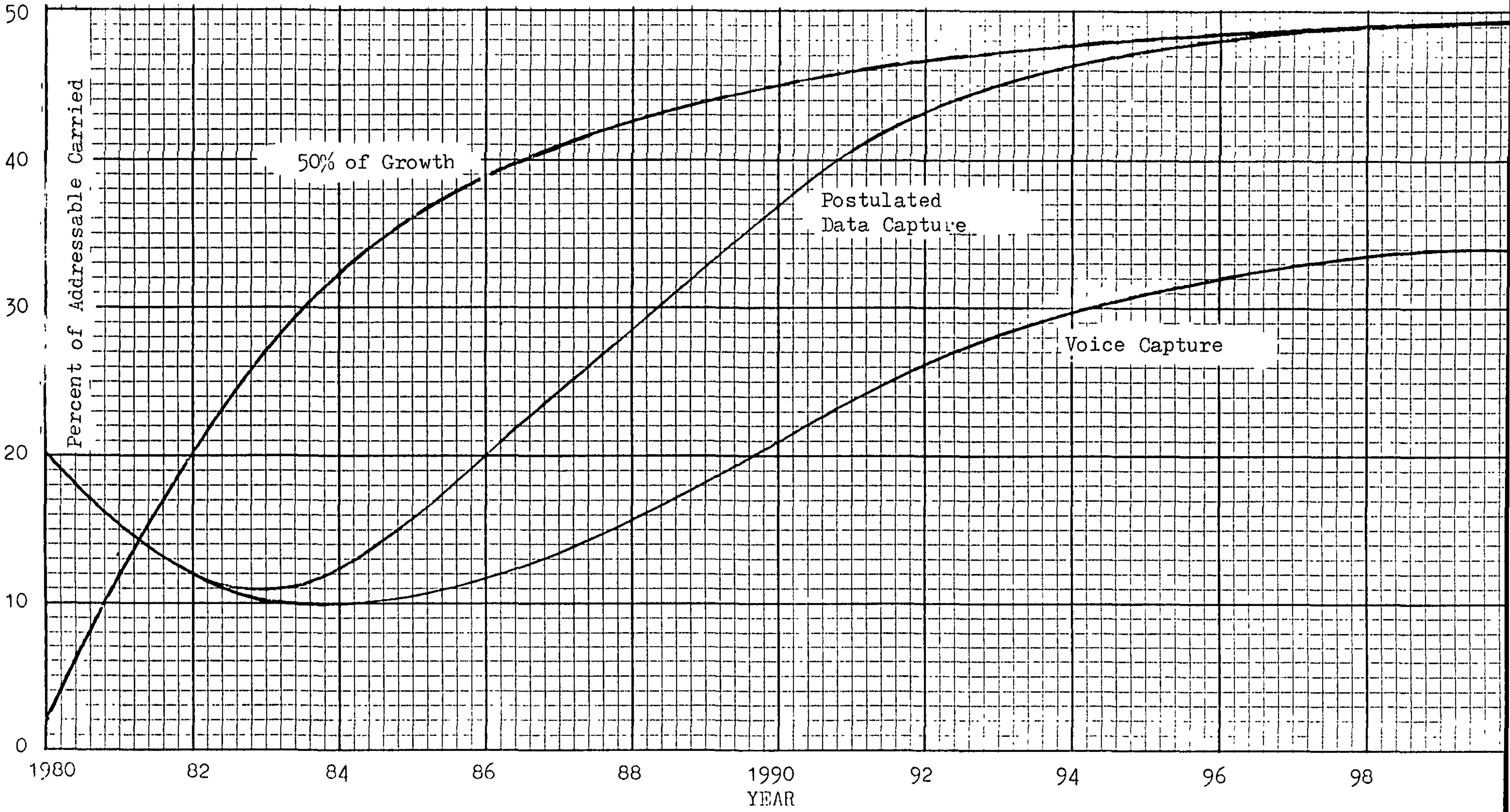


Figure 3-2

Satellite Capture Fractions for Data Traffic

Table 3-3

Satellite Data Traffic Forecast

(thousands of Mbps)

Year	Low	High
1980	0.16	0.64
1981	0.17	0.62
1982	0.18	0.61
1983	0.22	0.70
1984	0.32	0.98
1985	0.53	1.6
1986	0.88	2.5
1987	1.4	3.8
1988	2.0	5.4
1989	2.9	7.5
1990	4.0	10
1991	5.3	13
1992	6.3	17
1993	7.8	21
1994	8.9	25
1995	10	29
1996	11	34
1997	12	38
1998	13	43
1999	13	46
2000	14	51

Table 3-4

Satellite Data Traffic Forecast

Adjusted to Include Effects of Busy-Hour Staggering

(Gbps)

Year	Low	High
1980	0.21	1.2
1981	0.23	1.1
1982	0.25	1.0
1983	0.30	1.1
1984	0.45	1.5
1985	0.75	2.4
1986	1.2	3.6
1987	2.0	5.3
1988	2.9	7.3
1989	4.2	10
1990	5.9	13
1991	7.8	16
1992	9.7	18
1993	12	21
1994	13	23
1995	15	25
1996	17	27
1997	19	29
1998	20	31
1999	22	32
2000	23	33

3.4 Grade of Service Calculation for Data Transmission

These calculations are more problematical than those for voice. After all, there's just one size of voice circuit - it's either there or it's not - but data circuits come in an almost continuous range of sizes. Therefore, defining grade-of-service requirements is much more complex, unless one simply decides on a basic channel size and uses that. This is essentially what we have done, taking the lowest level of data transmission considered in the forecasts, 2.4 kbps, as the circuit rate, assuming bidirectionality.

We performed calculations for data that are essentially identical to those for voice. To reflect the deferrability of some data, a grade of service of five percent was used.

The circuit loading in these cases was essentially 100 percent. This reflects the large number of circuits under consideration and the reduced grade of service. Since data traffic is very amenable to efficient handling, this should be close to a realistic appraisal.

3.5 Transponder Capacity for Data

Data can be carried either in analog form on voice channels or in digital form over digital channels. While a great portion of the data traffic is voiceband as far as bit rate goes, this doesn't mean that it would be carried in analog form. For simplicity, and since we expect that eventually this will be the case, we have assumed that all data traffic is carried in digital form. There are several arguments in favor of this. First, connection to a digital channel is far less complex for the user, since channel conditioning, adaptive modems, and other devices for adapting the analog circuit to digital transmission are eliminated. Second, the presence of data in analog voice groups disrupts the statistics of the baseband, and renders the use of companders less effective (because the noise reduction from companding is subjective) thus reducing the capacity of a transponder in this mixed mode. Third, data carried by voice channels does not lend itself well to conversion to digital form using delta modulation, or other voice digitizing systems except 8 bit PCM. Thus, data channels cannot be mixed indiscriminantly with voice carried by this means, unless some additional measures are taken to demodulate the data and send it in digital form.

We are postulating three forms of digital access to a satellite transponder: large, single-carrier TDM or TDMA at speeds from 40 Mbps to 90 Mbps; multiple-carrier 1.544 Mbps access using large stations, for a transponder capacity of about 49 Mbps; multiple-carrier TDMA access using small, CPS stations at 3.088 Mbps for a total transponder capacity of 24.7 Mbps. The portion of data traffic designated as CPS by the traffic forecasts will be assumed to be carried at 24.7 Mbps per transponder. Ten percent of the remaining traffic will be assumed to be carried at 49 Mbps per transponder in multi-carrier mode. The rest of the traffic will be carried at 49 Mbps in 1980, 60 Mbps in 1990, and 90 Mbps in 2000. These figures are intended to reflect a mix of various transmission speeds. For example, the SBS transmit rate of 48 Mbps is equivalent to a rate of 40 Mbps through a 36 MHz transponder. By 1990, there will be some rates lower than 60 Mbps and some higher. These transmit rates are reflected in Table 3-5 which also contains the composite rates.

Table 3-5

Data Rates Per Transponder (36 MHz)

	1980	1990	2000
Portion at CPS rate of 24.7 Mbps			
Western Union	98.7%	97.2%	95.2%
ITT	15.6%	17.7%	18.9%
Portion at 49 Mbps			
Western Union	0.13%	0.28%	0.48%
ITT	8.4 %	8.3 %	8.1 %
Portion at varying rate			
Rate	49 Mbps	60 Mbps	90 Mbps
Western Union	1.17%	2.5%	4.3%
ITT	76%	74%	73%
Composite Rate			
Western Union	24.9 Mbps	25.1 Mbps	25.6 Mbps
ITT	42.5 Mbps	47.2 Mbps	57.4 Mbps

Composite Transponder Capacities

Figure 3-3 shows the capacity of a 36 MHz transponder in megabits per second as a function of time for both data and videoconferencing traffic. Different curves are shown for the high and low forecasts, since the fraction of traffic carried by CPS is different for both systems.

3.6 Transponder Requirements Forecast for Data

Table 3-6 shows the operational transponder requirements for both the high and low forecasts. On first inspection it may appear as if the data forecasts have been inadvertantly reversed high for low. This oddity came about because of the high proportion of CPS data that WU assumed in their forecasts and the resulting low capacity per transponder. In our further calculations, we treat them as shown in Table 3-6.

Table 3-6

Operational Transponder Requirements Forecast - Data

Year	Low (ITT)	High (Western Union)
1980	27	8
1981	25	9
1982	24	10
1983	26	12
1984	35	18
1985	53	30
1986	80	49
1987	116	78
1988	157	115
1989	213	168
1990	270	229
1991	322	304
1992	367	376
1993	411	457
1994	449	522
1995	484	590
1996	520	668
1997	547	723
1998	556	777
1999	561	835
2000	572	889

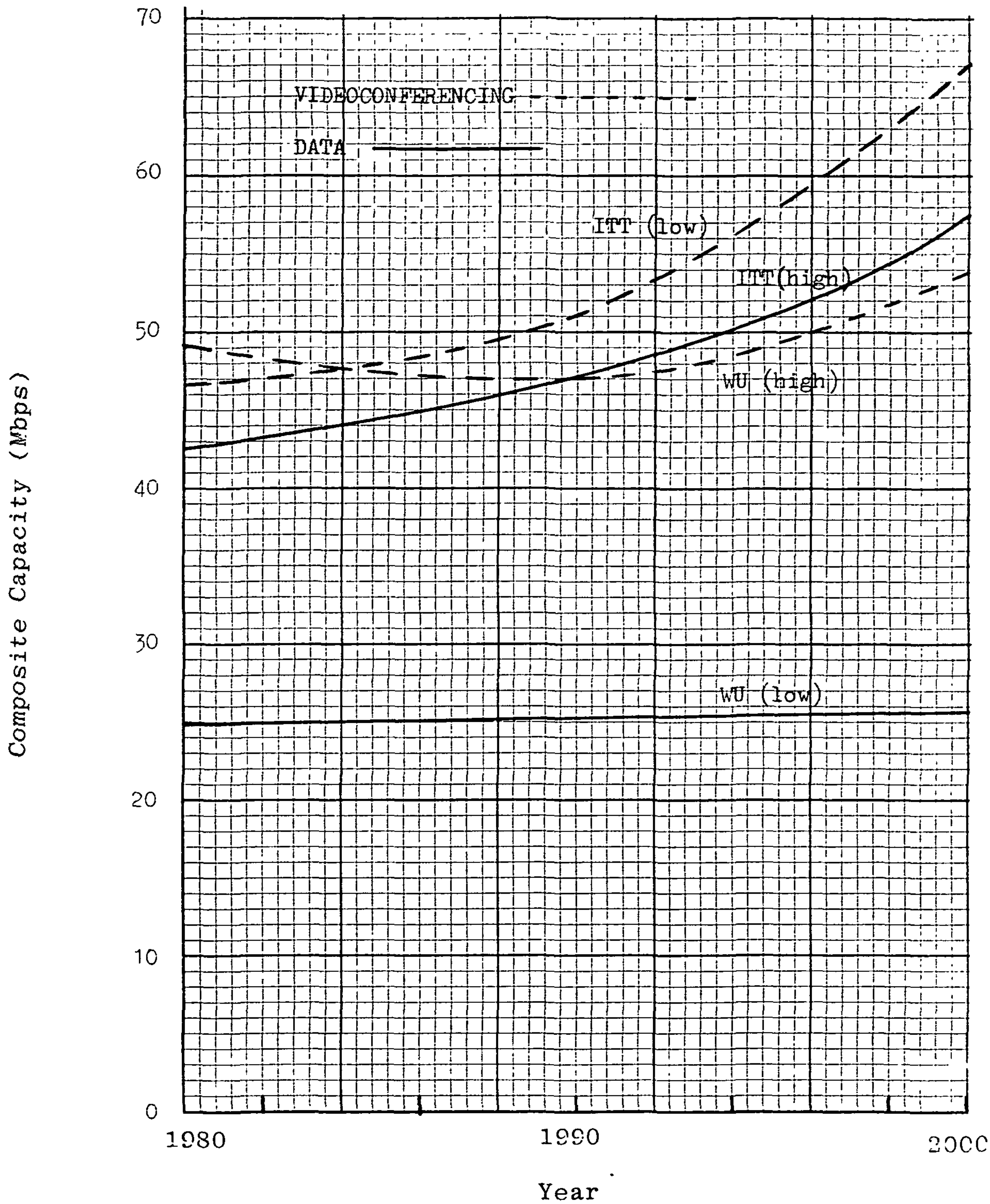


Figure 3-3

DIGITAL CAPACITY OF 36 MHz

SECTION 4
VIDEOCONFERENCING DEMAND FORECAST

4.1 Satellite-Addressable Videoconferencing Demand Forecasts

The ITT and WU forecasts for video conferencing are presented in considerably different forms. In order to produce a set of comparable forecasts, we've converted both to half-circuits of video. Specific procedures are as follows.

The ITT forecast is given in bits per second, and the transmit rate requirement for the three target years is also given. To model the transition between the 1980 figure of 42 Mbps per half-circuits, and the 1990 (and beyond) value of 1.15 Mbps, we chose a curve of constant rate of reduction, over 10 years, which works out to about 30 percent per year. This is shown in Table 4-1. The resulting forecast in half-circuits is shown in Table 4-2.

The Western Union forecast, as given, involves both so-called "limited motion" conferencing and "full motion" conferencing. We have chosen to lump the full motion portion together with the broadcast video forecast, because the degree of compression involved is much lower than that of the limited motion. Thus, the videoconferencing forecast here includes only limited motion, which we take to mean the typical compressed video at approximately T-1 rates or similar.

Western Union presents their forecast in transponders, and states that one transponder will accommodate an average of 12, 24, or 36 half-circuits in 1980, 1990, and 2000 respectively. These figures are averages of both CPS and trunking traffic, which are carried at different bit rates per transponder. The forecast for 1980 is zero for both CPS and trunking, so the only years of interest are 1990 and 2000. In these, the CPS transponder rate is 52.5 Mbps and the trunking rate is 90 Mbps. Assuming the same rate per half-circuit in both systems, the number of half-circuits in a CPS transponder is 14 in 1990 and 22 in 2000; corresponding figures for trunking transponders are 25 and 37. These don't represent very aggressive compression factors. The year 2000 rate is about 2.43 Mbps per half-circuit.

Using these figures, we transformed the forecasts from transponders to half-circuits for 1980, 1990, and 2000. These numbers were then plotted and a smooth curve drawn to interpolate the annual figures. The curves for CPS and non-CPS are shown in Figures 4-1 and 4-2. The annual figures are also shown in Table 4-3.

Table 4-1
Transmit Rate Requirements Per
Videoconferencing Half-Circuit — ITT

Year	Transmit Rate (Mbps)
1980	42
1981	29
1982	20.5
1983	14.3
1984	10.0
1985	7.0
1986	4.9
1987	3.4
1988	2.4
1889	1.6
1990	1.158
1991	1.158
1992	1.158
1993	1.158
1994	1.158
1995	1.158
1996	1.158
1997	1.158
1998	1.158
1999	1.158
2000	1.158

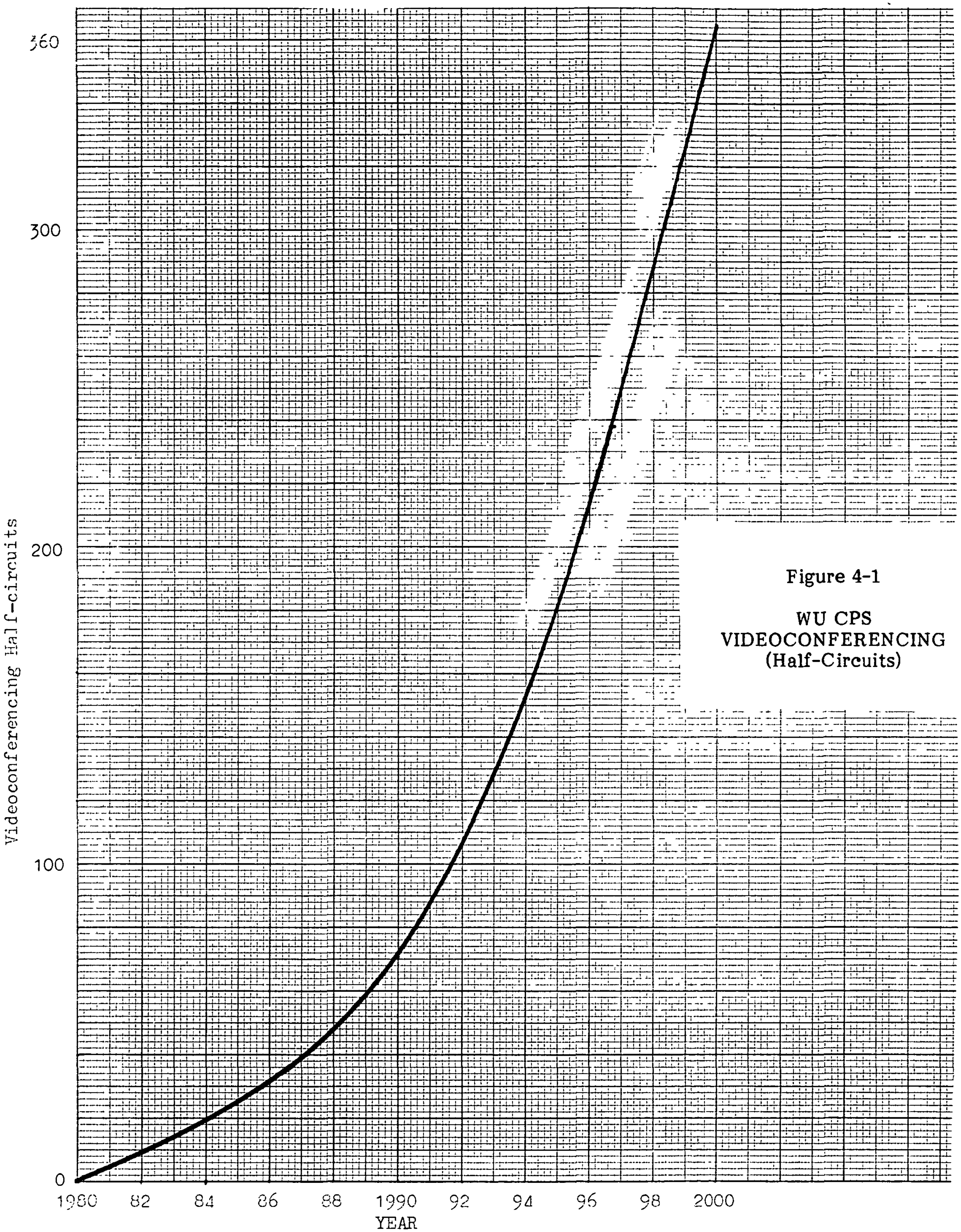


Figure 4-1

WU CPS
VIDEOCONFERENCING
(Half-Circuits)

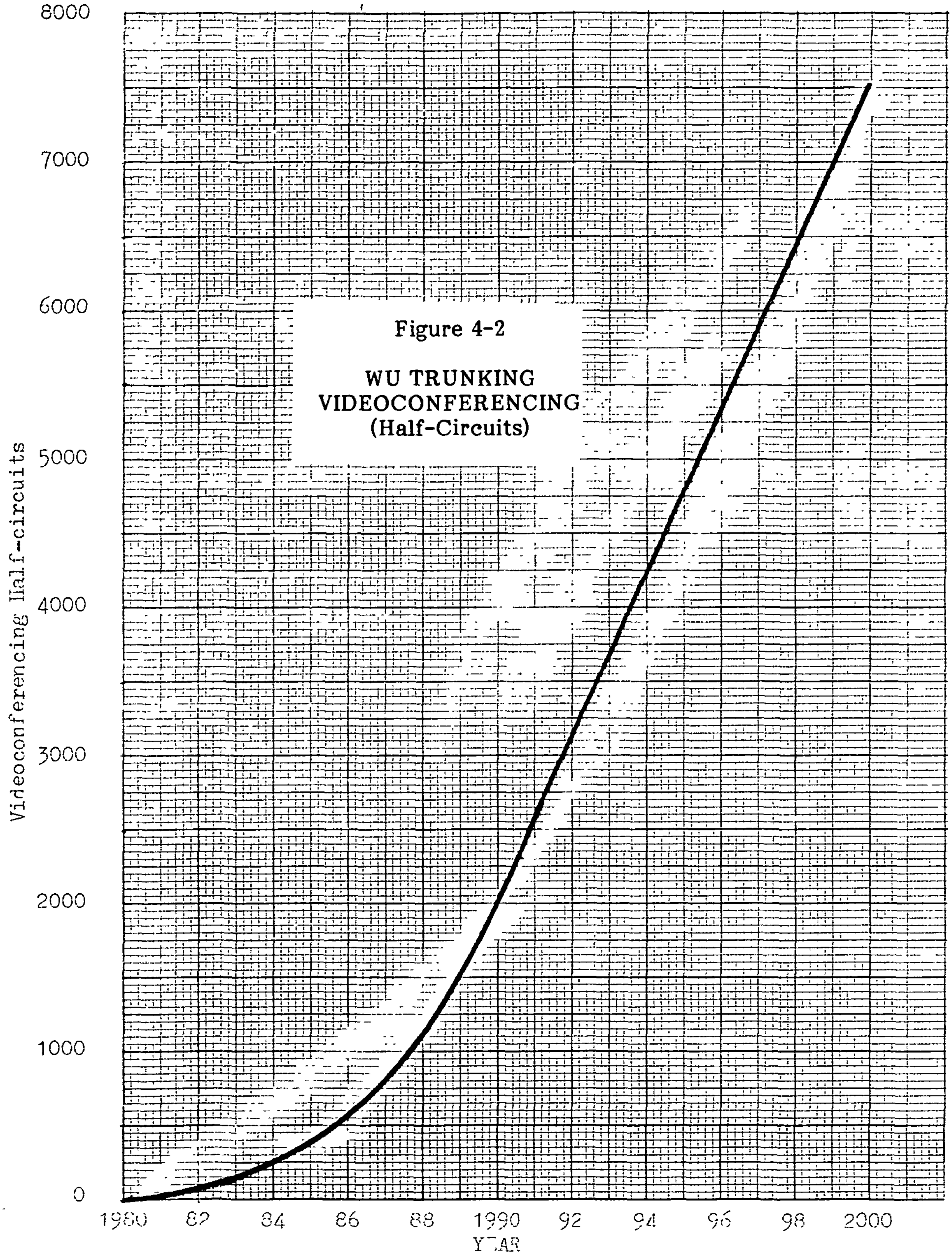


Figure 4-2

WU TRUNKING
VIDEOCONFERENCING
(Half-Circuits)

Table 4-2
ITT Forecast Satellite-Addressable
Videoconferencing — Traffic
(Half-Circuits)

Year	Traffic, Half-Circuits
1980	9
1981	15
1982	25
1983	42
1984	71
1985	120
1986	200
1987	338
1988	562
1889	994
1990	1,614
1991	1,848
1992	2,116
1993	2,426
1994	2,781
1995	3,187
1996	3,644
1997	4,180
1998	4,784
1999	5,484
2000	6,278

Table 4-3
WU Forecast Satellite-Addressable
Videoconferencing Traffic
(Half-Circuits)

Year	CPS	Trunking
1980	0	0
1981	4	10
1982	9	50
1983	14	125
1984	19	240
1985	25	375
1986	31	560
1987	39	800
1988	48	1,100
1989	58	1,500
1990	70	2,015
1991	87	2,575
1992	107	3,125
1993	128	3,675
1994	153	4,225
1995	182	4,775
1996	214	5,325
1997	250	5,875
1998	288	6,425
1999	326	6,975
2000	365	7,529

4.2 Satellite Capture of Videoconferencing

AT&T's original videoconferencing system, PMS, was an analog system which used terrestrial transmission exclusively. The video distribution channels employed were the same type as those used for network television distribution. Thus, there was essentially no satellite teleconferencing of the sort forecast here before about 1982. At that time, we estimate that there was some small amount of conferencing on SBS and other satellites.

The new PMS will be handled by a mix of satellite and terrestrial facilities. Under the divestiture, the equipment and room facilities will be handled by American Bell, and the transmission by AT&T Interexchange Services (ATTIX). Upon inquiry, they were not able to specify what fraction of the traffic they expected to be carried by satellite. However, AT&T has filed before the FCC stating that up to five transponders would be used for video teleconferencing. These are to be accessed by multiple T-1 (1.544 Mbps) carriers and would provide 12 half-circuits for videoconferencing in each transponder. No indication is available about when this capacity would be needed.

Meanwhile, ISACOMM (United Telecom) and American Satellite are offering teleconferencing at 1.544 Mbps each way. Some SBS users have their own in-house systems. It is very difficult to determine how many circuits are involved. For this reason, we have not been able to use present activity to pin down the videoconferencing satellite capture with any certainty.

We have chosen to postulate a relatively arbitrary videoconferencing capture, based on our own judgment. There are only a limited number of terrestrial T-1 lines available now, and the larger optical fiber systems will not have significant capacity on line until the late 1980's or later. Therefore, given the substantial growth of videoconferencing forecast by Western Union and ITT (and remember, we (FSI) have those forecasts as given) there is simply no alternative but to accommodate much of it by satellite.

Our estimate is that between 1990 and 2000, 90 percent of the videoconferencing will be carried by satellite. In making the transition between the zero capture situation in 1980 and 1981, we chose a simple straight line growth, reaching 90 percent in 1990. The estimated satellite capture of satellite-addressable video teleconferencing is shown in Table 4-4.

Table 4-4

Satellite Capture of

Satellite-Addressable Videoconferencing

Year	Capture Percent
1980	0
1981	0
1982	10
1983	20
1984	30
1985	40
1986	50
1987	60
1988	70
1889	80
1990	90
1991	90
1992	90
1993	90
1994	90
1995	90
1996	90
1997	90
1998	90
1999	90
2000	90

4.3 Busy-Hour Averaging and Peaking

As we see it, videoconferencing systems will remain in the business sector throughout the remainder of the century, with very little, if any, penetration into the residential sector. As such, videoconferencing systems will be used in the same manner as the business telephone, with the majority of usage occurring between the hours of 8 a.m. and 6 p.m.

Assuming this to be the case, the Outwards WATS usage profile (Figure 2-8) was employed and applied to ITT's and Western Union's satellite videoconferencing forecast of Table 4-5. Peak factors ranging from 2.5 in 1980, decreasing to 1.0 in the year 2000 were incorporated into Western Union's high forecast. A peak factor of 2.66 was used in ITT's low forecast. Table 4-6 shows the forecast of satellite videoconferencing adjusted to include the effects of busy-hour staggering.

Table 4-5
Satellite Videoconferencing Traffic Forecast
(Half-Circuits)

Year	Low (ITT)	High (Western Union)
1980	0	0
1981	0	0
1982	3	6
1983	8	28
1984	21	78
1985	48	160
1986	100	300
1987	200	500
1988	390	800
1989	800	1,200
1990	1,500	1,900
1991	1,700	2,400
1992	1,900	2,900
1993	2,200	3,400
1994	2,500	3,900
1995	2,900	4,500
1996	3,300	5,000
1997	3,800	5,500
1998	4,300	6,000
1999	4,900	6,600
2000	5,700	7,100

Table 4-6

Satellite Videoconferencing Traffic Forecast

Adjusted to Include Effects of Busy-Hour Staggering

(Half-Circuits)

Year	Low (ITT)	High (Western Union)
1980	0	0
1981	0	0
1982	2	7
1983	8	33
1984	20	99
1985	46	220
1986	96	430
1987	190	800
1988	380	1,400
1989	760	2,400
1990	1,400	3,900
1991	1,600	5,100
1992	1,800	6,300
1993	2,100	7,500
1994	2,400	8,800
1995	2,800	10,000
1996	3,200	12,000
1997	3,600	13,500
1998	4,100	14,000
1999	4,700	16,000
2000	5,400	18,000

4.4 Grade-of-Service for Video Teleconferencing

The situation for videoconferencing is even more confused than that for data. Not only is there a mix of circuit sizes, but also complicatings is the fact that most videoconferences are pre-arranged by schedule right now. During the early years, when the circuit is a high-capacity one-full transponder video, for example—more advance scheduling is in use. The low demand for relatively large circuits tends to load the system poorly for a good grade-of-service, while the scheduling and queueing tends to improve things. The reverse will be the case in the future, with more-or-less random access to much lower capacity channels and virtually no scheduling of transmission facilities* will make the situation more like voice traffic.

The computations are then essentially the same as for voice and data. Results are shown in Table 4-7. To allow for some scheduling, the grade-of-service was changed to 0.20.

Table 4-7
Grade-of-Service Results for Videoconferencing
(Half-Circuits)

		Year			
		1990		2000	
		Low	High	Low	High
TOTAL TRAFFIC		1,400	3,900	5,400	18,000
10 SMSAs:	Traffic	590	1,700	2,300	7,700
	Capacity	630	1,800	2,500	7,800
	Efficiency	94%	94%	92%	99%
20 SMSAs:	Traffic	450	1,300	1,800	5,800
	Capacity	540	1,400	1,900	6,100
	Efficiency	83%	93%	95%	95%
97 SMSAs:	Traffic	350	980	1,400	4,500
	Capacity	620	1,300	1,700	4,700
	Efficiency	56%	75%	82%	96%
TOTAL:	Capacity	1,790	4,500	6,100	18,600
	Efficiency	78%	87%	89%	97%

*Note that videoconferencing will probably still be scheduled, but only with the other parties, not with the carrier.

4.5 Transponder Capacity for Videoconferencing

We developed the transponder capacity for videoconferencing in the same way as that for data, assuming all digital transmission. The division of non-CPS transponder utilization was kept the same as for data as well. Table 4-8 shows the results of this development.

Table 4-8

Videoconferencing Rates Per Transponder (36 MHz)

	1980	1990	2000
Portion at CPS rate of 24.7 Mbps			
Western Union	0%	18%	23%
ITT	5%	11%	10%
Portion at 49 Mbps			
Western Union	10%	8%	8%
ITT	9%	9%	9%
Portion at varying rate			
Rate	49 Mbps	60 Mbps	90 Mbps
Western Union	90%	74%	69%
ITT	86%	80%	81%
Composite Rate			
Western Union	48 Mbps	47 Mbps	53.7 Mbps
ITT	46.5 Mbps	51 Mbps	67.2 Mbps

4.6 Transponder Requirements Forecast for Videoconferencing

By combining the transponder capacity (Table 4-8), and multiplying the rate per half-circuit (Table 4-1, plus related figures for Western Union forecast) by the number of half-circuits of Table 4-9, we get the transponders requirements shown in Table 4-10. Note that no sparing is included at this point. That the two forecasts should come out so nearly equal is attributable to the differing half-circuit capacity requirements.

Table 4-9
Net Videoconferencing Satellite Traffic
(Half-Circuits)

Year	Low (ITT)	High (Western Union)
1980	0	0
1981	0	0
1982	23	51
1983	56	137
1984	100	274
1985	169	457
1986	269	727
1987	424	1,156
1988	662	1,781
1989	1,122	2,807
1990	1,796	4,431
1991	2,014	5,664
1992	2,264	6,900
1993	2,541	8,203
1994	2,860	9,539
1995	3,216	10,917
1996	3,634	12,230
1997	4,115	13,824
1998	4,651	15,379
1999	5,301	16,981
2000	6,021	18,634

Table 4-10
Forecast of Net Transponder
Requirements for Videoconferencing

Year	Low (ITT)	High (Western Union)
1980	0	0
1981	0	0
1982	3	22
1983	6	41
1984	11	58
1985	17	66
1986	26	73
1987	38	80
1988	56	85
1989	90	93
1990	138	101
1991	147	126
1992	156	149
1993	166	174
1994	177	197
1995	189	219
1996	201	240
1997	215	262
1998	230	283
1999	249	303
2000	269	322

SECTION 5
BROADCAST VIDEO DEMAND FORECAST

5.1 Satellite-Addressable Broadcast Video Demand Forecasts

Broadcast video is at present a large user of satellite facilities. The standard transmission technique places a single video signal plus associated audio material in one 36 MHz transponder. Several compression devices are available which in effect multiplex two or three video signals into one transponder. As implemented for entertainment broadcasting, these are analog methods and all involve either a loss of resolution or a reduction in the total FM advantage for the multi-signal transmission. Digital compression hardware is also in use, which allows the reduction of broadcast-quality video to about 22 Mbps. Further improvements in digital compression are expected.

Because of a difference between the WU and ITT assumptions for compression factors, and because we may treat the reduction of video bandwidth requirements in a slightly different manner, we are showing the forecasts in terms of video program channels, with no compression included. The WU and ITT figures are shown in Table 5-1. The projections are plotted in Figure 5-1, and annual values are in Table 5-2.

We have included in the forecast for broadcast video the essentially uncompressed portion of the Western Union videoconferencing traffic. This component of videoconferencing is significantly different from the highly-compressed portion, and is in fact more akin to the broadcast video. Much of it is one-way, similar to current use of satellites for teleseminars. Requirements are generally more stringent than those for the highly-compressed videoconferencing. Since a large audience is usually involved, large-screen TVs are used. Motion handling and the absence of quantization effects are generally more important than transmission cost in this type of conference.

Table 5-1

WU & ITT Forecasts of

Satellite-Addressable Broadcast Video

(channels of video)

	1980	1990	2000
Western Union:			
Entertainment Video	58.2	116.9	221.2
Wideband Videoconferencing	5.2	261.8	221.4
WU Total	63.4	428.7	442.6
ITT Total	54	300	726

Table 5-2

Satellite-Addressable Broadcast Video

(channels of video and audio)

Year	Low	High
1980	63	54
1981	115	75
1982	165	100
1983	155	127
1984	220	120
1985	265	140
1986	308	165
1987	343	190
1988	395	243
1989	412	270
1990	429	300
1991	433	330
1992	439	363
1993	440	400
1994	440	437
1995	441	480
1996	442	525
1997	442	573
1998	442	620
1999	442	670
2000	442	726

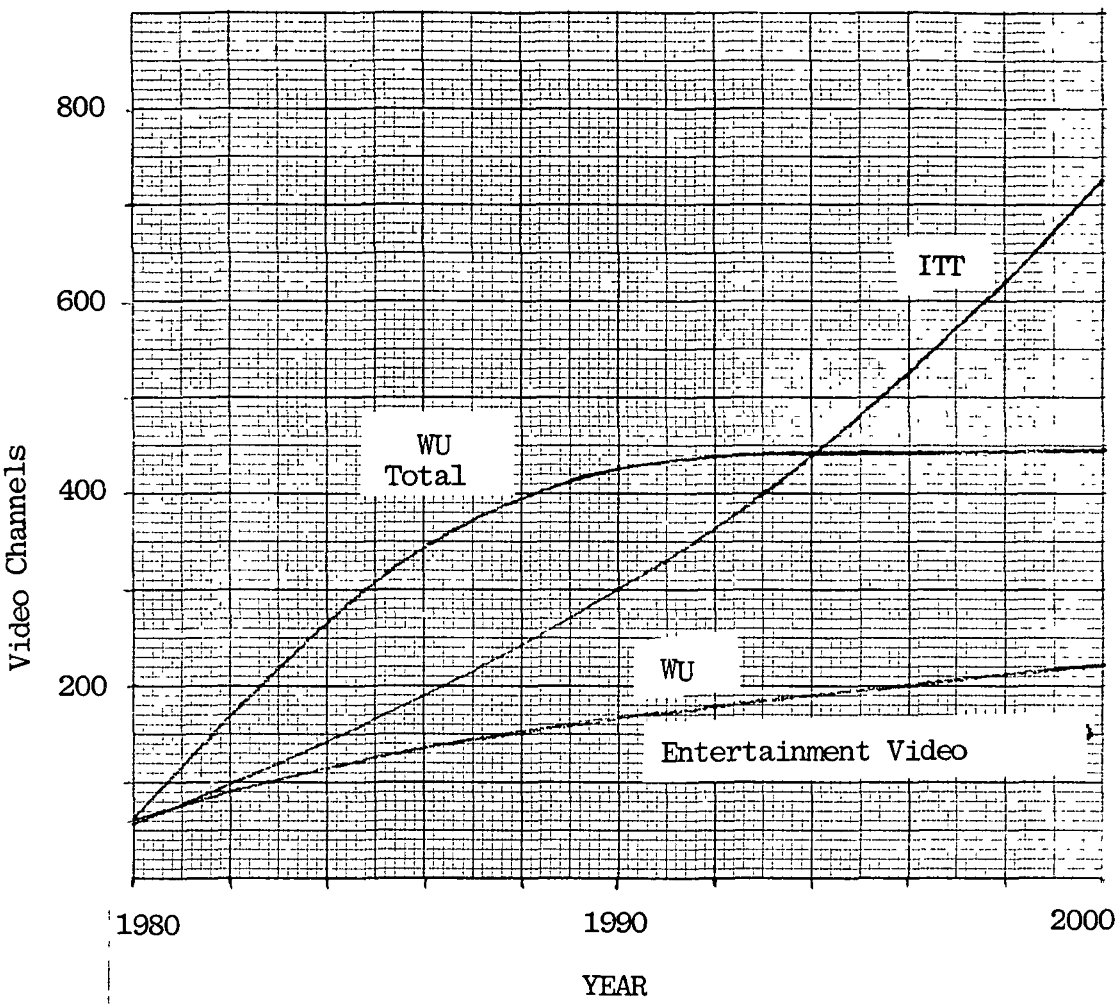


Figure 5-1

SATELLITE-ADDRESSABLE BROADCAST VIDEO
(includes point-to-multipoint video teleconferencing)

Capture of Broadcast Video

Inasmuch as satellites are ideally suited to broadcast applications, and the major networks have all commenced transferring their program distribution to satellites, we have assumed that 100 percent of the broadcasts are transmitted by satellite.

Time-Zone Effects

The effect of service to different time zones is to increase the number of video channels required, because the same programming will be repeated at later times to accommodate the later audience. This is especially true for the networks and larger cable programmers, since they are more interested in catering to their large audiences and less interested in distribution costs. Smaller programmers, including religious and public-interest groups, are operating on smaller budgets and tend to transmit on a take-it-or-leave-it basis.

We have assumed that the overall requirements, including provisions for additional channels to serve the time zones, were incorporated in the forecasts made by WU and ITT. Therefore, we have made no separate calculation of these effects on broadcast video.

Transponder Capacity for Broadcast Video

Broadcast video is now transmitted primarily using a single 36 MHz transponder per video channel, although several techniques are available for multiplexing two video signals per carrier. The 36 MHz bandwidth is excessive, and high-quality performance can be obtained using 24 MHz or 27 MHz. Some examples derived from studies for DBS are shown in Table 5-3 and Figure 5-2. Compression techniques which alternate lines from two pictures, restoring the missing lines by interpolation at the receiving end, can be used with reduced bandwidth at no penalty. However, systems which frequency-multiplex the two video signals and use the resulting baseband to modulate a single carrier would suffer a reduction in FM advantage as a result of the reduced bandwidth and could not be used without penalty.

Table 5-3

Examples of Picture Quality Rating

Grade		Radio-Frequency Signal-to-Noise Ratio for the Percentage of Viewers Indicated (dB) (1)	
		50%	75%
1.5	half-way between excellent and fine	39.5	42.5
2	fine	35.2	38.2
3	passable	30.0	33.0
4	marginal	25.6	28.6
5	inferior	20.4	23.4

(1) Radio-frequency r.m.s. signal during sync. peaks, no weighting, over 6 MHz gand, amplitude-modulation vestigial-sideband.

Digital video compression systems are also available now. More elaborate digital compression may be developed if and when high-definition TV is offered commercially. HDTV would have some effect on the demand for video transponders, however, and we haven't considered this in depth in this study, so it seems somewhat unfair to assume that advanced compression spinoffs from HDTV would be available.

Our feeling is that compression and multiplexing will be of interest primarily for teleconferencing and for CATV operators whose programming doesn't generate substantial revenue. For example, religious broadcasters, with some notable exceptions, are hardly getting rich from their video ministries, and would be receptive to a reduction in space segment costs. Other small programmers and narrowcasters would also be candidates. However, for the networks and the larger CATV programmers, such as HBO, whose fare consists of first-run movies, sporting events and high-quality, broad-based specials, find that transmission costs are a

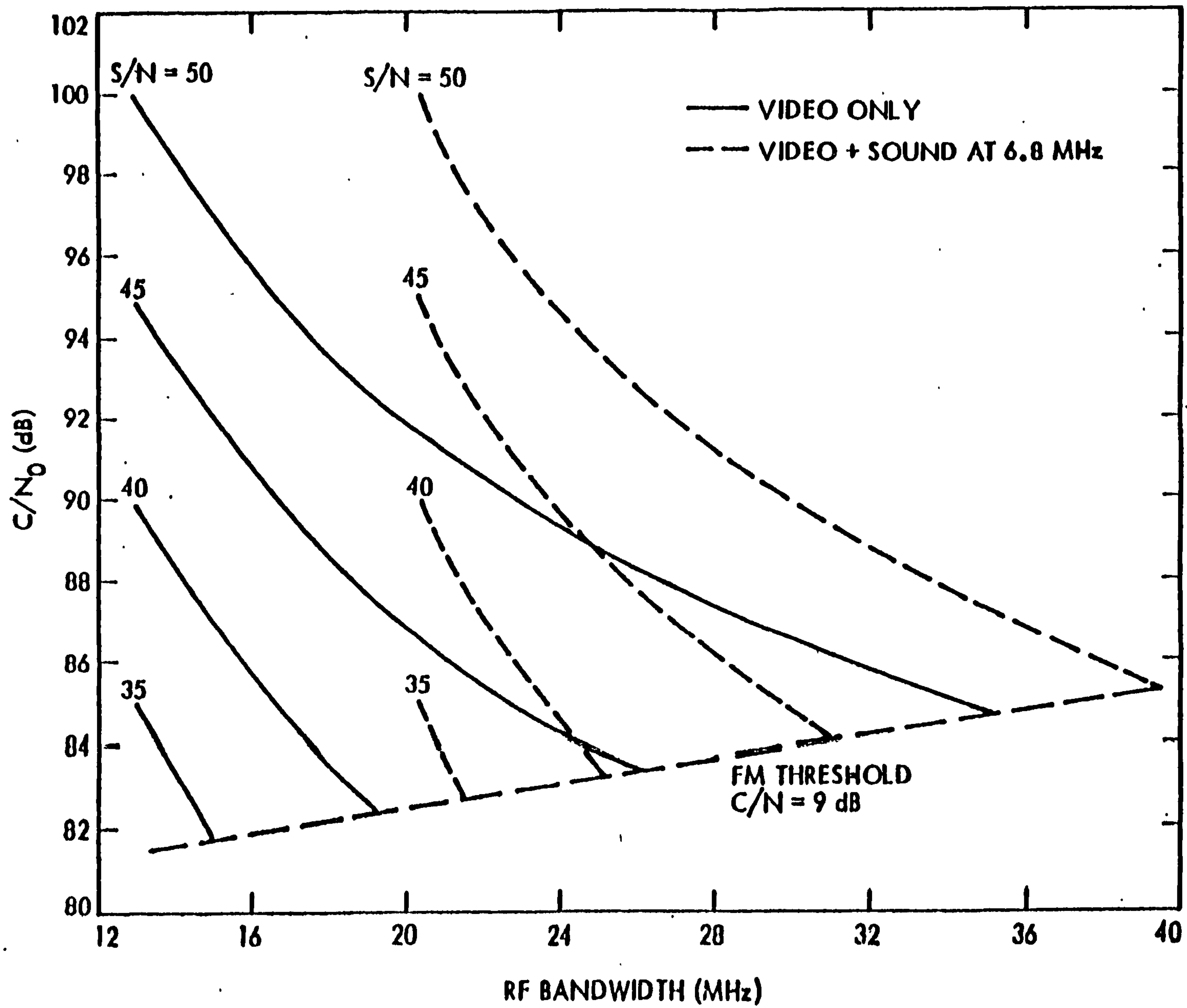


Figure 5-2

REQUIRED C/N_o VERSUS VIDEO S/N AND RF BANDWIDTH (SYSTEM M) small fraction of their operating budgets. Their first concern (and this is especially so for the networks) is reliable, very-high quality transmission with flexibility. To the extent that any reduction in picture quality is inherent in video compression, these programmers will be very reluctant to use it. However, we think that a bandwidth reduction to 27 MHz would be acceptable to these programmers, and this is an effective compression of 1.33. This would apply to about 20 percent of video traffic. Based on the estimates of the contractors, we expect the remaining 80 percent to have a compression factor of 3.0 by the year 2000. Figure 5-3 shows the estimated number of video signals per 36 MHz transponder.

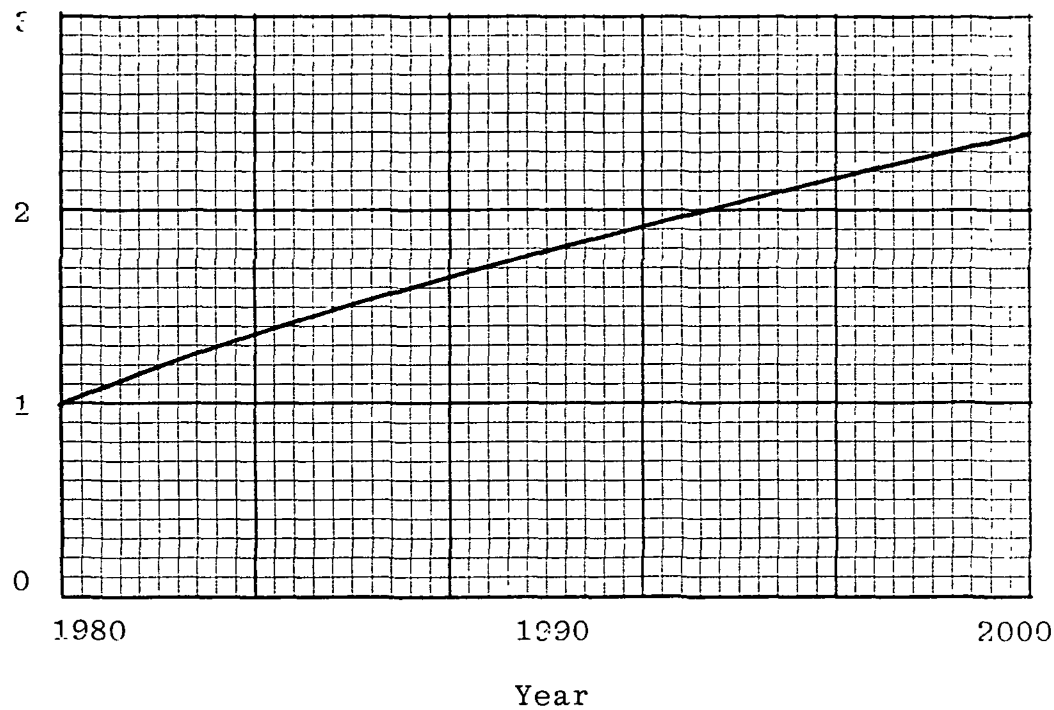


Figure 5-3

VIDEO SIGNALS PER 36 MHz TRANSPONDER

5.2 Broadcast Video Transponder Requirements

Using Table 5-2 and Figure 5-3, we have produced a forecast for transponder requirements. This is shown in Table 5-4. Note that these figures are net requirements and don't include any spare transponders.

Table 5-4
Broadcast Video Forecast
(transponders)

Year	Low	High
1980	63	54
1981	105	68
1982	138	83
1983	173	94
1984	195	103
1985	212	114
1986	229	127
1987	231	134
1988	239	147
1989	241	158
1990	241	169
1991	234	178
1992	231	191
1993	223	203
1994	215	213
1995	210	229
1996	203	241
1997	199	258
1998	192	270
1999	188	285
2000	184	303

SECTION 6
SPARING AND REDUNDANCY CONSIDERATIONS

Sparing requirements may be different for different traffic types, and may also be modified by the existence of low-availability traffic. The philosophy of sparing versus redundancy is also applicable. As we define it, sparing is the provision of one or more completely independent transmission facilities which can be used simultaneously with the primary facilities they back up. Redundancy is the provision of non-independent facilities, which may comprise less than a full transmission chain. Consider, for example, two identical satellites. If they are colocated, the one not in use is redundant, since its transponders cannot be used independently without shutting down corresponding transponders on the other spacecraft. If, however, they occupy separate orbital slots, one may be used to spare the other, since its transponders can be used independently until needed to replace a failure on the primary. Note that this is consistent with the intention in this task, since redundant transponders (or satellites) do not increase the gross spectrum/orbit requirement, while sparing does. The user of a spared transponder has, for practical purposes, zero risk of a long-term disruption. The user of a non-spared transponder has a risk equal to the probability of his transponder failing (including whatever redundancy is supplied on-board the satellite). However, the user of a preemptible transponder has twice the risk, since a failure of his own or failure on the primary spacecraft can put him out of his transponder. These factors are generally compensated for by price adjustments. However, the willingness of a certain fraction of the users to accept the increased risk will affect the gross spectrum/orbit needs. The increased reliability of flight hardware and the provision of redundancy within the satellite have both reduced the need for spares, and increased the willingness of customers to accept the risk.

Redundancy (as defined above) does not increase the need for spectrum/orbit, but it does affect the satellite design. Therefore, we will not consider redundancy explicitly in this section. The discussion is deferred until specific spacecraft are examined.

6.1 Sparing Philosophies

The pioneering communications satellite network, INTELSAT, has always had a fairly conservative sparing approach. This is in keeping with the important role of INTELSAT in trans-oceanic communications. Complete spare satellites are always kept in orbit, although they may be leased for preemptible traffic. Since subsequent INTELSAT spacecraft generally incorporate many features of their predecessors, the concepts involved in traffic management and outage handling have not changed much over the years. Figure 6-1 shows recent deployment plans, including spares, and Table 6-1 illustrates the excellent continuity of service that has resulted.

Table 6-1

System Status Report for October 1982

	Average Path (System) (1)	Average E.S. (2)	Space Segment (3)
1977	99.904	99.955	99.999
1978	99.877	99.942	99.999
1979	99.883	99.945	99.998
1980	99.893	99.952	99.996
1981	99.927	99.968	99.997
1982	99.914	99.960	99.999
1982 (Sept.)	99.943	99.975	99.999

(1) Average continuity of service for circuits computed on "earth station-to-satellite-to-earth station" basis.

(2) Average continuity of service achieved for circuits through an earth station within the INTELSAT system.

(3) Continuity of service of circuits through satellites within the INTELSAT system including satellite outages and circuit downtime which may have resulted from reconfiguration and other causes.

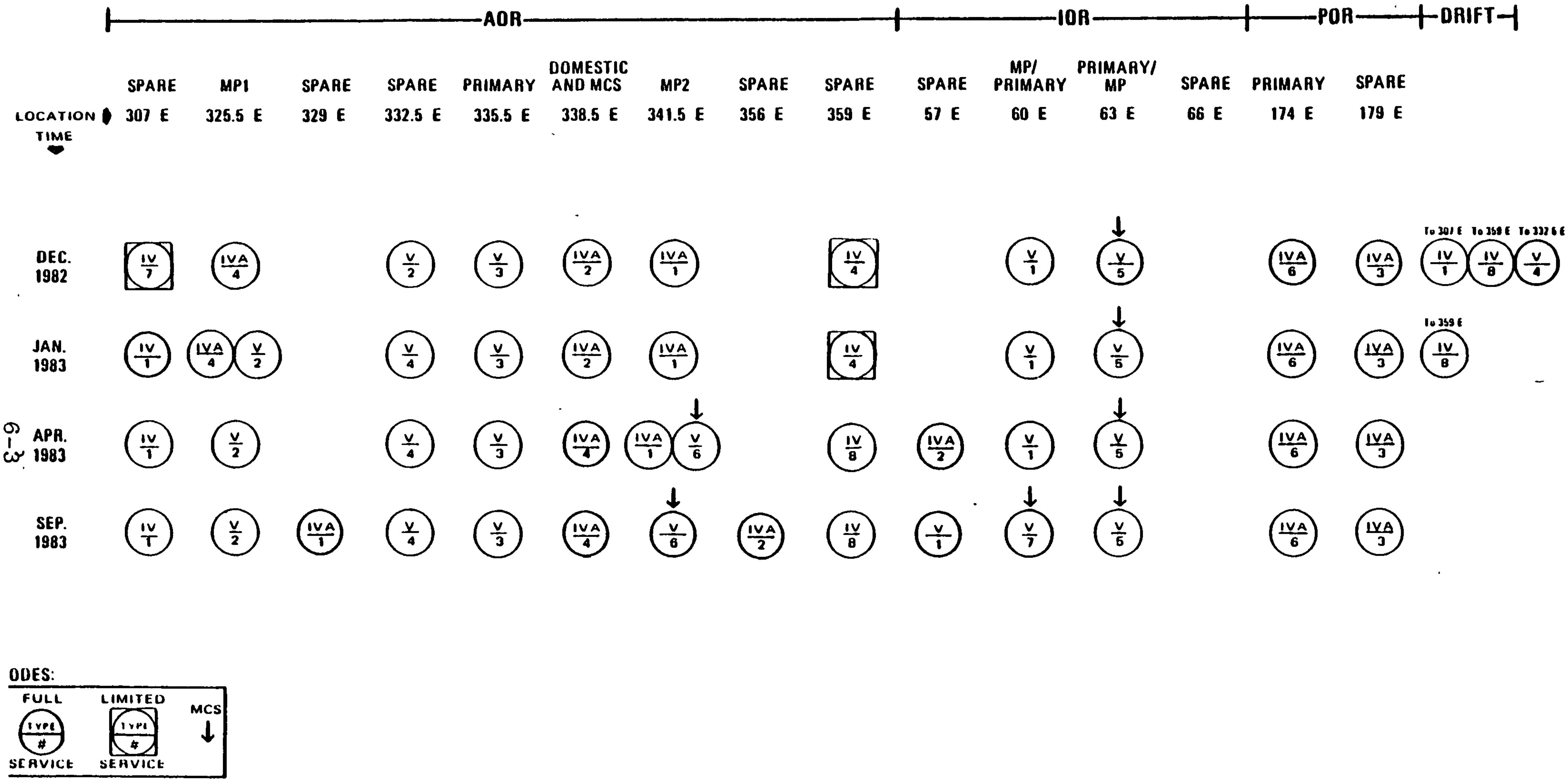


Figure 6-1

TENTATIVE SATELLITE DEPLOYMENT PLAN THROUGH MID-1983

Current philisphies among the domestic operators lean more toward making the customer responsible for protection, while providing a potential deep backup in the event of a total failure. This latter is done by means of a ground spare. This is often a euphemism for a satellite to be launched later, but does provide fairly rapid response in the event that an entire spacecraft is lost.

Table 6-2 shows the announced plans of some of the domsat operators. There is a preponderance of ground spares. Note that, although the sparing ratios of some operators are shown, there is no way to determine how many protected transponders will be sold, or how many preemptible transponders can be sold. Therefore, the overall ratio of protected to preemptible pure spare transponders can only be estimated. RCA's comments below seem to indicate that fewer TV customers are expected to be happy with preemptible services.

"RCA Americom's largest customer group consists of program suppliers who are using the SATCOM system for distribution to CATV systems. This is a service which can be provided economically only by satellites. A rapidly growing network of receive-only earth stations owned and operating by CATV systems functions in conjunction with the RCA Americom satellite system to bring television programming to millions of people each day. There are several thousand CATV antennas receiving numerous channels of daily programming from pay TV, independent station, news, sports and religious broadcasters. This compares with approximately 375 stations at mid-1978."

"In the early years of CATV program distribution, program suppliers were struggling to establish profitable businesses. Under these circumstances, low price was often more important than restoration capability, and many customers were satisfied with or preferred unprotected or even preemptible service. As their businesses have grown, however, service protection has become increasingly important. It is expected that all cable program distributors will demand protected service with the guarantee of restoration in the event of satellite or transponder failure."

"Since the distribution of CATV programs is a point-to-multipoint service, all traffic must be restored on a single satellite in the event of satellite failure. This constraint on service protection is an important and demanding requirement for this service."

"In general, satellite service to the TV broadcast industry can be classified in two fashions—full-time versus occasional part-time service, and point-to-point versus point-to-multipoint service."

"The protection requirements for full-time TV broadcast service are usually more severe and as demanding as for commercial telephone service. Satisfactory occasional service on the other hand can be provided on unprotected or preemptible transponders. The occasional service is offered in short segments and the probability that preemption will be necessary during these brief periods is very low."

RCA's tariff provides for protected, unprotected (but <u>not</u> preemptible) and preemptible levels of service. The charges for these are such that the sum of the price of a protected transponder and the price of a preemptible transponder is exactly twice the price of an unprotected transponder. This means that RCA could lease as many preemptible transponders as protected transponders, thus providing 2 for 1 protection, with no penalty relative to unprotected service.

There is no inherent need to have spare satellites; redundant (that is, colocated with an operational satellite and turned off) satellites could be used. However, this is an uneconomical solution for two reasons. First, the identity of the "failed" satellite cannot be determined beforehand. A redundant satellite might be in the wrong place, and valuable time would be lost while it was repositioned. Second, the transponders on the redundant satellite, by definition could not be used for service until a failure occurred. Since there will continue to be a market for preemptible services, this is revenue lost to the system operator. In addition, the technical performance of the spacecraft probably could not be maintained during a prolonged period with all transponders shut down. Therefore, there will continue to be a need for sparing.

Table 6-2

Some Sparing Plans

Operator	Planned Number of Satellites In Orbit	Spares
ABC	2	GS
American Satellite	2	GS
AT&T TELSTAR	3 or 4	1 in-orbit (96 for 72)*
FASSC	2	GS
GTE/GSTAR	2	GS
RCA C-band	5	24 for 18*
Ku-band	3	16 for 12* or 18 for 14*
SBS	5	10 spare transponders
Western Union	6	5 for 4 and 2 for 1
Spacenet	3	6 for 5*
USAT	2	20 for 16*

*Note - preemptible service is offered on backup transponders.

6.2 Estimates of Sparing

Figures are available for the survival probability of a given number of transponders on several current or planned spacecraft. These are shown in Table 6-3. Using these figures, standard statistical formulas and estimates of the required continuity of service and availability, we can compute the needed sparing levels. These calculations were made as follows:

Table 6-3

Satellite Reliability Estimates

Satellite	Time, Years	Redundancy	Transponder Survival	Probability
SATCOM I	7	R	24/24	0.05
	7		20/24	0.637
	7		16/24	0.739
	10		20/24	0.392
SATCOM IR	8	T, R	24/24	0.765
	8		20/24	0.814
	10		24/24	0.691
	10		20/24	0.760
RCA Ku	7	T, R	16/16	0.6472
	7		12/16	0.8577
	10		16/16	0.3909
	10		12/16	0.7571
Hughes Galaxy	7	T, R	20/24	0.78
	8.5		20/24	0.67
GSTAR	7	T, R	13/16	0.68
	10		13/16	0.61

The probability of a transponder failing at any time was approximated using the manufacturers' data on transponder survival. Various kinds of reconfiguration were also considered. When redundant units are still available on the satellite, reconfiguration was assumed to take two hours. If a spare transponder is available on the same spacecraft, reconfiguration is assumed to take two hours. If a spare transponder on another spacecraft must be used to restore service, the process is assumed to take two hours for high-volume trunking stations with autotrack antennas, such as C-band antennas of ten meters diameter or larger; two hours for high priority services such as network TV distribution, whether tracking or fixed antennas are used; and 48 hours for all other systems, which are assumed to employ fixed-pointing (non-tracking) antennas.

A reasonable estimate is that there is about a one to two percent chance that a given satellite transponder will fail in any given year. The failure might arise from equipment specific to that transponder or from equipment common to several transponders. If redundant items are provided, then the failure can be alleviated within a short time. However, as the satellite ages, it becomes more likely that any redundant equipment will already have been used to replace failed items, and thus that an outage will have to be restored in some other manner.

Tables 6-3 and 6-4 can be used to make rough estimates of the probability that some failures (and subsequent restoration if possible) will occur over a seven-year satellite lifetime. Table 6-5 shows the overall reliability associated with various protection arrangements. These figures were used as guidelines when sorting traffic among the various protection arrangements.

Table 6-4
Seven-Year Reliability of
Several Redundancy Arrangements

Redundancy	Number Operational	Reliability t = 7 yr.
None	24	0.05
5 for 4	4	0.89
5 for 3	3	0.986
7 for 6	6	0.805
7 for 5	5	0.960
None	1	0.882

Table 6-5

Overall Reliability for Various Protection Scheme

(percent)

Primary Redundancy	Sparing Ratio	Net 7-Year Reliability
None	72/48	99.89
5/4	2/1	99.99
5/4	72/48	99.99
7/6	24/20	97.2
7/6	72/48	99.98
5/4	96/72	99.2

In order to divide up the traffic categories, we used the forecasts for CPS addressable traffic and common-carrier traffic. This enabled us to identify traffic that could use either no sparing or a less-convenient form of sparing. Table 6-6 shows the division of the traffic into these categories.

We assumed that traffic requiring no protection could be carried in spare or preemptible transponders. This reduces the gross transponder requirement slightly. Table 6-7 shows the factors by which each component of net traffic must be multiplied to obtain the gross requirement, accounting only for sparing.

Table 6-6

Year 2000 Traffic Segregation into Sparing Categories

(percent of traffic)

Sparing	Traffic Type: Voice	Data	Broadcast Video	Video Conferencing
Preemptible	7	6	30	20
Different Satellites 96 for 72	93	94	50	80
2 for 1	—	—	20	—

Table 6-7

Transponder Multipliers for Sparing

Voice	Data	Broadcast Video	Video Conferencing
1.24	1.25	1.07	1.07

6.3 Gross Transponder Requirements

To derive the gross requirements for in-orbit transponders, we have applied the sparing ratios of Table 6-7 to the net forecasts shown earlier. Both net and gross are shown for clarity, in Tables 6-8 through 6-11.

Table 6-8

OPERATIONAL TRANSPONDER REQUIREMENTS FORECAST
LOW TRAFFIC FORECAST

YEAR	VOICE	DATA	VIDEOCONF	TV	TOTAL
1980	27.	27.	0.	63.	117.
1981	24.	25.	0.	105.	[illegible]
1982	20.	24.	5.	150.	[illegible]
1983	19.	[illegible]	[illegible]	[illegible]	[illegible]
1984	20.	35.	[illegible]	[illegible]	[illegible]
1985	[illegible]	54.	[illegible]	[illegible]	[illegible]
1986	27.	80.	26.	[illegible]	[illegible]
1987	32.	[illegible]	38.	[illegible]	[illegible]
1988	39.	137.	57.	[illegible]	[illegible]
1989	[illegible]	[illegible]	90.	[illegible]	595.
1990	[illegible]	770.	[illegible]	[illegible]	[illegible]
1991	77.	[illegible]	147.	234.	774.
1992	84.	[illegible]	156.	[illegible]	[illegible]
1993	100.	411.	[illegible]	223.	[illegible]
1994	118.	[illegible]	177.	[illegible]	[illegible]
1995	134.	404.	189.	210.	[illegible]
1996	153.	[illegible]	[illegible]	203.	[illegible]
1997	173.	[illegible]	215.	[illegible]	[illegible]
1998	176.	[illegible]	230.	192.	[illegible]
1999	[illegible]	561.	[illegible]	185.	[illegible]
2000	247.	572.	[illegible]	[illegible]	[illegible]

Table 6-9

GROSS IN-ORBIT TRANSPONDER REQUIREMENTS FORECAST
LOW TRAFFIC FORECAST

YEAR	VOICE	DATA	VIDEOCONF	TV	TOTAL
1980	33.	34.	0.	67.	[illegible]
1981	30.	31.	0.	112.	173.
1982	25.	29.	3.	[illegible]	203.
1983	23.	32.	7.	165.	[illegible]
1984	25.	43.	11.	[illegible]	[illegible]
1985	28.	66.	18.	227.	340.
1986	34.	100.	27.	245.	[illegible]
1987	40.	145.	41.	247.	[illegible]
1988	[illegible]	[illegible]	60.	[illegible]	562.
1989	60.	[illegible]	97.	258.	[illegible]
1990	73.	337.	147.	[illegible]	[illegible]
1991	89.	402.	157.	250.	[illegible]
1992	104.	[illegible]	167.	[illegible]	[illegible]
1993	124.	514.	177.	[illegible]	1055.
1994	[illegible]	561.	187.	230.	[illegible]
1995	167.	[illegible]	[illegible]	[illegible]	[illegible]
1996	[illegible]	650.	215.	[illegible]	[illegible]
1997	215.	684.	230.	213.	1342.
1998	243.	[illegible]	246.	206.	[illegible]
1999	276.	701.	267.	[illegible]	1444.
2000	306.	[illegible]	287.	[illegible]	[illegible]

Table 6-10

OPERATIONAL TRANSPONDER REQUIREMENTS FORECAST
HIGH TRAFFIC FORECAST

YEAR	VOICE	DATA	VIDEOCONF	TV	TOTAL
1980	30.	8.	0.	[illegible]	[illegible]
1981	27.	9.	0.	[illegible]	[illegible]
1982	23.	10.	22.	83.	[illegible]
1983	23.	12.	41.	94.	170.
1984	25.	18.	56.	[illegible]	[illegible]
1985	31.	30.	[illegible]	[illegible]	[illegible]
1986	37.	[illegible]	[illegible]	[illegible]	[illegible]
1987	47.	76.	80.	[illegible]	311.
1988	64.	[illegible]	[illegible]	147.	412.
1989	84.	[illegible]	[illegible]	158.	[illegible]
1990	110.	[illegible]	101.	[illegible]	[illegible]
1991	144.	304.	[illegible]	178.	[illegible]
1992	181.	[illegible]	[illegible]	[illegible]	[illegible]
1993	[illegible]	[illegible]	174.	202.	[illegible]
1994	260.	[illegible]	[illegible]	[illegible]	[illegible]
1995	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1996	410.	[illegible]	[illegible]	[illegible]	[illegible]
1997	479.	[illegible]	[illegible]	258.	[illegible]
1998	573.	777.	[illegible]	[illegible]	[illegible]
1999	657.	855.	[illegible]	[illegible]	[illegible]
2000	753.	[illegible]	322.	[illegible]	[illegible]

Table 6-11

GROSS IN-ORBIT TRANSPONDER REQUIREMENTS FORECAST
HIGH TRAFFIC FORECAST

YEAR	VOICE	DATA	VIDEOCONF	TV	TOTAL
1980	38.	11.	0.	36.	[illegible]
1981	33.	11.	0.	[illegible]	117.
1982	27.	12.	14.	[illegible]	134.
1983	28.	15.	44.	101.	188.
1984	31.	22.	62.	110.	225.
1985	38.	37.	71.	120.	266.
1986	46.	62.	78.	[illegible]	[illegible]
1987	60.	97.	86.	144.	387.
1988	80.	147.	[illegible]	[illegible]	[illegible]
1989	104.	210.	[illegible]	[illegible]	[illegible]
1990	136.	286.	108.	[illegible]	[illegible]
1991	179.	379.	125.	171.	[illegible]
1992	214.	470.	160.	204.	[illegible]
1993	282.	571.	156.	217.	[illegible]
1994	347.	652.	211.	228.	[illegible]
1995	426.	731.	235.	245.	1642.
1996	508.	855.	237.	[illegible]	[illegible]
1997	594.	[illegible]	280.	[illegible]	[illegible]
1998	711.	[illegible]	292.	288.	[illegible]
1999	813.	1047.	321.	305.	2488.
2000	934.	[illegible]	345.	324.	[illegible]

SECTION 7
EARTH STATION CAPACITY REQUIREMENTS FORECAST

7.1 Geographical Distribution of Requirements

Table 7-1 summarizes the communications requirements for voice, video and data for the years 1980, 1990 and 2000. Incorporating these results together with the geographical distribution of population, which we assumed was an adequate approximation for traffic distribution determination, results in a forecast of communications traffic throughput and its distribution across the contigous United States.

Tables 7-2 through 7-4 present the low forecast regional requirements for voice, video and data for the years 1980, 1990 and 2000. Tables 7-5 through 7-7 present the high forecast requirements. A detailed breakdown of the states by region is given in Figure 7-1.

Table 7-1
Satellite Communications Requirements

		Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
Low	1980	40,300	160	0
	1990	220,000	4,000	1,796
	2000	1,290,000	14,000	6,021
High	1980	40,300	640	0
	1990	302,000	10,000	4,431
	2000	2,580,000	51,000	18,634

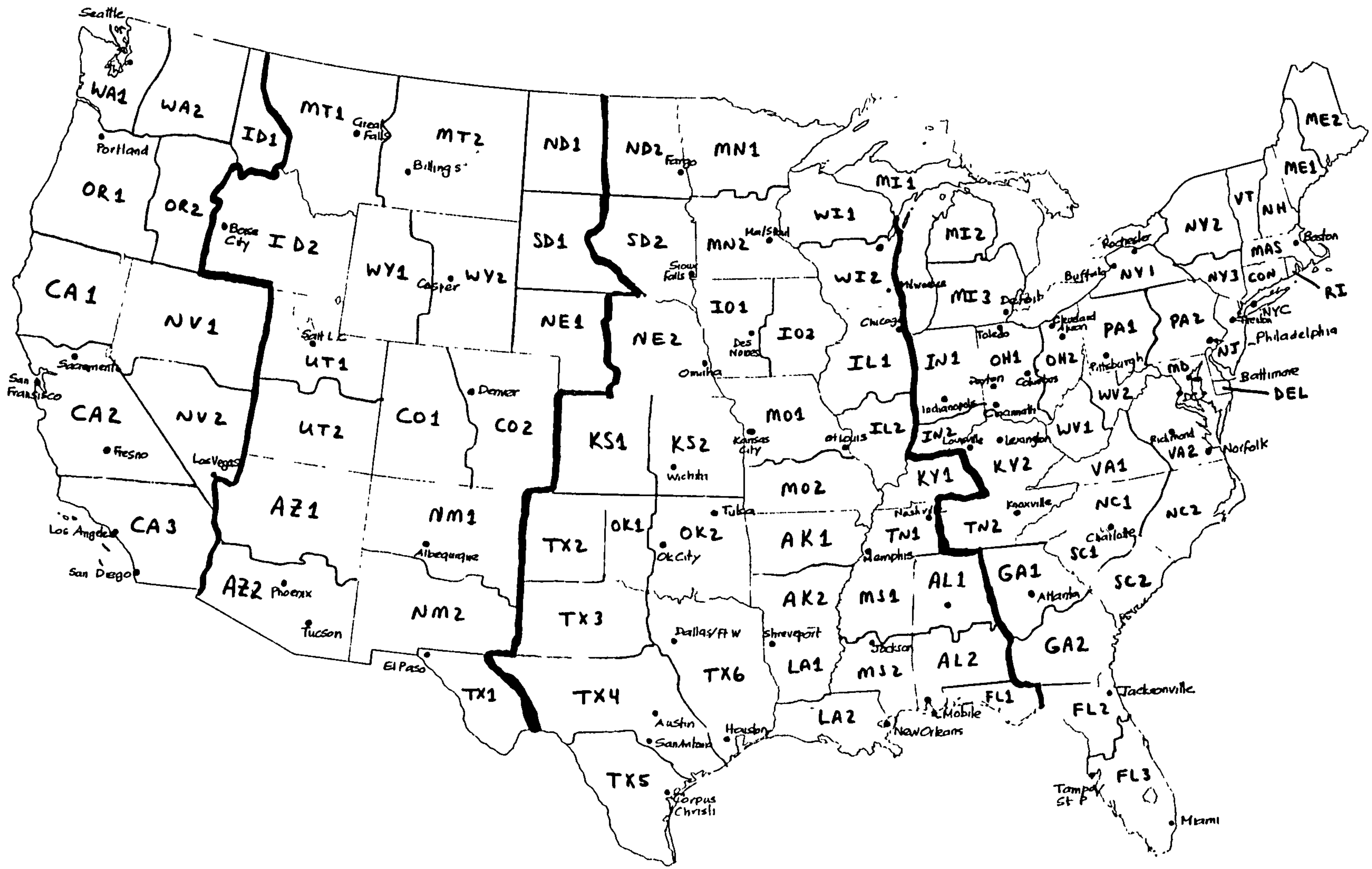


Figure 7-1

STATE SUBDIVISIONS

Table 7-2

Geographical Distribution of Traffic (1980)

Low Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
WA1	564.	16.13	0.00
WA2	185.	[illegible]	0.00
ID1	36.	1.04	0.00
OR1	451.	12.74	0.00
OR2	33.	.91	0.00
CA1	139.	4.28	0.00
CA2	1870.	54.20	0.00
CA3	2201.	63.09	0.00
NV1	56.	1.61	0.00
NV2	87.	2.54	0.00
MT1	77.	2.[illegible]	0.00
MT2	48.	1.39	0.00
[illegible]	133.	3.81	0.00
WY1	28.	.81	0.00
WY2	36.	1.02	0.00
UT1	[illegible]42.	[illegible]	0.00
UT2	24.	.67	0.00
CO1	[illegible]	[illegible].08	0.00
CO2	455.	13.[illegible]	0.00
AZ1	[illegible]	[illegible]	0.00
AZ2	[illegible]33.	12.40	0.00
NM1	[illegible]	[illegible]	0.00
NM2	64.	1.[illegible]	0.00
ND1	[illegible]	1.50	0.00
SD1	36.	1.04	0.00
NE1	32.	.92	0.00
TX1	97.	2.77	0.00
ND2	64.	1.[illegible]	0.00
SD2	87.	2.54	0.00
NE2	250.	7.17	0.00
KS1	56.	1.62	0.00
KS2	371.	10.63	0.00
TX2	67.	1.96	0.00
TX3	172.	4.97	0.00
TX4	536.	15.71	0.00
TX5	230.	6.57	0.00
TX6	1459.	41.04	0.00
OK1	73.	2.08	0.00
OK2	476.	13.64	0.00
MN1	133.	3.81	0.00
MN2	607.	17.43	0.00
IO1	25[illegible].	7.40	0.00
IO2	274.	7.86	0.00
MO1	673.	19.30	0.00
MO2	222.	6.36	0.00
AR1	200.	5.6[illegible]	0.00
AR2	210.	6.01	0.00
LA1	214.	6.13	0.00

Table 7-2 (continued)

Geographical Distribution of Traffic (2000)

Low Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
IA2	548.	15.72	0.00
WI1	141.	4.05	0.00
WI2	713.	20.46	0.00
IL1	1797.	51.55	0.00
IL2	274.	7.86	0.00
KY1	177.	5.09	0.00
TN1	451.	12.94	0.00
MS1	210.	6.01	0.00
MS2	250.	7.17	0.00
AL1	443.	12.71	0.00
AL2	262.	7.51	0.00
FL1	149.	4.28	0.00
MI1	56.	1.62	0.00
MI2	99.	2.84	0.00
MI3	1439.	41.[illegible]	0.00
OH1	1050.	30.[illegible]	0.00
OH2	883.	25.31	0.00
IN1	838.	24.04	0.00
IN2	161.	4.62	0.00
KY2	488.	13.98	0.00
TN2	383.	10.98	0.00
GA1	645.	18.49	0.00
GA2	347.	9.94	0.00
FL2	266.	7.63	0.00
FL3	1353.	38.[illegible]	0.00
ME1	145.	4.16	0.00
ME2	56.	1.62	0.00
NH	165.	4.74	0.00
VT	93.	2.66	0.00
CT	564.	16.18	0.00
MA	1044.	29.93	0.00
RI	173.	4.97	0.00
NY1	536.	15.37	0.00
NY2	419.	12.02	0.00
NY3	2233.	64.03	0.00
PA1	814.	23.35	0.00
PA2	933.	26.61	0.00
WV1	222.	6.36	0.00
WV2	133.	3.81	0.00
MDDC	883.	25.31	0.00
NJ	1338.	38.37	0.10
VA1	254.	7.28	0.00
VA2	717.	20.57	0.00
DE	109.	3.12	0.00
NC1	729.	20.92	0.01
NC2	334.	9.59	0.00
SC1	242.	6.93	0.00
SC2	326.	9.36	0.00

Table 7-3

Geographical Distribution of Traffic (1990)

Low Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
WA1	[illegible]	[illegible]	[illegible]
WA2	[illegible]	[illegible]	[illegible]
ID1	[illegible]	11.41	[illegible]
OR1	2462.	142.00	[illegible]
OR2	154.	8.37	1.25
CA1	813.	[illegible]	[illegible]
CA2	[illegible]	374.62	[illegible]
CA3	[illegible]	[illegible]	[illegible]
NV1	308.	17.73	[illegible]
[illegible]	484.	[illegible]	[illegible]
MT1	528.	30.43	[illegible]
MT2	[illegible]	15.21	[illegible]
ID1	727.	41.01	[illegible]
WY1	[illegible]	8.87	[illegible]
WY2	308.	17.75	2.50
UT1	[illegible]	[illegible]	[illegible]
UT2	[illegible]	[illegible]	[illegible]
CO1	[illegible]	[illegible]	[illegible]
CO2	2434.	[illegible]	[illegible]
AZ1	306.	[illegible]	[illegible]
AZ2	2374.	[illegible]	[illegible]
NM1	[illegible]	[illegible]	[illegible]
NM2	374.	21.55	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
SD1	[illegible]	11.41	[illegible]
NE1	[illegible]	10.14	[illegible]
TX1	528.	30.43	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	3.
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	308.	17.75	[illegible]
[illegible]	[illegible]	116.64	[illegible]
TX2	[illegible]	21.55	3.04
TX3	[illegible]	[illegible]	[illegible]
TX4	3034.	[illegible]	[illegible]
TX5	[illegible]	[illegible]	[illegible]
TX6	[illegible]	[illegible]	[illegible]
OK1	[illegible]	22.82	[illegible]
OK2	[illegible]	[illegible]	[illegible]
MN1	725.	41.84	[illegible]
MN2	[illegible]	[illegible]	27.0
IO1	[illegible]	[illegible]	[illegible]
IO2	1475.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
MO2	[illegible]	[illegible]	[illegible]
AR1	[illegible]	[illegible]	[illegible]
AR2	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

Table 7-3 (continued)

Geographical Distribution of Traffic (1990)

Low Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	44.37	[illegible]
[illegible]	3871.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1493.	86.21	[illegible]
[illegible]	967.	55.70	7.67
[illegible]	2462.	142.00	[illegible]
[illegible]	1143.	[illegible]	[illegible]
[illegible]	1363.	78.61	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1427.	82.41	[illegible]
[illegible]	813.	46.91	6.62
[illegible]	306.	17.75	[illegible]
[illegible]	404.	[illegible]	[illegible]
[illegible]	8377.	484.31	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4814.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2088.	120.44	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1870.	107.93	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	7406.	427.26	[illegible]
[illegible]	791.	45.64	[illegible]
[illegible]	308.	17.75	[illegible]
[illegible]	901.	[illegible]	[illegible]
[illegible]	506.	[illegible]	[illegible]
CT	3077.	177.50	[illegible]
[illegible]	[illegible]	328.37	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2724.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	702.38	[illegible]
[illegible]	[illegible]	256.10	[illegible]
[illegible]	5100.	[illegible]	[illegible]
[illegible]	[illegible]	69.73	[illegible]
[illegible]	725.	41.84	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1385.	[illegible]	[illegible]
[illegible]	[illegible]	225.67	[illegible]
[illegible]	[illegible]	34.23	4.83
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1825.	[illegible]	14.65
[illegible]	[illegible]	76.07	10.73
[illegible]	1781.	[illegible]	[illegible]

Table 7-4
Geographical Distribution of Traffic (2000)

Low Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
WA1	10113.	257.67	54.27
WA2	5951.	151.03	27.73
IO1	1164.	29.55	5.42
OR1	14490.	367.73	67.44
OR2	906.	22.98	4.21
CA1	4787.	121.48	22.30
CA2	60673.	1520.68	282.38
CA3	72500.	1841.05	337.76
NV1	1811.	45.97	8.45
NV2	2846.	72.26	13.25
MT1	3105.	78.80	14.45
MT2	1593.	40.43	7.43
ID1	4267.	108.35	19.87
WY1	906.	22.98	4.21
WY2	1811.	45.97	8.45
UT1	7763.	197.00	36.13
UT2	776.	19.70	3.61
CO1	2329.	59.10	10.84
CO2	14670.	372.47	68.34
AZ1	1811.	45.97	8.43
AZ2	13573.	344.60	63.03
NM1	5304.	134.62	24.67
NM2	2199.	55.82	10.24
MD1	1680.	42.68	7.83
SD1	1164.	29.55	5.42
NE1	1035.	26.27	4.82
TX1	3105.	78.80	14.45
ND2	2070.	52.53	9.63
SD2	2846.	72.23	13.25
NE2	8021.	203.57	37.33
KS1	1811.	45.97	8.45
KS2	11903.	302.07	55.39
TX2	2199.	55.82	10.24
TX3	5563.	141.18	25.89
TX4	17534.	433.10	83.07
TX5	7374.	187.15	34.32
TX6	46834.	1188.56	217.96
OK1	2329.	59.10	10.84
OK2	15266.	387.45	71.05
MN1	4266.	108.35	19.87
MN2	17536.	445.70	[illegible]
IO1	8280.	210.13	38.51
IO2	8778.	223.27	40.94
MO1	21606.	548.32	100.55
MO2	7116.	180.58	33.12
AR1	6598.	167.45	30.71
AR2	6728.	170.75	31.31
LA1	6857.	[illegible]	31.44

Table 7-4 (continued)

Geographical Distribution of Traffic (2000)

Low Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
[illegible]A2	17575.	446.73	[illegible]
WI1	4518.	114.72	[illegible]
WI2	22900.	381.13	100.37
IL1	57700.	1464.36	[illegible]
IL2	8700.	223.27	40.74
[illegible]Y1	5693.	144.47	26.49
TN1	14470.	367.73	67.44
MS1	6728.	170.73	31.31
MS2	8021.	203.57	37.72
AL1	14231.	361.17	[illegible]
AL2	8410.	213.41	[illegible]
[illegible]	[illegible]	121.48	[illegible]
MI1	1811.	45.97	8.43
MI2	2046.	72.[illegible]	[illegible]
[illegible]	[illegible]	1254.23	230.0[illegible]
OH1	[illegible]	[illegible]	[illegible]
OH2	[illegible]	[illegible]	[illegible]
IN1	[illegible]	[illegible]	[illegible]
IN2	5175.	131.35	24.05
KY[illegible]	15655.	[illegible]	[illegible]
TN2	12291.	311.72	57.29
GA1	[illegible]	525.53	[illegible]
GA2	11126.	282.37	[illegible]
FL2	[illegible]	[illegible]	[illegible]
FL3	43600.	1106.48	202.71
ME1	4656.	118.22	21.68
ME2	1811.	45.97	8.45
NH	[illegible]	134.[illegible]	[illegible]
VT	2976.	75.52	13.[illegible]
CT	18013.	[illegible]	[illegible]
MA	33509.	850.38	155.74
RI	5563.	141.[illegible]	[illegible]
NY1	17207.	476.68	[illegible]
NY2	13455.	[illegible]	[illegible]
NY3	71675.	1818.76	333.56
PA1	[illegible]	[illegible]	[illegible]
PA2	30015.	761.73	[illegible]
WV1	7116.	[illegible]	33.12
WV2	4259.	108.33	[illegible]
MDDC	28334.	[illegible]	131.56
NJ	[illegible]	[illegible]	[illegible]
VA1	8151.	206.85	[illegible]
VA2	[illegible]	584.43	[illegible]
DE	3493.	88.65	[illegible]
NC1	[illegible]	[illegible]	108.96
NC2	[illegible]	[illegible]	[illegible]
SC1	[illegible]	[illegible]	[illegible]
SC2	[illegible]	[illegible]	[illegible]

Table 7-5
Geographical Distribution of Traffic (1980)
High Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
WA1	[illegible]	[illegible]	0.00
WA2	161.	[illegible]	0.00
ID1	35.	.19	0.00
OR1	440.	2.37	0.00
OR2	27.	.15	0.00
CA1	145.	.78	0.00
CA2	1641.	[illegible]	0.00
CA3	2102.	[illegible]	0.00
NV1	55.	.30	0.00
NV2	86.	.47	0.00
MT1	94.	.51	0.00
MT2	47.	.25	0.00
ID1	130.	.70	0.00
WY1	27.	.15	0.00
WY2	55.	.30	0.00
UT1	235.	1.27	0.00
UT2	24.	[illegible]	0.00
CO1	[illegible]	.38	[illegible]
CO2	444.	[illegible]	0.00
AZ1	55.	.30	0.00
AZ2	424.	2.29	0.00
NM1	161.	[illegible]	0.00
NM2	67.	.36	0.00
ND1	71.	.38	0.00
SD1	35.	.19	0.00
NE1	31.	.17	0.00
TX1	94.	.51	0.00
ND2	63.	.34	0.00
SD2	86.	.47	0.00
NE2	[illegible]	[illegible]	[illegible]
KS1	55.	.30	0.00
KS2	361.	1.95	0.00
TX2	67.	.36	0.00
TX3	169.	.91	0.00
TX4	542.	2.92	0.00
TX5	224.	[illegible]	0.00
TX6	1421.	7.66	0.00
OK1	71.	.38	0.00
OK2	463.	2.50	0.00
MN1	130.	.70	0.00
MN2	573.	[illegible]	0.00
IO1	251.	1.35	0.00
IO2	267.	1.44	0.00
MO1	655.	3.53	0.00
MO2	216.	1.16	0.00
AR1	200.	1.08	0.00
AR2	204.	1.10	0.00
LA1	208.	1.12	[illegible]

Table 7-5 (continued)

Geographical Distribution of Traffic (1980)

High Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
IA2	384.	1.66	[illegible]
WI1	137.	.74	[illegible]
WI2	675.	3.75	0.00
IL1	1731.	9.44	0.00
IL2	267.	1.44	0.00
IN1	173.	.93	0.00
TN1	440.	2.37	0.00
MS1	204.	1.10	0.00
MS2	245.	1.31	0.00
AL1	432.	2.33	0.00
AL2	255.	1.38	0.00
FL1	143.	.76	0.00
MT1	55.	.30	0.00
[illegible]	66.	.47	0.00
[illegible]	1477.	8.06	0.00
OH1	1052.	5.67	0.00
OH2	860.	4.63	0.00
[illegible]	816.	4.40	0.00
[illegible]	137.	.65	0.00
[illegible]	475.	[illegible]	[illegible]
MI2	373.	2.01	0.00
GA1	620.	[illegible]	0.00
GA2	336.	1.92	0.00
FL2	259.	1.70	0.00
FL3	1323.	7.13	0.00
ME1	141.	.76	0.00
ME2	55.	.30	0.00
NH	161.	[illegible]	[illegible]
[illegible]	70.	.37	0.00
[illegible]	547.	[illegible]	0.00
MA	1017.	5.40	0.00
RI	169.	.91	0.00
NY1	522.	2.81	0.00
NY2	400.	2.20	0.00
NY3	2174.	11.72	0.00
PA1	792.	4.27	0.00
PA2	911.	4.71	0.00
WV1	216.	1.16	0.00
WV2	130.	.70	0.00
MDDC	860.	4.63	0.00
[illegible]	1305.	7.01	0.00
VA1	247.	1.23	0.00
VA2	679.	3.77	0.00
DE	106.	.57	0.00
NC1	710.	3.83	0.00
NC2	330.	1.76	0.00
SC1	235.	1.27	0.00
SC2	316.	1.73	0.00

Table 7-6

Geographical Distribution of Traffic (1990)

High Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
[illegible]	4236.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	272.	[illegible]	[illegible]
[illegible]	3389.	65.42	[illegible]
[illegible]	212.	4.09	[illegible]
CA1	1120.	[illegible]	[illegible]
CA2	[illegible]	273.74	[illegible]
CA3	[illegible]	[illegible]	[illegible]
[illegible]	424.	8.18	[illegible]
[illegible]	[illegible]	12.85	[illegible]
[illegible]	726.	14.02	[illegible]
[illegible]	363.	7.01	[illegible]
[illegible]	[illegible]	19.23	[illegible]
[illegible]	[illegible]	[illegible]	3.10
[illegible]	424.	8.18	[illegible]
[illegible]	[illegible]	20.05	[illegible]
[illegible]	162.	[illegible]	[illegible]
[illegible]	545.	10.51	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	424.	8.18	[illegible]
[illegible]	[illegible]	63.05	[illegible]
[illegible]	1241.	[illegible]	[illegible]
[illegible]	314.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	272.	5.26	[illegible]
[illegible]	242.	4.67	[illegible]
[illegible]	726.	14.02	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	666.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	424.	8.18	[illegible]
[illegible]	2784.	53.74	[illegible]
[illegible]	514.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4173.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	211.44	[illegible]
[illegible]	545.	10.51	[illegible]
[illegible]	3570.	[illegible]	[illegible]
[illegible]	[illegible]	19.28	[illegible]
[illegible]	4369.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2057.	[illegible]	[illegible]
[illegible]	5053.	[illegible]	[illegible]
[illegible]	1664.	[illegible]	[illegible]
[illegible]	1543.	[illegible]	[illegible]
[illegible]	1573.	30.37	[illegible]
[illegible]	1604.	[illegible]	[illegible]

Table 7-6 (continued)

Geographical Distribution of Traffic (1990)

High Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
LA2	[illegible]	77.44	56.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
WI2	3355.	103.37	75.[illegible]
IL1	13495.	260.51	197.02
IL2	2037.	59.72	30.1[illegible]
KY1	1331.	25.70	19.5[illegible]
TN1	3387.	65.42	47.65
MS1	1573.	30.37	23.0[illegible]
MS2	1876.	36.21	27.4[illegible]
AL1	2320.	64.25	34.74
AL2	1967.	37.77	28.80
[illegible]	1120.	21.61	16.5[illegible]
MI1	424.	8.18	6.20
MI2	666.	12.85	9.[illegible]
MI3	11550.	223.13	167.25
OH1	8109.	156.54	118.[illegible]
OH2	6626.	127.92	97.[illegible]
IN1	[illegible]	121.49	[illegible]
IN2	1110.	21.36	17.[illegible]
KY2	3661.	70.68	53.0[illegible]
TN2	2874.	55.47	42.0[illegible]
GA1	4641.	89.46	[illegible]
GA2	2607.	50.33	38.11
FL2	1997.	38.56	[illegible]
FL3	10107.	196.84	147.32
ME1	1009.	21.03	15.[illegible]
NH2	424.	8.18	6.20
[illegible]	1231.	23.75	18.[illegible]
VT	676.	13.45	10.1[illegible]
CT	4236.	81.77	62.[illegible]
MA	7837.	151.28	114.76
RI	1301.	25.12	19.[illegible]
NY1	4024.	77.68	58.75
NY2	3147.	60.75	46.[illegible]
NY3	16762.	323.57	245.45
PA1	6112.	117.97	89.[illegible]
PA2	7020.	135.51	102.80
WV1	1664.	32.12	24.37
WV2	[illegible]78.	19.28	14.61
MDDC	6626.	127.92	97.01
NJ	10045.	193.92	147.11
VA1	1906.	36.80	27.92
VA2	5586.	103.97	75.87
DE	817.	15.77	11.9[illegible]
NC1	5477.	105.72	80.20
NC2	2511.	48.48	36.78
SC1	1310.	25.[illegible]	26.3
SC2	2421.	47.01	35.0[illegible]

Table 7-7

Geographical Distribution of Traffic (2000)

High Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
ID1	2327.	20.40	16.77
OR1	20980.	[illegible]	[illegible]
OR2	1811.	13.87	13.04
CA1	[illegible]	83.87	[illegible]
CA2	121376.	1063.08	[illegible]
CA3	145161.	[illegible]	[illegible]
NV1	[illegible]	31.73	[illegible]
NV2	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	74.50	[illegible]
WY1	1811.	[illegible]	[illegible]
WY2	3613.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	244.50	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	3364.	29.47	[illegible]
SD1	[illegible]	20.40	[illegible]
NE1	2070.	[illegible]	[illegible]
TX1	6210.	[illegible]	[illegible]
[illegible]	4140.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	31.73	[illegible]
[illegible]	[illegible]	200.54	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
TX4	35708.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
TX6	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	267.47	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
MN2	39072.	342.27	[illegible]
[illegible]	[illegible]	145.07	[illegible]
[illegible]	17593.	154.14	[illegible]
MO1	[illegible]	[illegible]	[illegible]
MO2	14231.	124.67	[illegible]
AR1	13196.	[illegible]	[illegible]
AR2	13453.	117.87	[illegible]
LA1	13714.	[illegible]	[illegible]

Table 7-7 (continued)

Geographical Distribution of Traffic (2000)

High Forecast

Region	Voice (half-voice circuits)	Data (Mbps)	Videoconferencing (half-circuits)
IA2	35171.	308.27	253.[illegible]
WI1	9050.	79.33	65.[illegible]
WI2	45779.	401.21	329.[illegible]
IL1	115404.	1010.45	831.00
IL2	17575.	154.14	126.71
KY1	11385.	99.73	81.[illegible]
TN1	28980.	253.87	208.72
MS1	13455.	117.87	96.[illegible]
MS2	16043.	140.57	115.[illegible]
AL1	28430.	249.04	204.[illegible]
AL2	16817.	147.34	121.[illegible]
FL1	9574.	83.87	68.[illegible]
MI1	3622.	31.73	26.0[illegible]
MI2	[illegible]	4[illegible].67	40.[illegible]
MI3	98641.	86[illegible].[illegible]	71[illegible].[illegible]
OH1	69346.	607.47	4[illegible].[illegible]
OH2	56567.	4[illegible].41	40[illegible].[illegible]
IN1	[illegible]	471.47	38[illegible].[illegible]
IN2	10350.	90.67	74.3[illegible]
KY2	31307.	274.27	225.4[illegible]
TN2	24352.	213.34	175.[illegible]
GA1	41441.	363.07	298.14
GA2	22253.	194.74	160.[illegible]
FL2	17070.	149.60	122.[illegible]
FL3	87200.	763.88	627.77
ME1	9319.	81.60	67.[illegible]
ME2	3623.	31.73	26.0[illegible]
NH	[illegible]	92.[illegible]	7[illegible].[illegible]
VT	5951.	52.13	42.[illegible]
CT	36226.	317.34	260.[illegible]
MA	67017.	587.07	481.62
RI	11126.	97.47	80.[illegible]
NY1	34414.	301.47	247.33
NY2	26910.	235.74	193.[illegible]
NY3	143330.	1255.75	1030.[illegible]
PA1	52268.	457.87	375.[illegible]
PA2	60031.	525.87	431.[illegible]
WV1	14231.	124.67	102.[illegible]
WV2	8539.	74.80	61.4[illegible]
MDDC	56667.	496.41	406.[illegible]
NJ	[illegible]	732.34	619.63
VA1	16302.	142.80	117.[illegible]
VA2	46058.	403.47	331.6[illegible]
DE	6986.	61.20	50.[illegible]
NC1	46834.	410.27	337.26
NC2	21477.	188.14	154.[illegible]
SC1	15525.	136.00	111.6[illegible]
SC2	2095[illegible].	183.60	150.74

SECTION 8
COMPARISON OF SUPPLY AND DEMAND
BASED ON KNOWN PLANS

This section uses the known plans of satellite operators and would-be operators to produce an estimate of the available capacity at C-band and Ku-band for the next few years. This is compared with the traffic forecasts to provide an indication of the need for additional satellites or for increased capacity per satellite.

An important consideration is the availability of orbital slots at the desired frequency band or bands. We have recently seen what a great effect such a limitation can have on the plans of would-be system operators. Depending on the needs of the customer base to be addressed, there may be one band which is more desirable than others; however, if slot is not available, then the operator will be out of luck.

Tables 8-1 and 8-2 illustrate some factors of future availability of orbital locations. In Table 8-1 the longitude limits which we used in this study are shown together with the number of slots available at two degree spacing at each frequency band. Table 8-2 shows the assigned orbital locations for satellites whose launch has been approved. In addition to those shown in Table 8-2, there are a number of as-yet unapproved satellites which have not been assigned orbital locations; these are noted in Table 8-3. Clearly, the central portion of the U.S. coverage arc is more valuable than the outer edges, primarily because it affords the earth station a high elevation angle. This is not especially significant at C-band, but is a definite factor in marketability at Ku-band and certainly at 30/20 GHz.

Table 8-1

Orbital Arc

Band	Number of Slots	Orbital Range
6/4	35*	59° - 101° 119° - 143°
14/12	34	59° - 105° 120° - 139°
30/20	23	75° - 119°

*Based on 1983 assignments, these are actually only 30 slots. The 35 figure assumes all 2° spacing.

Table 8-1

1983 Orbital Assignments

Orbital Slot (W.L)/	Frequency Band(s)	Satellite User
143	(4/6 GHz)	Satcom V
141	(4/6 GHz)	Unassigned
139	(4/6 GHz)	Satcom I-R
137	(4/6 GHz)	Unassigned
134	(4/6 GHz)	Galaxy I
132	(12/14 GHz)	Rainbow
131	(4/6 GHz)	Satcom III-R
130	(12/14 GHz)	ABCI
128	(4/6 & 12/14 GHz)	Amsat
126	(4/6 & 12/14 GHz)	RCA
125	(4/6 GHz)	Telstar/Comstar
124	(12/14 GHz)	SBS
122	(4/6 & 12/14 GHz)	Spacenet
120	(12/14 GHz)	USSSI
119.5	(4/6 GHz)	Westar V
117.5	(12/14 GHz)	Canada
116.5	(4/6 & 12/14 GHz)	Mexico
113.5	(4/6 & 12/14 GHz)	Mexico
112.5	(12/14 GHz)	Canada
111.5	(4/6 GHz)	Canada
110	(12/14 GHz)	Canada
108	(4/6 GHz)	Canada
107.5	(12/14 GHz)	Canada
105	(12/14 GHz)	Gstar
104.5	(4/6 GHz)	Canada
103	(12/14 GHz)	Gstar
101	(4/6 & 12/14 GHz)	Unassigned
99	(12/14 GHz)	SBS
98.5	(4/6 GHz)	Westar IV
97	(12/14 GHz)	SBS
96	(4/6 GHz)	Telstar
95	(12/14 GHz)	SBS
93.5	(4/6 GHz)	Galaxy II
93	(12/14 GHz)	Unassigned
91	(4/6 & 12/14 GHz)	Spacenet
89	(12/14 GHz)	SBS
88.5	(4/6 GHz)	Telstar
87	(12/14 GHz)	RCA
86	(4/6 GHz)	Westar
85	(12/14 GHz)	USSSI
83.5	(4/6 GHz)	Satcom IV
83	(12/14 GHz)	ABCI

Table 8-1 (continued)

1983 Orbital Assignments

Orbital Slot (W.L)/ Frequency Band(s)		Satellite User
81	(4/6 & 12/14 GHz)	Amsat
79	(12/14 GHz)	Rainbow
78.5	(4/6 GHz)	Westar
77	(12/14 GHz)	RCA
76	(4/6 GHz)	Telstar
75	(12/14 GHz)	Unassigned
74	(4/6 GHz)	Galaxy
73	(12/14 GHz)	Unassigned
72	(4/6 GHz)	Satcom
71	(12/14 GHz)	Unassigned
69	(4/6 & 12/14 GHz)	Spacenet
67	(4/6 GHz)	Satcom

Table 8-3

Satellites Not Yet Approved

Applicant	Number Desired	Capacity Each*
Ford Aerospace	2	54+
GTE	1	24
Hughes (Ku-band)	3	24
National Exchange	4	24
SBS	1	24
Western Union	5	24

*Equivalent 36 MHz transponders
+Hybrid

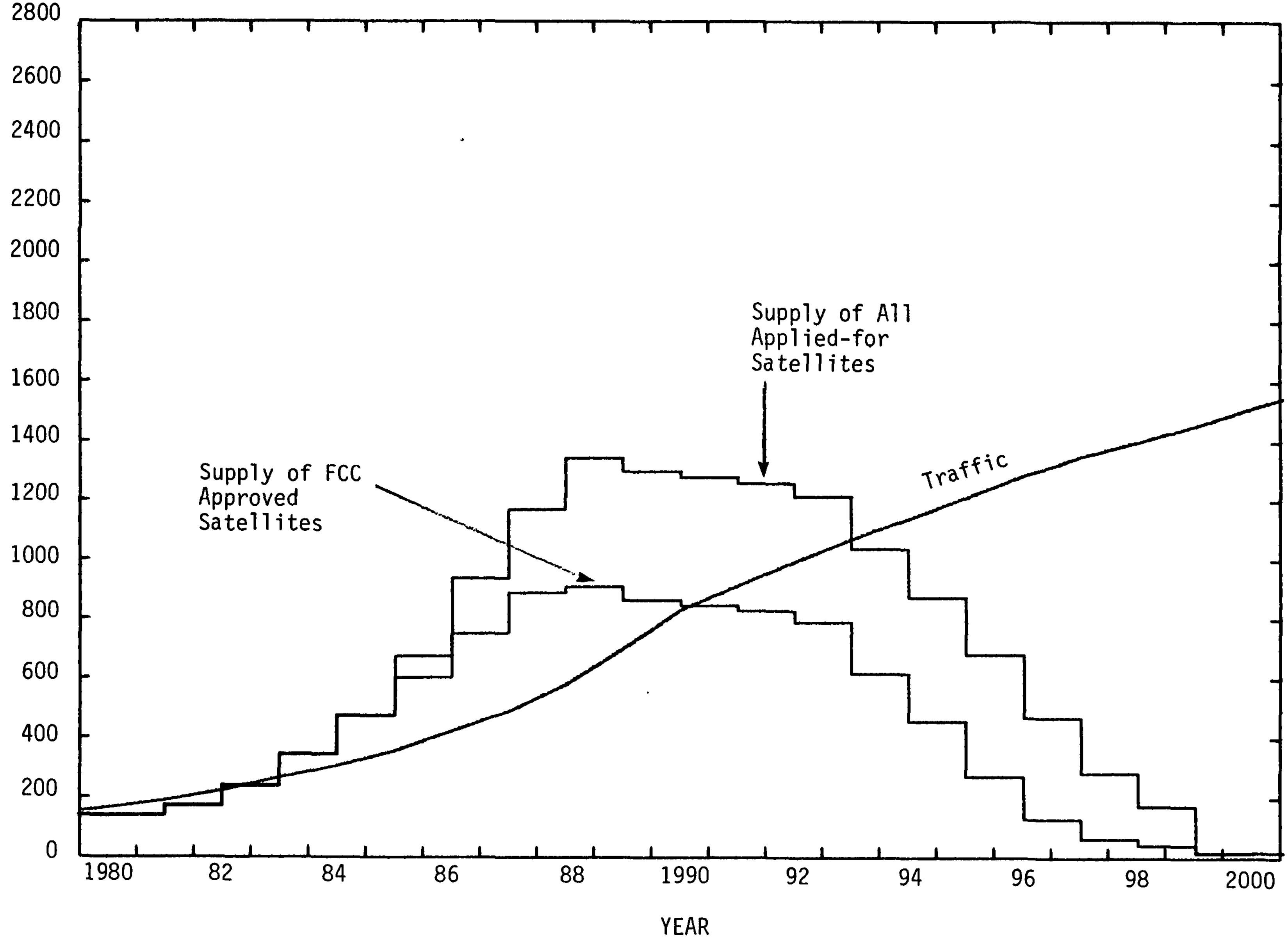
We have calculated the available supply (without launching any as-yet unannounced satellites) in two ways: first, using only the satellites that have been approved, and second, using all satellites for which we have information. The figures also include random failures of transponders, but don't include-relatively recent events such as the failure of twelve transponders on SATCOM II (which is almost dead anyway). These projections are shown in Table 8-4, and are plotted in Figure 8-1 and 8-2, along with the Low and High traffic forecasts respectively.

Table 8-4
Projected Capacity Versus Time
(including random failures)

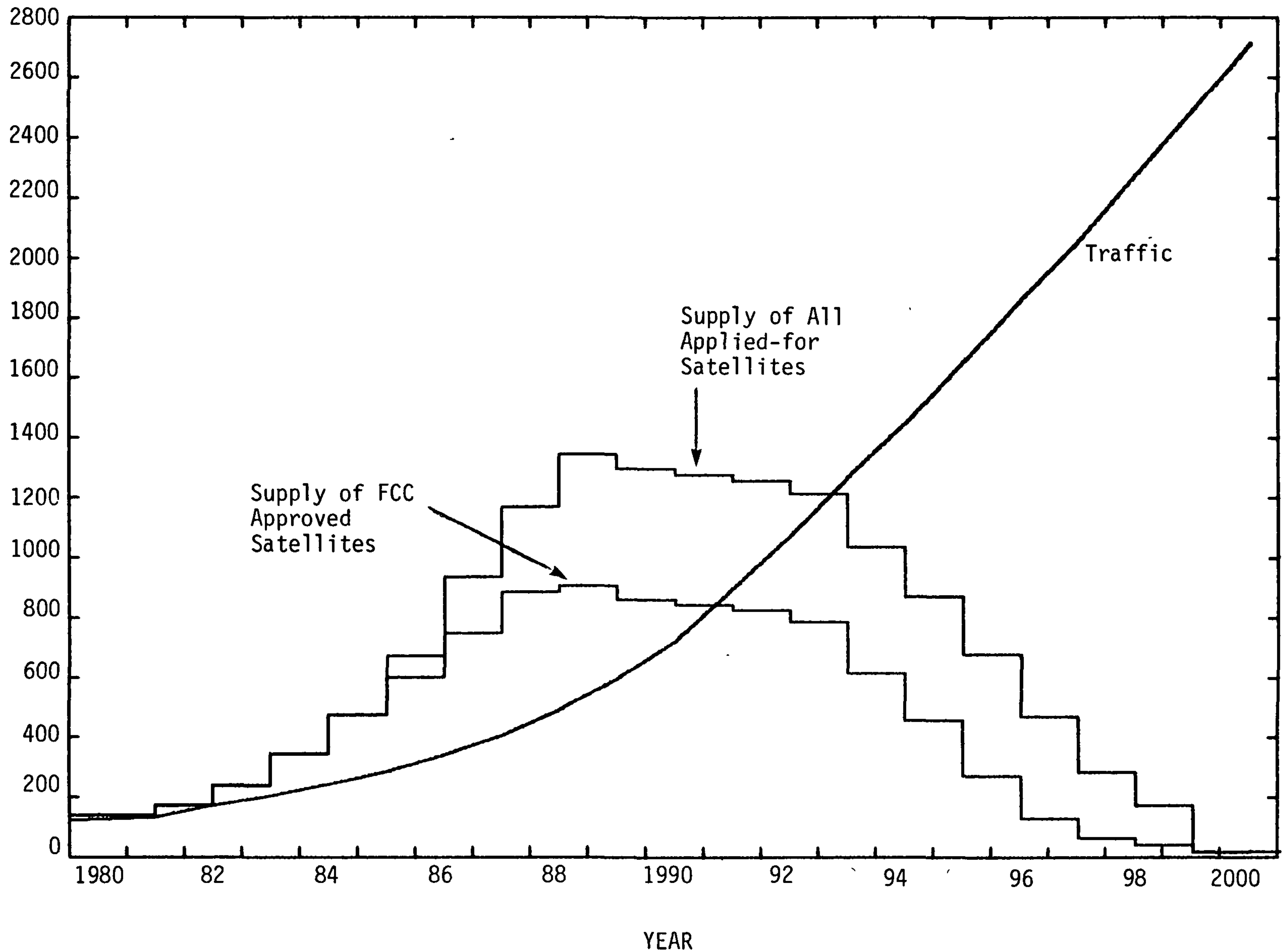
	All Satellites		Approved Only	
Year	C-band	Ku-band	C-band	Ku-band
1980	128	0	128	0
1981	147	12	147	12
1982	203	24	203	24
1983	298	36	298	36
1984	367	96	367	96
1985	486	180	438	156
1986	560	372	512	228
1987	558	612	510	371
1988	630	720	534	371
1989	600	708	504	359
1990	600	696	504	347
1991	600	684	504	336
1992	576	672	480	324
1993	432	636	336	288
1994	288	612	192	264
1995	168	540	72	192
1996	120	370	72	48
1997	72	224	24	24
1998	72	104	24	0
1999	0	0	0	0
2000	0	0	0	0

Figure 8-1

SUPPLY OF KNOWN SATELLITES AND LOW TRAFFIC



SUPPLY OF KNOWN SATELLITES AND HIGH TRAFFIC



SECTION 9
EFFICIENCY CALCULATIONS FOR FIXED-BEAM MULTI-BEAM SATELLITES

When we talk about the efficiency of a multi-beam satellite (which presumably provides connectivity among all beams, although not necessarily complete CONUS coverage by the beams) we really have to distinguish between two different measures of efficiency. The first is the efficiency with which the satellite uses the theoretical capacity of its beam configuration. The second is the efficiency with which the satellite can be loaded given its actual transponder configuration. Both of these depend on the traffic distribution among the beams (which we have approximated by using the population distribution), but in slightly different ways.

Theoretical Beam Efficiency

Figure 9-1 shows a possible (idealized) multi-beam coverage of the CONUS. If every beam is provided with the same capacity, and we assume (reasonably) that the traffic originating in any beam is divided among the other beams according to their population, then the satellite will be unable to carry additional traffic when the beam carrying the most traffic is saturated. Given the uneven population distribution of the CONUS, this results in rather poor efficiency compared with the maximum possible capacity, if traffic were evenly distributed. In fact, the efficiency under such conditions is given by:

$$\eta = \frac{1}{N \times P_{max}}$$

where

N = number of beams

P_{max} = fraction of traffic (population) carried on most heavily loaded beam.

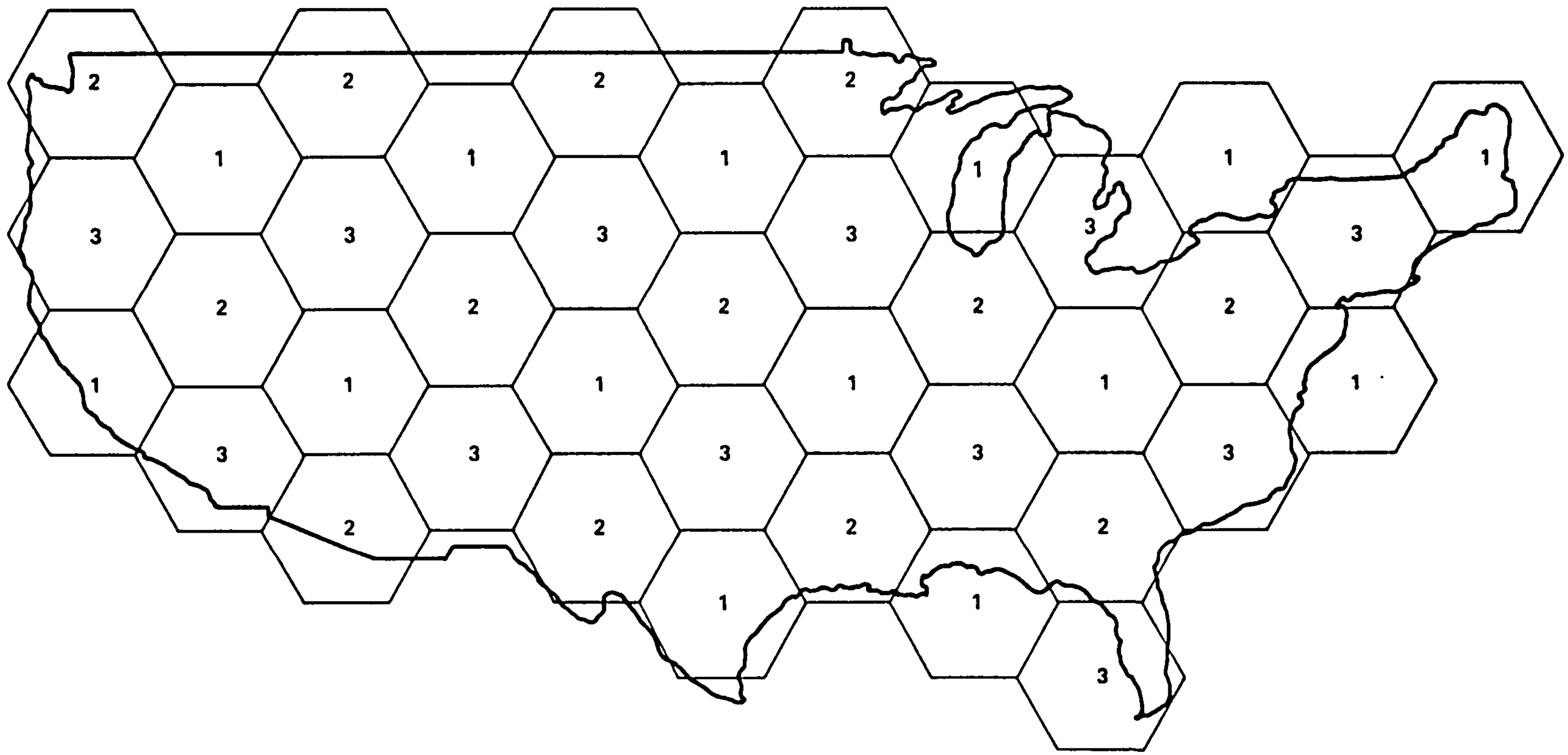


Figure 9-1

SPOT BEAM COVERAGE OF CONUS
(Numbers 1, 2 and 3 Indicate Frequency Assignment)

Using this formula, we can calculate the capacity at saturation given the number of beams and the capacity of each. However, to design a satellite, we must calculate the number of beams required for a given saturated capacity. In order to do this, we need further information about the population distribution. Dealing with the actual, detailed population distribution and physical aspects of the coverage pattern is unwieldy, and unnecessary as well, since we only require the population features in the region of densest traffic. We can therefore make some approximations that will be valid for the range of beam sizes expected (although they will break down for very large or very small beams).

The New York City area will always produce the densest traffic from any region in CONUS. The specific thing we need to know is: given the number of beams and assuming a beam size, what fraction of the total traffic will appear in the beam centered on New York? We can then solve the equations for efficiency, and finally invert the relationship to obtain the number of beams needed for a given capacity. At C-band and Ku-band, we assume that the beams taken together provide contiguous coverage. At 30/20 GHz, we assume a spot-beam configuration, starting at 10 beams of about 0.35 degree, and eventually expanding to provide contiguous coverage at about 135 beams. (Figure 9-2)

For the two lower bands, we proceed as follows:

Based on the N.Y. SMSA population and the population density of the surrounding area, the population fraction in the New York beam is approximately:

$$P_{max} = 0.05 + \frac{3.2}{N}$$

where N = the number of equal-size beams for CONUS coverage

The efficiency, , is given by:

$$\eta = \frac{1}{N\,P_{max}} = \frac{1}{0.05\,N + 3.2}$$

SATELLITE AT 110°W LONGITUDE

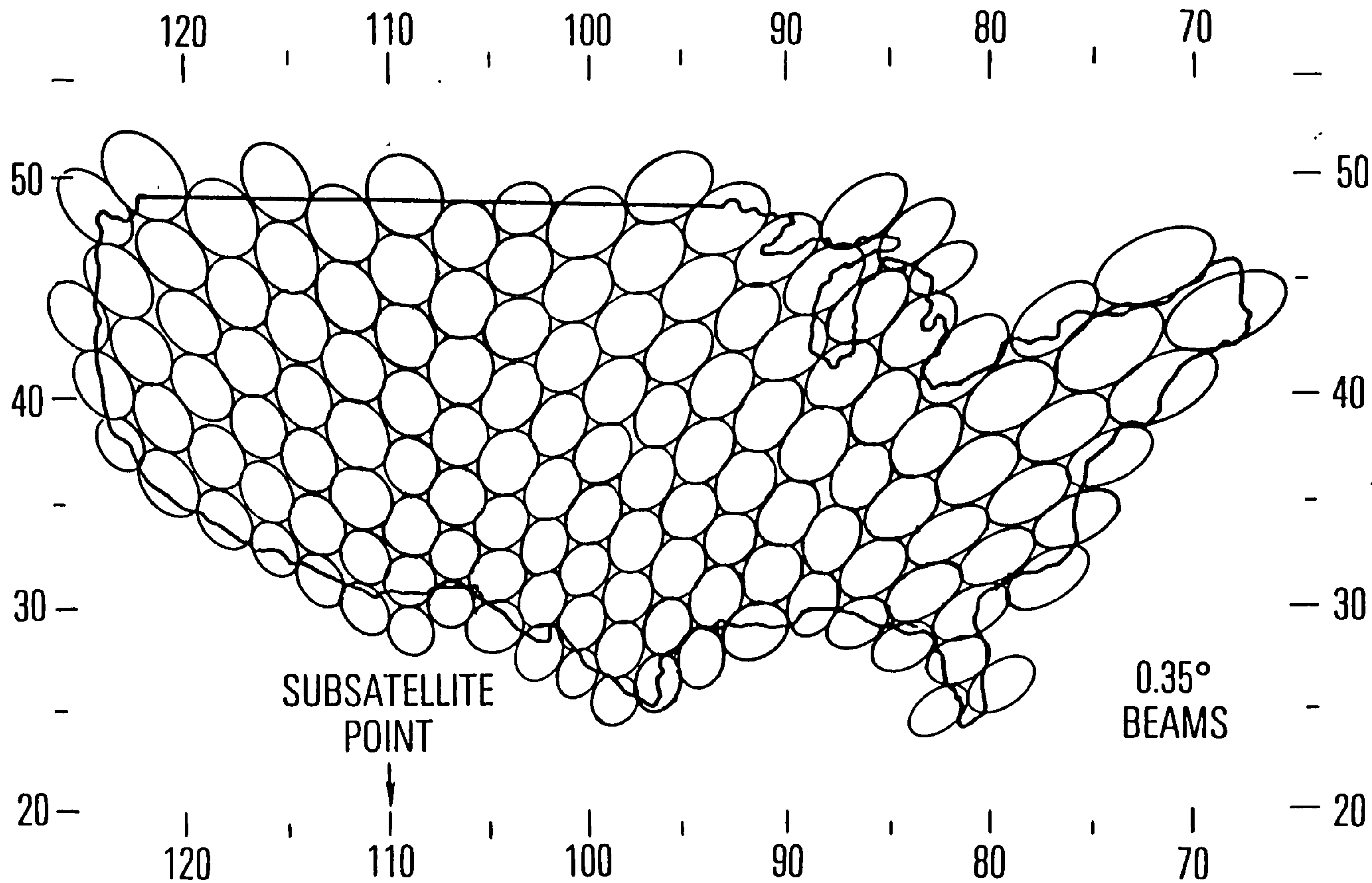


Figure 9-2

The capacity at saturation is then:

$$C_{Net} = 8 \ \frac{\text{transponders}}{\text{beam}} \ x \ N \text{ beams } x \ \eta \ = \ \frac{8N}{0.05 \ N + 3.2}$$

And the number of beams is:

$$N = \frac{3.2 \ C_{Net}}{8 - 0.05 \ C_{Net}} \quad \text{for } 24 < C_{Net} \leq 108$$

Approximately 108 transponders is the maximum net C-band or Ku-band capacity with 0.35 degree beams.

At 30/20 GHz, coverage was limited to SMSAs, using 0.35 degree beams, until the number of beams was 136, which constitutes contiguous coverage. The minimum network was 10 SMSAs (the largest). This provides net capacities up to 101 transponders. For an 0.35 degree beam, the N.Y. area population comprises about 7.15 percent of the United States total; the 10 largest SMSAs comprise about 34.9 percent of the United States. Therefore, the efficiency for the 10-beam network is:

$$\eta = \frac{1}{\frac{7.15}{34.9} N} = \frac{34.9}{7.15 \ x \ 10} = 0.49$$

Beyond 101 transponders, we have to add beams to increase the capacity. We've approximated the population of SMSA's smaller than the top 10 by two linear relationships:

for #11 to #33:

$$P_i = 1.77 - 0.0309i$$

for #34 to #65

$$P_i = 1.163 - 0.013i$$

where

i = rank of SMSA

P_i = Percent of total U.S. population for the i^{th} SMSA

In order to get the fraction of United States population contained in the 1st through i^{th} SMSAs, we integrate the above relationships and add the population for the top 10 SMSAs:

10 SMSAs:

$$P_t = 34.9 \text{ percent}$$

11 to 33 SMSAs:

$$P_t = 34.9 + 1.77\,(i - 10) - \frac{0.0309}{2}\,(i^2 - 100)$$

34 to 65 SMSAs:

$$P_t = 57.8 + 1.163\,(i - 33) - \frac{0.013}{2}\,(i^2 - 1089)$$

where

P_t = total integrated percent of U.S. population

Since the largest SMSA always contains 7.15 percent, the efficiency for any number of beams N is:

$$\eta = \frac{1}{\dfrac{7.15N}{P_t}}$$

At 30/20 GHz, using single polarization and assuming a division of the band into thirds to accommodate the beam interleaving, each beam could have about 20.8 equivalent 36 MHz transponders. Using this fact, and the equations given above, we can solve for N given the desired capacity C_{Net}.*

*Note that a quadratic equation is involved; the smaller root turns out to be the correct one.

Thus, for

$C_{Net} \leqslant 101$:

$$N = 10$$

$101 < C_{Net} \leqslant 168$:

$$N = \frac{5.15 - \sqrt{26.5 - 018\,(C_{Net} - 54.5)}}{0.09}$$

$168 < C_{Net} \leqslant 218$:

$$N = \frac{3.39 - \sqrt{11.5 - 0.0756\,(C_{Net} - 77.1)}}{0.0378}$$

for $C_{Net} > 218$, the same efficiency as that for contiguous coverage is used, so:

$218 < C_{Net} \leqslant 282$

$$N = \frac{3.2\, C_{Net}}{20.8 - 0.05\, C_{Net}}$$

Practical Satellite Efficiency

The efficiency values calculated above tell how effectively the beam coverage pattern is used by the traffic distribution pattern. In constructing an actual satellite, however, we would not necessarily have to provide the maximum possible capacity per beam, but could use the assumed traffic distribution to tailor the satellite to the beam loading. That is, if at saturation a given beam will only carry 2 transponders, then we only install 2 transponders for that beam. Thus, although the efficiency with which the beam pattern is used will be low, the efficiency with which the physical facilities of the satellite are used will be much higher.

In designing our satellite, we would generally wish to ease the interconnection problem by selecting a transponder bandwidth and using it throughout, although this is not absolutely necessary. Therefore, there will be a mismatch between the capacity installed and that actually used at saturation. For example, a particular beam may only require 0.4 transponder at saturation, but we have to install 1.0 transponder to service it. Since the capacity has to exceed the requirement (or at least equal it) this error will always be positive, and the satellite will always be somewhat underutilized.

We have chosen to approximate the error by assuming that all beams but the most heavily loaded beam have an average error of 0.5 transponder. Thus, we install $\frac{N-1}{2}$ additional transponders over and above C_{Net}. This can best be illustrated (and the entire process summed up) by some examples. These are shown in Table 9-1.

Table 9-1
Satellite Capacity Examples

Band	C_{Net}	N	Efficiency η	Gross Capacity
C or Ku	24	1	100%	24
30/20	24	10	49%	29
C or Ku	36	18	24%	45
30/20	36	10	49%	41
C or Ku	48	27	22%	61
30/20	48	10	49%	53
C or Ku	96	96	13%	144
30/20	96	10	49%	101

SECTION 10
SATELLITE INDUSTRY SCENARIOS

10.1 Introduction

This section explores one possible model for the satellite industry. This model is traffic-driven, and includes a number of assumptions about the distribution of traffic among the various frequency bands. Because of these assumptions, we have run the model using several scenarios, varying the assumed behavior to show the sensitivity of the results. Virtually all of the scenarios converge to systems which make use of multiple-spot-beam antennas and/or the 30/20 GHz band. The specific traffic distributions and satellite constellations don't all converge, however, and the difference can provide some illustration of the effects of different constraints.

10.2 Structure of the Model

10.2.1 Traffic-Driven

In trying to progress from a set of traffic forecasts to a set of development scenarios for the satellite industry, we have to consider a number of factors. First and foremost is the role that demand — both as perceived by us and as perceived by the satellite operators — plays in determining the need for additional capacity. Differences between perceived (anticipated) demand and actual demand can arise in several ways. There may be an imperfect perception on the part of the using public about what services are offered and what their advantages are. There may also be an imperfect marketing effort on the part of the operator. Competing transmission media may arise during the inevitable delay between system conception and operation, or the regulatory or economic environment change in an unexpected way. The result is that the actual traffic carried may be quite unlike the market projections contained in the FCC filing, both in type and volume.

We, however, are working from a set of agreed-upon traffic forecasts, and therefore will imagine that system planners in our model are working from these data also. This, then gives us two scenarios to begin with, based on the High Traffic Forecast and the Low Traffic Forecast of Task 1. We will assume as a starting point that the system operators (and prospective operators) will attempt to satisfy this demand insofar as it is possible. This will lead to their planning satellite launches of sufficient capacity, with adequate lead time, that the projected demand can be met.

In reality, of course, there are complications. Some system owners will be using the High forecast to plan, while others will be using the Low (or, for that matter, any number of values in between). The actual traffic will lie somewhere in the middle. In addition, there will be delays of uncertain length in obtaining a license, having satelites constructed, and having them successfully launched. One might construct two somewhat more extreme scenarios, by assuming that every thing goes according to schedule in the Low case, and all the delays are unfavorably large in the High case. However, we have assumed that schedules will be met on the average, having been formed with possible delays incorporated to begin with.

10.2.2 Demand Related Factors - Frequency Preferences

There are essentially two ways in which we can assume the traffic is allocated among frequency bands. First, we might assume that the frequency bands will fill from the bottom up; in other words, that C-band will be required by any and all traffic until there is no more capacity available at C-band, then Ku-band will be used and after that is filled, higher frequencies. This approach has some drawbacks. First, it conflicts somewhat with history since the first Ku-band satellites, those of SBS, were launched long before the C-band orbit was anywhere near being filled. Second, all other considerations are not equal amongst the frequency bands. In spite of the poor availability performance of higher frequency bands for certain types of traffic or for certain types of customers, there may be compelling reasons to use a higher band. For example, at C-band earth stations potentially suffer from or interfere with transmissions in the terrestrial microwave environment. This situation does not exist at the higher frequency bands because they are not used for terrestrial microwave at this time. Another consideration is antenna size. Although the antenna gain and the path loss exactly equal one another as the frequency is increased, the angular discrimination on an antenna of a given size increases as frequency is increased thus providing improved interference performance at higher frequencies. Thus, for a given satellite spacing, say two degrees, a smaller antenna can be used at Ku-band and a smaller one still at 30/20 GHz, and the same adjacent satellite performance can be achieved. This is a real effect and can be very important to some customers, for example, if the earth station must be unobtrusive, if it must be light-weight, if it must be subject to very little wind loading.

These considerations lead us into a second matter of considering division of traffic among the frequency bands and in fact, the second approach is the one we have decided to use. We make the assumption that there is an a priori preference for different frequency bands for different kinds of traffic, that this preference is a freely expressed one, in other words, given that there is adequate capacity available at any frequency band, there will be a certain preference for each one depending on the type of traffic and the type of customer. The user will only depart from his unrestrained choice when there is some restraint such as unavailability of capacity. Naturally, these choice matrices will change with time because users will become more familiar with other frequency bands or because capacity will become available where it was not available before. Since these preferences are not expecially well known, we have had to make estimates and use these as input to the model. Some sensitivity runs of the computer model have also been made in order to determine the degree of effect that these preference matrices have on the outcome of the scenarios. These preference matrices are applied in the model to new traffic which arises in each year rather than to the total traffic data base. Thus, the traffic distribution among the frequency bands in any given year will be a sum of the effects of all the previous years rather than a straightforward multiplication of the traffic matrix by the preference matrix. This is a reasonable approach because users who have chosen one frequency band previously, either from unrestrained or from restrained choice will have a certain investment in the use of that frequency band. They may have configured their system around the use of this band, they may have actually bought equipment that uses this band, in any event, there will be a relatively small probability of migration from one band to another.

Target Capacity

When planning a satellite which will be in service for a number of years there are two conflicting considerations. First, from a profitability standpoint one would like to have the satellite as full as possible immediately after launch. However, if this situation were to prevail it would eventually be necessary to turn away customers. These customers might in fact go elsewhere for their communications needs and once having done so, be very difficult to attract again. Therefore it is always desirable to have some excess capacity provided of course that this excess is not so much as to make the operation unprofitable. In selecting a target size for a satellite to be launched we have taken a moderate approach and assume that a desirable target will be the average capacity per orbital location in that frequency band which will prevail halfway through the satellites useful life. This target capacity will of course be limited by other considerations such as available technology, available satellite busses and available launch vehicles. Therefore, in the model it is used only as a target and not as an absolute constraint.

10.2.3 Ground Rules for the Model

The model tries to satisfy traffic demand in several ways, and has a specified set of actions that can be taken. These are as follows:

The model examines the growth in each of the traffic categories in each year and allocates this growth among the frequency bands in accordance with the preference matrix. If capacity exists to accommodate all of the growth in a particular band then that growth is assumed to be added to the traffic carried and no additional action is necessary to ensure sufficient capacity for that year. If however, the capacity in a particular frequency band is filled in that year and the growth cannot be accommodated, some form of action will be necessary in order to satisfy the demand. Naturally, our first attempt would be to launch additional capacity in that frequency band, assuming of course that slots were available. This launch of additional capacity could take several forms. First, a previously launched satellite may reach the end of its useful lifetime in that year in which case it would be replaced by a satellite with increased capacity, thus providing capacity to accommodate the growth and demand. In general, it appears that capacity increases from one generation of satellites to the next are in the range of 0 to 100 percent, that is, that the new satellite either has the same capacity as the old one or up to twice that capacity based on the operating history and plan of the satellite system operators we think this is a reasonable range, and in the model have generally used a capacity increase of 50 percent from one generation to the next as a working maximum.

Second, if empty slots are available, new satellites are launched. Capacity will be limited by the technology.

The last alternative is to retire a satellite of lower capacity somewhat before the end of its life in order to launch a satellite with higher capacity. Actually, one would not want to do this unless all other alternatives had been exhausted first.

If no alternatives are available to satisfy the demand at the desired frequency band, another possibility is the use of an alternative frequency band. For example, demand for capacity at C-band which cannot be filled might be satisfied at Ku-band and vice versa. We believe that only in the event that both lower frequency bands are filled is excess capacity likely to migrate to 30/20 GHz. This is not to say, however, that there will be no independent demand for 30/20 GHz. Based on the specific features of the satellite systems which might be available, it is quite reasonable to suppose that there will be applications for this frequency band even in circumstances where there is capacity available at the lower frequency bands. For example, use of a very small antenna aperture can produce quite good clear sky performance at 30/20 GHz. These might be used in earth stations which serve applications having a very low availability requirement. Alternatively, the availability requirements might be relaxed in order to procure the advantages associated with a very small earth station size. Other users might be attracted to 30/20 GHz by a considerably reduced space segment cost or possibly by the availability of a great deal of spectrum which could allow them to use frequency inefficient modulation techniques which would be prohibitively expensive at the crowded lower frequency bands. The preference matrices for one scenario reflect our thinking along these lines, that even given an unrestrained choice there will be a preference for the use of 30/20 GHz.

Other Ground Rules

Satellite Replacement: The actual lifetime of a given satellite will be assumed to equal the mission life, with zero residential capacity. The design life of satellites launched in later years will increase; this is one of the technology variables. Satellite transponders will "fail" according to estimates of the overall spacecraft reliability, including redundancy. This reliability estimate will be another technology variable. If a satellite has lost more than half of its original (physical) transponders, it will be considered for replacement when no other slots are available and additional capacity is needed.

In general, satellites will not be replaced before they are "dead." However, as a last resort, when additional capacity is needed and no other slots are available, a satellite can be retired a year early and replaced with a satellite of higher capacity.

Satellite Capacity: The transponders in each frequency band will be considered as separate satellites (that is, the program model does not recognize a hybrid satellite as a physical entity). This may produce some anomalies, but in general is much more manageable. The maximum capacity that can be launched on a single new satellite will be a function of time. This is a technology variable which encompasses several considerations such as antenna design and on-board switching.

10.2.4 Technology Variables

A number of technology variables limit and define the range of possible satellite configurations that can be formulated by the model. Most of these are explicitly contained in the weight/power and cost models that are used. However, several somewhat arbitrary choices for limiting values were necessary and these are discussed below.

Satellite Lifetime

As satellite hardware has been improved and tested by actual use, spacecraft lifetimes have increased. This trend has been augmented by a more accurate assessment of the degree of redundancy needed to ensure an adequate life for components with recognized failure mechanisms.

Failures can arise from several sources. Infant mortality is the failure of a component which normally has a very long life, but which has some manufacturing flaw. This failure mode can be eliminated by burn-in testing, and should not be a problem in general.

Random failures are usually sudden failures of components which have several possible failure modes. As implied by the name, these failures occur at unpredictable times and are not visibly the result of progressive wearout mechanisms. Some of these are caused by imperfect quality control procedures; others are often of undetectable origin. A certain percentage of such difficulties can be traced to unforeseen environmental effects. These could be prevented by more careful systems modelling before construction, in some cases.

Wearout failures generally involve depletion or fatigue of some parts; examples are battery degradation with cycling and TWT cathode depletion. Some wearout mechanisms are externally driven, for example the degradation of solar cell output caused by radiation and solar particles. In most cases, these failures can be countered by suitable inherent redundancy or overdesign. In addition, improved components can be used to lengthen the lives of future satellites.

Trends

Reliability of current spacecraft hardware has improved, and the introduction of devices such as solid-state power amplifiers will increase it further still. Although the use of new frequency bands is likely to decrease reliability somewhat for a short while, we expect that the present trend of increasing satellite lifetimes will continue.

More sophisticated redundancy schemes have been designed for the current generation of satellites. These are motivated by the need to squeeze the maximum performance into the weight and volume constraints of available launch vehicles such as the Delta 3920. However, these designs will continue to be used even on spacecraft freed from those particular limitations.

Device improvements will also be available in the non-communications portions of the satellite. For example, nickel-cadmium batteries have been supplanted almost entirely by nickel-hydrogen cells in recent designs. These promise better cycle life and reduced mass for the same capacity. Various improvements in spacecraft reliability will be achieved by the following means:

Design: More careful design, including overdesign of solar arrays, increased expendables allowances, new and more extensive redundancy and the ability to reconfigure the spacecraft to some extent to allow fault recovery;

Fault Analysis: The fault tree method used in other disciplines, especially those in which safety of operation and safe failure are important, can be applied to identify various failure modes. Design steps to alleviate or avoid these modes can then be incorporated.

Command Chain Reliability: The command and control chain is important not only for day-to-day operation, but also for fault recovery. More reliable and flexible command systems will not contribute to failures, and will enable other operational procedures to be used to compensate for certain failures.

Parts Qualification: All components should undergo rigid testing or be qualified by pedigree. Cleanliness and strict process control are necessary, especially during assembly and semiconductor metallization. Burn-in of active devices is desirable, especially new technology devices. When new devices are used, the redundant item should use different technology or a different configuration to avoid common failure modes.

In some respects, increasing satellite lifetimes are beneficial. Increases in life generally are available (when they are) at relatively small incremental costs, and the resulting satellite will have a lower cost per trans ponder-year of service. This can be used to lower charges to users, to increase profits, or, to a lesser extent, both.

However, at times, satellites may outlive their usefulness. This is more likely at times when the technology is changing rapidly, such as during the late 1960's and early 1970's. Satellite communications was at that period very new, and as a result the available technology grew and improved very quickly. This process happens all the time, though, since technology is always improving at some rate.

Satellites can become obsolete for other reasons as well. An example of this can be found in the INTELSAT system and another in the early, 12-transponder, WESTAR satellites. Traffic in the INTELSAT Atlantic region has grown rapidly enough over the years that higher capacity spacecraft were needed before the present generation had expired. In some cases, of course, residual capacity on INTELSAT spacecraft has been used to provide service in the more lightly-loaded Indian Ocean and Pacific areas.

At the time they were launched, the WESTAR I and II satellites, with 12 transponders each, were somewhat less than state-of-the-art, since dual-polarization operation was already possible. However, at that time it was not at all clear that a substantial market for domestic satellite use would develop, let alone the shortage of transponders that occurred during the latter part of these satellites' lives. It was because of this unexpected market surge that the 12 transponder design became obsolete, albeit still useful for service.

In order to reflect the increasing trends of lifetime, we chose to vary the projected life as a function of launch date. This was done in the simplest way. Since by the year 2000 it will certainly be feasible to have a satellite lifetime of 20 years, and by that time if may be operationally desirable as well, we chose that value for year 2000 launches. A typical lifetime for satellites launched this year is 8.5 years. Between now and 2000, the lifetime varies linearly. This is shown in Table 10-1.

Table 10-1

Postulated Satellite Lifetime

	Year of Launch				
	1980	1985	1990	1995	2000
Life (years)	8.0	9.9	13.2	16.6	20.0

Busses and Launch Vehicles

The availability of an existing, developed and proven satellite bus is also an important consideration when planning the kinds of satellites that will be launched. An existing bus, particularly one which has supported more than one generation of satellites is generally less expensive than one which is newly developed. In addition, the capacity of the primary launch vehicle used for that bus will probably have been tailored with moderate increases to fit moderate increases in the size, weight and power of the bus. This vehicle which will most likely be constructed on a proven base and which will have been used for a number of satellite launches, will provide a higher reliability during launch than an alternate vehicle might provide, especially if that alternate vehicle is being mated to a satellite bus with which it has not been used before. Naturally, the consideration of available launch facilities enters into the choice of satellite bus. This is particularly important at this time since there is a wide variety of launch vehicles potentially available. These are shown in Table 10-2 together with some of their pertinent characteristics. Launch capacity in expendable launch vehicles is generally available in rather large increments. The Shuttle, while having a large capacity to low earth orbit, will also provide geosynchronous capability incrementally because of the need for a perigee stage. In addition, an existing apogee kick motor is often used in order to keep the cost down. In some cases, the apogee motor may be somewhat undersized for the launch vehicle and it will be necessary to reduce the satellite mass in order to compensate for this. In our model, we have assumed that the choice of launch vehicle is based only on the satellite mass and in general, have used the least expensive alternative for a particular mass range. We have also assumed that an appropriately-sized apogee motor is available for every satellite designed. Although this is not always the case, we did not wish to introduce the additional complication of attempting to choose an apogee motor from existing designs.

In addition to the considerations mentioned above, each operator will perceive a certain risk associated with the use of a frequency band and/or a satellite technology other than that which he now uses. For prospective operators the risk is received in relation to applications and user communities with which he is familiar and which he knows can be supported by existing satellite systems.

Table 10-2
Launch Vehicles

Vehicle	Mass to G.E.O. kg	Approximate Cost, 1983 Dollars (millions)
Delta 3920	620	38
STS/PAM DII	920	25
Ariane 1	970	34
STS/PAM-A	985	40
Ariane 2	1,140	43
Atlas/Centaur	1,150	65
Ariane 3	1,380	47
Ariane 4	2,000	82
STS/IUS	2,250	125
Titan 34D/TRAN	2,900	100
STS/Centaur	5,400	168

Capacity Limitations

In order to prevent the model from postulating a single enormous satellite capable of satisfying the excess demand, but considerably different from lany others then in orbit, we postulated some reasonable limits on the capacity that could be launched. These limits increased with time, to accommodate improved availability of the relevant technology. The primary limiting factor will be a combination of antenna beamwidth and beam quantity limits, and mass/power limits (although cluster satellites could alleviate this latter item). We have used the antenna limitations to drive the capacity model.

As explained in Section 9, the net capability limit of a satellite configuration depends on the number of beams and the traffic distribution. Therefore, even in the absence of other constraints, the antenna engineering provides an upper limit. Table 10-3 shows the selected capacity limits and the number of beams required.

In this connection, you should note that the variations on the basic scenarios (for the High Traffic Forecast only) involve limiting the capacity of satellites at C-band and Ku-band. These lower limits over-ride the limits shown in Table 10-3.

Table 10-3

Capacity Limits Versus Year of Launch

	Transponders (Net)	Transponders (Gross)	Beams
C-band			
1980 - 1987	24	24	1
1988 - 1994	48	62	28
1995 - 2000	72	98	52
Ku-band			
1980 - 1987	24	24	1
1988 - 1994	48	62	28
1995 - 2000	72	98	52
30/20 GHz			
1980 - 1987	Not Available		
1988 - 1991	13	18	10
1992 - 1995	72	77	10
1996 - 2000	150	162	24

Market Considerations of Multi-beam Satellites

A significant component of today's satellite market is transponder sales and a related component is whole transponder leasing. Both of these forms of marketing satellite capacity would be affected by the use of multiple beam antennas for the simple reason that there would no longer be a separable identifiable transponder on-board the satellite which the owner could sell or lease as a unit. This lack would necessitate a completely different marketing approach in selling satellite capacity. To some extent such a different approach has been anticipated by the sale and leasing agreements for current satellites such as the Hughes Communications' Galaxy. While recognizing the desire of the customer to identify his transponder, these agreements also account for the fact that there are components which are shared among all the transponders on-board the spacecraft. Many of these of course are housekeeping functions and need not be mentioned explicitly in the agreement. However, some of them such as multiplex filters, waveguide switches, connectors, redundant transponder components and receivers are an intimate part of the transponder performance and in fact are mentioned explicitly in the agreements. In such a sale, the buyer takes legal possession of a fraction of a spacecraft component. This does not seem to have caused any problems for Hughes and in fact may be perfectly acceptable to the majority of users even if applied to the entire capacity which they purchase. Of course, similar considerations would apply to brokering and reselling such as that which is done by Robert Wold.

10.3 Satellite Weight, Power and Cost Models

Aside from being an obvious input to Task 3 Economic Analysis, the satellite weight, power and cost models are also used in the performance of the scenario evaluation. We have attempted to find a minimum cost per transponder in orbit for each satellite to be launched given the range of capacities within which we would like it to fall. Thus, the weight, power and cost models are used in an iterative way in the evaluation of the scenarios. This section describes these models and describes some alternative models which we considered but did not use.

Satellite Mass and Power Model

The satellite mass and power model is based on an aggregation of mass and power information for the spacecraft shown in Table 10-4. These satellites were broken up into subsections as follows:

Communications antennas
Communications electronics
Attitude control system
reaction control system
Structure

Thermal control

Electrical harness

TT&C

Electrical power supply

Table 10-4

Satellites Used for Mass/Power Model

INTELSAT	IV, V
Hughes	HS361, HS376, Leasat, 30/20 GHz Concept Spacecraft
RCA	SATCOM and Ku-band SATCOM
TDRS	
FLT SAT	
TRW	30/20 GHz Concept Spacecraft
Ford Aerospace	30/20 GHz Concept Spacecraft

The amount of propellant needed for stationkeeping was also estimated based on the satellite lifetime. The antenna mass was based on several assumptions. First, the need for separate receive and transmit antennas and reflectors. Second, the use of shaped beams which were assumed to be formed by seven feeds each. Of course, we recognize that many beams would be more complex and would require more feeds, however, the level of detail in this model is insufficient to support such a detailed calculation. We assumed that if the size of the satellite at C-band and Ku-band was 24 transponders or fewer then CONUS coverage would be used and this would require a single shaped beam. 30/20 GHz satellites were assumed to always use multiple spot beams of one kind or another and also C-band and Ku-band satellites with capacity greater than 24 transponders were assumed to use multiple beams. Table 10-5 shows the parameters used to calculate the antenna mass at each frequency band. Clearly, these are rough approximations and are not intended as anything else.

Table 10-5

Antenna Design Parameters

NB	=	number of beams
NF	=	number of feed horns = 7 x NB

Basic design assume: reflector diameter is proportional to $\sqrt{NB}$

Reflection mass:

if diameter < 4.6 meters

mass = 2.3 x $(\text{diam.})^{1.95}$ (kg)

if diameter > 4.6 meters

mass = 0.182 x $(\text{diam.})^{2.4}$ (kg)

The communications electronics was estimated based on mass and power requirements for the larger components for miscellaneous items such as waveguide, connectors and redundancy switches. All satellites were assumed to use dual polarization and redundancy resulting in the requirements for components shown in Table 10-6. We assumed that the transponder output power and hence, transponder EIRP would increase with time at the rate of about 0.25 dB per year. This is less than the actual rate at which the EIRP of some domestic satellites have increased from one generation to the next. Such an increase can come from a variety of sources, improvements in power amplifier efficiency, improvements in antenna beam shaping, and increases in the total primary power available for the communications electronics. The TT&C subsystem, attitude control subsystem and thermal control subsystems as well as the electrical distribution harness were calculated as functions of the communications electronics mass. Relationships are shown in Table 10-7 for these subsystems.

Table 10-6

Communications Subsystem Requirements

Receivers:	4 per beam (4 for 2 redundant)
Drivers:	1.2 per transponder (6 for 5)
Power Amplifiers:	1.2 per transponder (6 for 5)
Note - mass varies with frequency band.	

Base RF output power (1980) & efficiency

C-band:	8.5 watts for CONUS coverage (increases 0.25 dB per year)
	η = 40% (increases 2.4% per year)
Ku-band:	20 watts for CONUS coverage (increases 0.25 dB per year)
	η = 40% (increases 1.9% per year)
30/20 GHz:	20 watts per beam (increases 0.25 dB per year)
	η = 25% (increases 2.8% per year)

Table 10-7

Some Subsystem Relationships

M_R = communications subsystem mass
(mass in kg, power in watts)

TT&C:

mass = $0.0394\ M_R + 21$ kg

power = $0.0488\ M_R + 27$ W

Attitude Control:

mass = $0.093\ M_R + 37$ kg

power = $0.665\ M_R + 4$ W

Thermal Control:

mass = $0.135\ M_R$

Harness mass = $0.26\ M_R - 9.5$ kg
(minimum 5 kg)

The electrical power subsystem parameters were calculated based on the power requirements of the subsystems already mentioned. We assumed that a three-axis stabilized satellite would be used and we made allowances for battery charging during eclipse with a total charge efficiency of 90 percent and for a 10 percent margin. We calculated solar array degradation at the rate of 3.5 percent per year for the first seven years and 2 percent per year for every year thereafter. The array mass and battery mass were calculated on the basis of figures shown in Table 10-8.

Table 10-8

Electric Power Subsystem

Battery mass factor:

$f_b = 18.0 \times (1.05^{(\text{year}-1980)})$ w-hr/kg

connectors + redundancy = 17%

margin for contingencies = 10%

Array mass factor:

$$f_a = 18 \times \left[\frac{\log(\text{power})}{2} - 0.5 \right] \times \left[1.09^{(\text{year}-1980)} \right] \frac{W}{kg}$$

The mass of the satellite bus structure is clearly a function of the mass of the remaining subsystems and the mass of the reaction control subsystem including propellant is a function of the total satellite mass and the total satellite lifetime. Our assumption was that there was a 51.5 meter per second delta V budget per year for stationkeeping, a 75 meter per second budget for initial positioning and possible repositioning and a 5 percent margin. The reaction control thrusters were assumed to have a specific impulse of 300 seconds. The complete model is presented in Appendix G of the Final Report.

Other Models

The satellite mass and power model discussed above is clearly a simple one. More sophisticated models are available as are other simple models which can be used for comparison.

Ford Aerospace and Communications Company has developed a more sophisticated method for estimating spacecraft weight and power. The basics of this model have recently been published in a document resulting from preparation for the 1983 RARC. Because of Ford's considerable communications satellite experience, this model clearly has substantial credibility and in fact, we have incorporated some of the estimates particularly for communication subsystem element weight and power consumption figures in the model used in these scenarios.

Satellite Cost Models

In costing out the satellites used in this study, we have employed a combination of the SAMSO Unmanned Spacecraft Cost Model and cost data available from other sources. These latter have included cost model evaluations on advanced satellites, using other models, and published figures for the cost of recently-contracted spacecraft. Several issues concerning costs and the projection of future costs are also discussed in this section.

The SAMSO Model

The latest SAMSO cost model published in June, 1981 was generated from a data base containing detailed cost information relative to different space programs (including INTELSAT IV). The SAMSO historical cost model basically divides the spacecraft into a number of cost elements and applies cost estimation relationships (CER) to derive the cost of each element as a function of a combination of its physical characteristics (mass and power requirements). The CER's were developed by SAMSO by applying least square regression techniques to the cost data base obtained from the sample space hardware development programs.

The various cost elements which enter the model are defined below:

a. Structure, thermal control, and adapter

   This includes (i) struts, substrates, equipment platforms, booms, antenna supports, solar panel suports, the mechanical despin equipment for spin-stabilized designs, and balance weights; (ii) thermal control hardware items such as insulation, louver assemblies, and heat pipes; and (iii) the booster adapter and separation mechanism between booster and spacecraft.

b. Electrical power (EPS)

This includes solar cells, solar panels, regulators, converters, power distribution units, batteries, and wire harnesses.

c. Attitude control (ACS)

This includes sun and earth sensors, reaction control nozzles, fuel lines, valves, fuel tanks, control electronics, momentum wheels, gyros and gyro electronics, solar panel drive mechanism and drive electronics, spacecraft spinup and despin system, nutation dampers, and accelerometers.

d. Telemetry, tracking, and command (TT&C)

This includes all TT&C hardware items such as receiving and transmitting horns, command receivers, beacon transmitters, and signal conditioners.

e. Communications

This includes receiving and transmitting antennae, receivers, TWT amplifier and associated power supplies, input filters, cross-connect filter matrices, RF switches, on-board switch matrices, attenuators, and equalizers.

f. Program level

This includes all program level activity which cannot be directly related to any specific contract end item; this element can typically be broken down into program management, systems engineering, systems test and evaluation, acceptance test, reliability/quality assurance, and data management.

For each of the foregoing elements, the SAMSO model supplies two CER's: one for determining how much of the nonrecurring development cost is attributable to the element in question; and the other for determining how much of the first unit cost may be so attributed. As an alternative to treating the Communications and TT&C subsystems separately, the model includes an additional pair of CER's which may be used to compute cost estimates for these subsystems considered in combination. The calculation method resulting in the highest cost should be used.

Other Cost Models

Other cost models have been developed by TRW, Canadian Astronautics Ltd. (CAL) and by other spacecraft manufacturers. In general, these are not available for public use.

In conjunction with the mass and power model mentioned previously, Ford Aerospace also developed a satellite cost model. This satellite cost model is similar in many respects to the SAMSO model but applies only to communications satellites and incorporates a large number of complexity factors accounting for various technology sophistications in the spacecraft. This cost model was also published in conjunction with preparation with the 1983 RARC. We have chosen to use the SAMSO model instead because the satellite configurations particularly in the evaluation of the scenarios are not sufficiently well developed to justify the use of a more sophisticated model. The complexity factors in particular would be difficult to estimate given the rough approximations used in sizing and configuring the spacecraft.

Some indications can be drawn from costs quoted in the press for recent satellite contracts, and from data on costs of previous satellites. While this information is of limited value in estimating the cost of larger spacecraft, it is likely that there will be a mix of spacecraft sizes and complexities through the period under study. Therefore, these historical examples will have some value.

10.4 Scenarios and Results

We have postulated three scenariosto use in our model. The first, Case #1, which we believe to be fairly realistic, assumes that there is a certain amount of demand for each frequency band. This demand changes over time. The frequency preference matrix for Case 1 is shown in Table 10-9.

Case #2 is an extreme. In this scenario, we assume that C-band is preferred above all, and that the other bands are used only when there is no capacity available at C-band. This is shown in Table 10-10.

Table 10-9
Frequency Preference for Scenario 1
(%)

	Year				
	1980	1985	1990	1995	2000
TV DISTRIBUTION					
C-band	100	96	90	85	80
Ku-band	0	4	10	15	20
30/20 GHz	0	0	0	0	0
DATA					
C-band	100	71	50	41	33
Ku-band	0	29	50	45	34
30/20 GHz	0	0	0	14	33
VOICE					
C-band	100	71	50	45	40
Ku-band	0	29	50	46	40
30/20 GHz	0	0	0	9	20
TELECONFERENCING					
C-band	100	55	30	17	10
Ku-band	0	45	70	59	45
30/20 GHz	0	0	0	24	45

Table 10-10

Frequency Preference for Scenario 2

(%)

	Year				
	1980	1985	1990	1995	2000
TV DISTRIBUTION					
C-band	100	100	100	100	100
Ku-band	0	0	0	0	0
30/20 GHz	0	0	0	0	0
DATA					
C-band	100	100	100	100	100
Ku-band	0	0	0	0	0
30/20 GHz	0	0	0	0	0
VOICE					
C-band	100	100	100	100	100
Ku-band	0	0	0	0	0
30/20 GHz	0	0	0	0	0
TELECONFERENCING					
C-band	100	100	100	100	100
Ku-band	0	0	0	0	0
30/20 GHz	0	0	0	0	0

Case #3 assumes that 30/20 GHz is undesirable, but that C-band and Ku-band eventually become equally desirable, except for TV distribution service. For TV, the same split is used as in Case 1. These probabilities are expressed in Table 10-11.

Table 10-11
Frequency Preference for Scenario 3
(%)

	Year				
	1980	1985	1990	1995	2000
TV DISTRIBUTION					
C-band	100	96	90	85	80
Ku-band	0	4	10	15	20
30/20 GHz	0	0	0	0	0
DATA					
C-band	100	84	71	59	50
Ku-band	0	16	29	41	50
30/20 GHz	0	0	0	0	0
VOICE					
C-band	100	84	71	59	50
Ku-band	0	16	29	41	50
30/20 GHz	0	0	0	0	0
TELECONFERENCING					
C-band	100	84	71	59	50
Ku-band	0	16	29	41	50
30/20 GHz	0	0	0	0	0

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All three scenarios are driven by both the High and Low traffic forecasts, and use the general ground rules described earlier. Two variations were run for the High traffic cases: One (B cases) in which both C-band and Ku-band were limited to a net capacity per slot of 24 equivalent transponders, and another (C cases) in which C-band was limited to 24 transponders and Ku-band was limited to 36 net (45 gross) transponders.

The actual scenarios runs are included separately. The computer printouts are too long to include in the text at this point. However, the important results can be summarized by noting the significant events and showing graphs of demand and supply versus time.

Tables 10-12 through 10-23 show the maximum individual satellite capacity needed for each band, for each scenario, and the year in which such a satellite capacity is first launched. The tables also show the average gross capacity in each band for all occupied orbital slots, and the first year in which a multi-beam satellite is needed (excluding the Ford Aerospace & Spotnet satellites, which already propose spot beams). Figures 10-1 through 10-12 show capacity and demand versus time for the scenarios.

10.5 Conclusions From Scenario Runs

Somewhat different scenarios could have been generated from the same model, using different assumptions. For example, allowing follow-on (replacement) satellites to increase by more than 50 percent over the size of the previous satellite would have resulted in a traffic distribution that more nearly matched the preference matrices, with lower probability of using 30/20 GHz in Scenarios 2 and 3. This would be counterbalanced by a higher requirement for multi-beam technology at C-band and Ku-band. The assumption of 50 percent is justifiable based on the known behavior of the satellite manufacturers and operators. For example, the first U.S. domsats launched, the WESTAR I series, had 12 transponders each. These were followed by the RCA SATCOM I series, with 24 transponders each. Now, the WESTAR I's have been replaced by WESTARs with 24 transponders, but the SATCOMs are being replaced by still more 24 transponder

Table 10-12

SUMMARY FOR
CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

LOW TRAFFIC FORECAST

	FREQUENCY BAND		
	C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	37	37	65
YEAR LAUNCHED:	1994	1999	2000
FIRST MULTIBEAM SATELITE IN:	1994	1999	1992
GROSS CAPACITY			
1980	128	0	0
1990	672	744	0
2000	917	842	180
NET CAPACITY			
1980	128	0	0
1990	672	744	0
2000	812	831	164
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	33	25	45

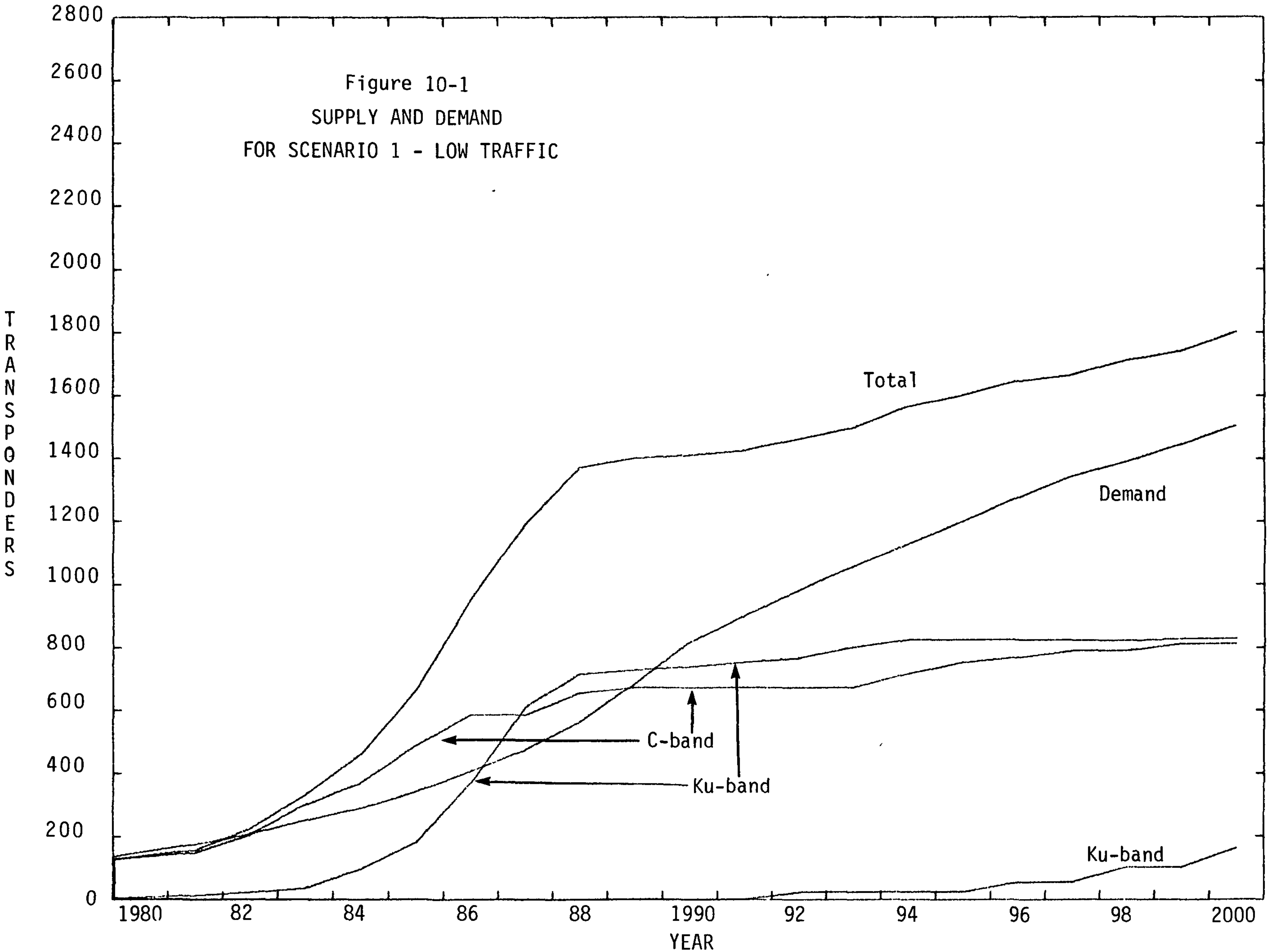

Figure 10-1
SUPPLY AND DEMAND
FOR SCENARIO 1 - LOW TRAFFIC

Table 10-13

SUMMARY FOR
CASE #2 -- TOTAL C-BAND PREFERENCE -- NO LIMIT AT C-BAND OR KU-BAND
EXCEPT PURELY TECHNICAL AS ESTIMATED.

LOW TRAFFIC FORECAST

	FREQUENCY BAND		
	C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	68	37	0
YEAR LAUNCHED:	1992	1999	0
FIRST MULTIBEAM SATELITE IN:	1989	1999	0
GROSS CAPACITY			
1980	128	0	0
1990	839	744	0
2000	1449	842	0
NET CAPACITY			
1980	128	0	0
1990	805	744	0
2000	1223	831	0
AVERAGE CAPACITY			
1980	19	0	0
1990	27	22	0
2000	41	25	0

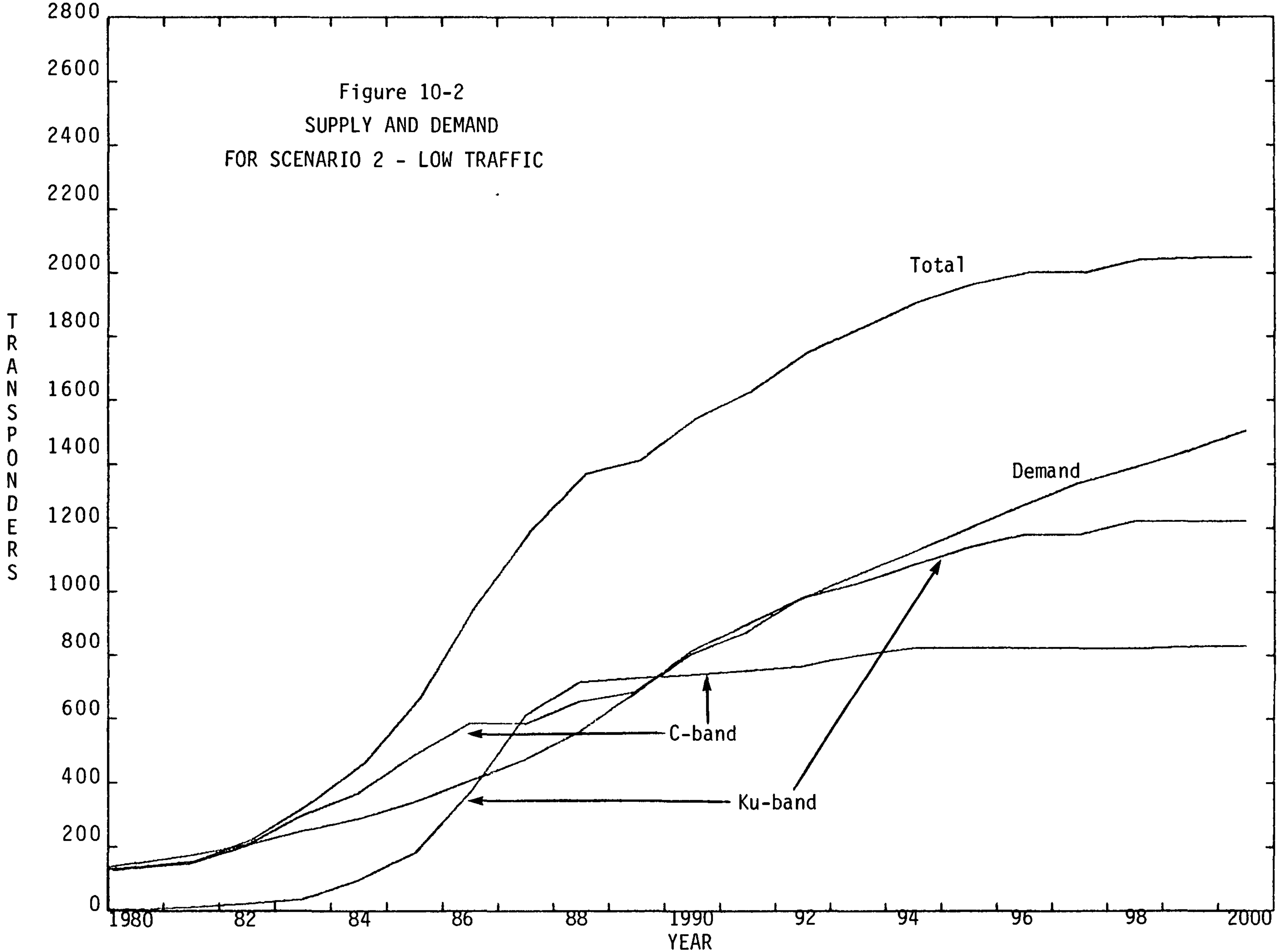

Figure 10-2
SUPPLY AND DEMAND
FOR SCENARIO 2 - LOW TRAFFIC

Table 10-14

SUMMARY FOR
CASE #3 -- EVEN SPLIT BETWEEN C AND KU BY 2000;
NO LIMIT AT C-BAND OR KU-BAND EXCEPT TECHNICAL AS ESTIMATED

LOW TRAFFIC FORECAST

	FREQUENCY BAND C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	53	37	0
YEAR LAUNCHED:	1998	1999	0
FIRST MULTIBEAM SATELITE IN:	1991	1999	0
GROSS CAPACITY			
1980	128	0	0
1990	672	744	0
2000	1269	842	0
NET CAPACITY			
1980	128	0	0
1990	672	744	0
2000	1084	831	0
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	37	25	0

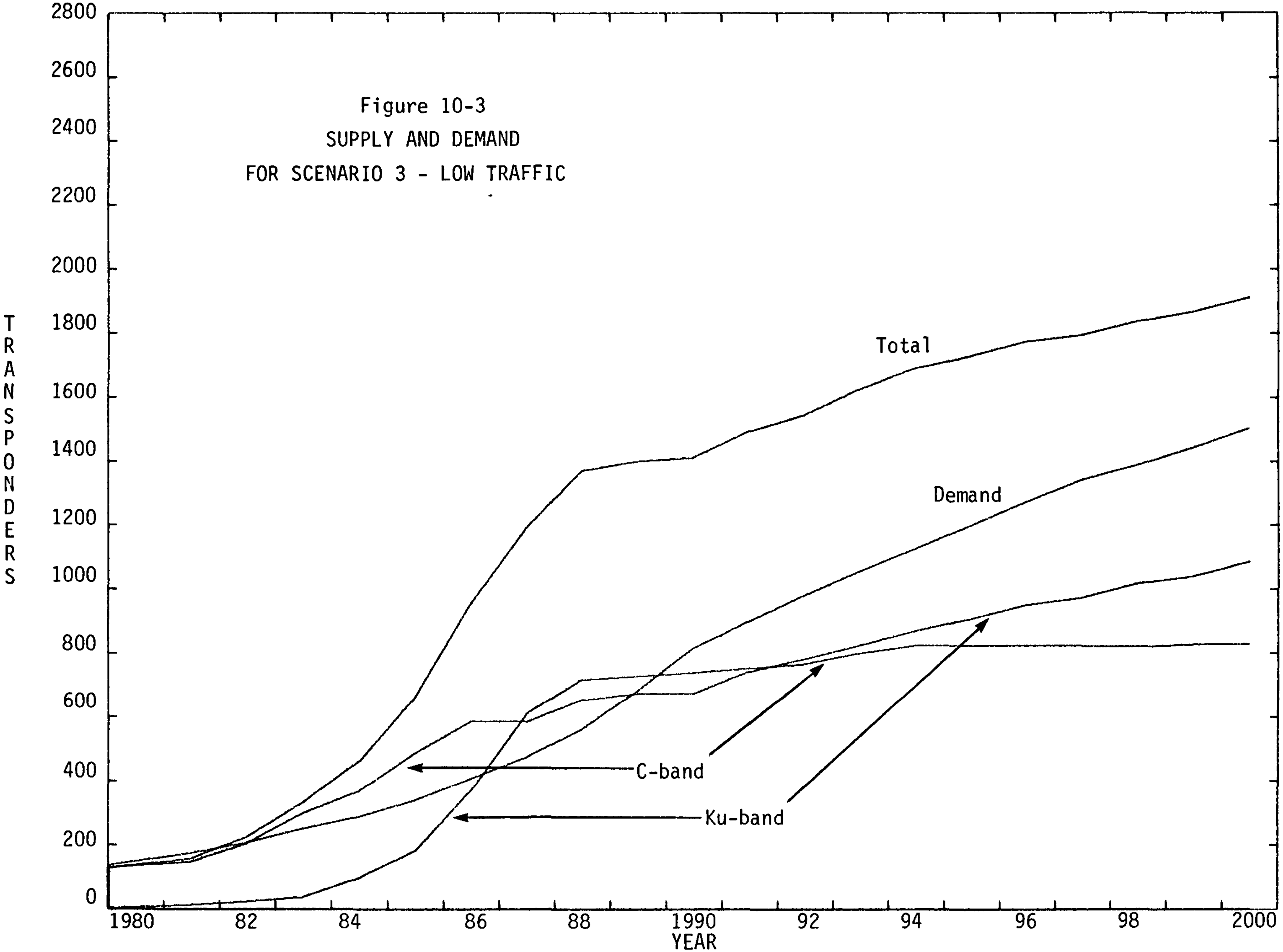

Figure 10-3
SUPPLY AND DEMAND
FOR SCENARIO 3 - LOW TRAFFIC

SUMMARY FOR
CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

	FREQUENCY BAND C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	58	61	84
YEAR LAUNCHED:	1996	1999	2000
FIRST MULTIBEAM SATELITE IN:	1992	1996	1992
GROSS CAPACITY			
1980	128	0	0
1990	672	744	0
2000	1329	1148	641
NET CAPACITY			
1980	128	0	0
1990	672	744	0
2000	1133	1016	595
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	38	34	58

Table 10-15

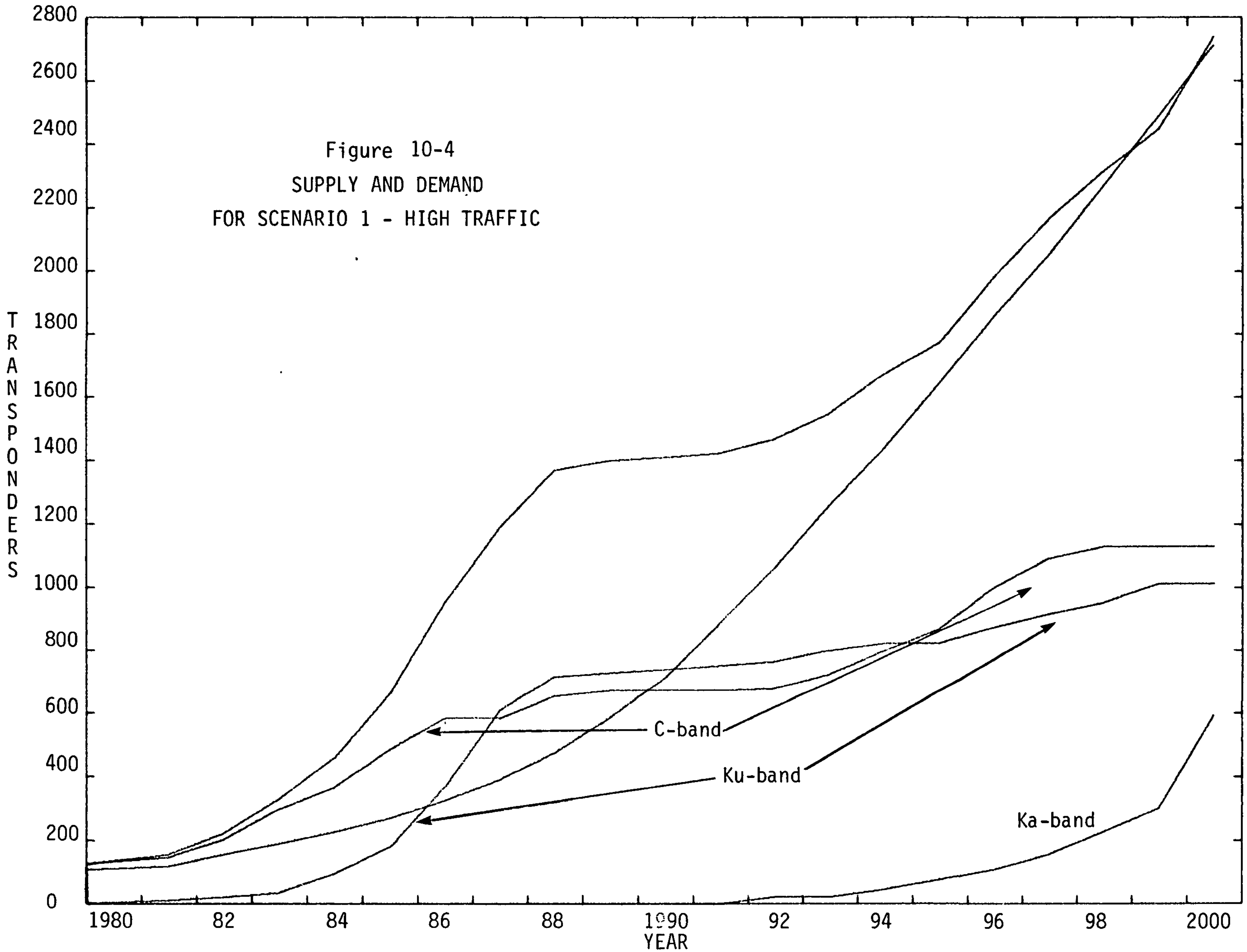

Figure 10-4
SUPPLY AND DEMAND
FOR SCENARIO 1 - HIGH TRAFFIC

SUMMARY FOR
CASE #2 -- TOTAL C-BAND PREFERENCE -- NO LIMIT AT C-BAND OR KU-BAND
EXCEPT PURELY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

	FREQUENCY BAND		
	C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	76	61	51
YEAR LAUNCHED:	1991	1998	1999
FIRST MULTIBEAM SATELITE IN:	1990	1998	1998
GROSS CAPACITY			
1980	128	0	0
1990	755	744	0
2000	1566	996	506
NET CAPACITY			
1980	128	0	0
1990	742	744	0
2000	1321	933	453
AVERAGE CAPACITY			
1980	19	0	0
1990	25	22	0
2000	45	29	39

Table 10-16

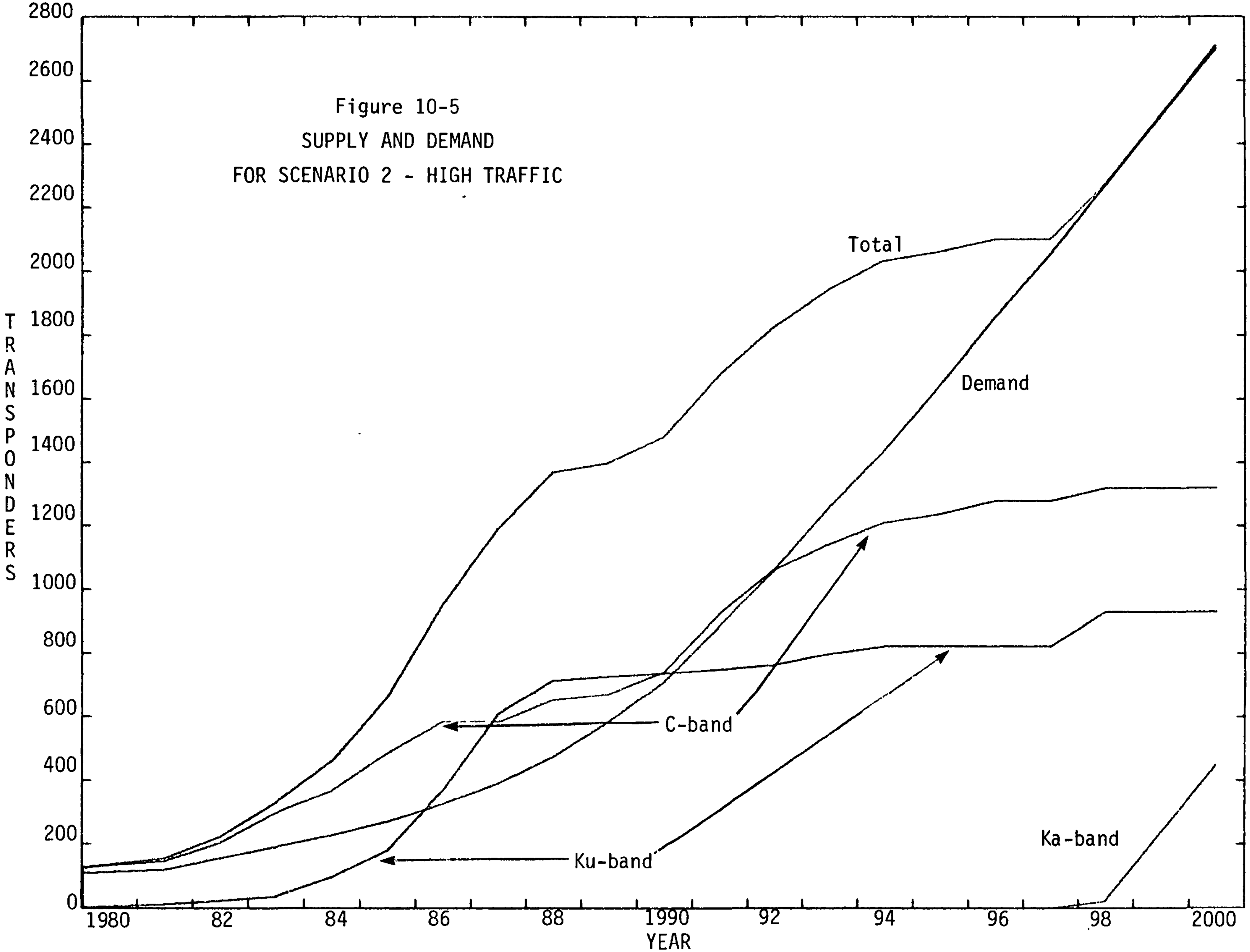

Figure 10-5
SUPPLY AND DEMAND
FOR SCENARIO 2 - HIGH TRAFFIC

SUMMARY FOR
CASE #3 -- EVEN SPLIT BETWEEN C AND KU BY 2000;
NO LIMIT AT C-BAND OR KU-BAND EXCEPT TECHNICAL AS ESTIMATED

HIGH TRAFFIC FORECAST

	FREQUENCY BAND C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	61	61	51
YEAR LAUNCHED:	1994	1998	1999
FIRST MULTIBEAM SATELITE IN:	1991	1995	1998
GROSS CAPACITY			
1980	128	0	0
1990	672	744	0
2000	1392	1226	506
NET CAPACITY			
1980	128	0	0
1990	672	744	0
2000	1183	1070	453
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	40	36	39

Table 10-17

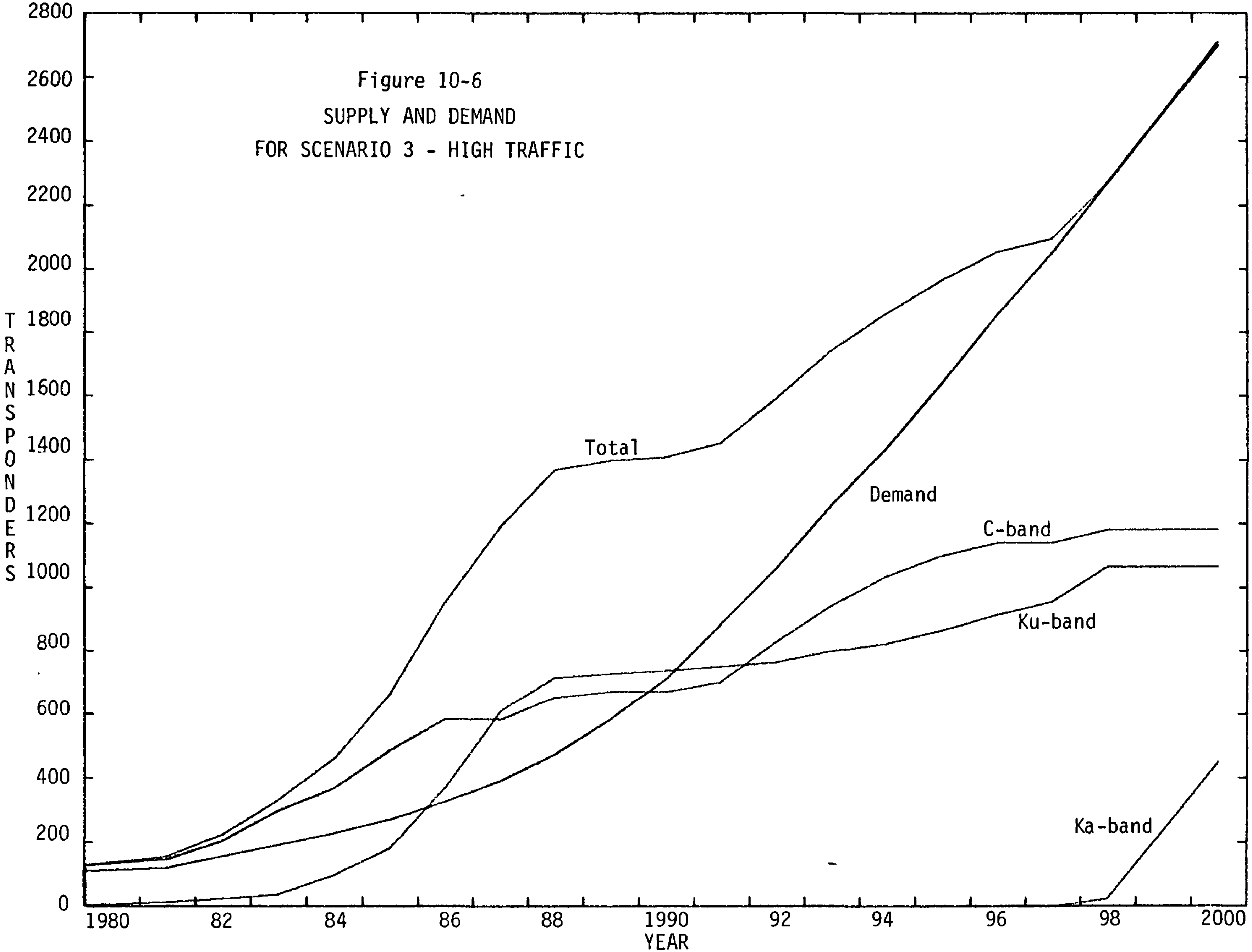

Figure 10-6
SUPPLY AND DEMAND
FOR SCENARIO 3 - HIGH TRAFFIC

Table 10-18

SUMMARY FOR
CASE #1B -- SOME DEMAND FOR EACH BAND -- 24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

	FREQUENCY BAND		
	C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	24	24	92
YEAR LAUNCHED:	1986	1989	1998
FIRST MULTIBEAM SATELITE IN:	0	0	1992
GROSS CAPACITY			
1980	128	0	0
1990	672	744	0
2000	840	816	1197
NET CAPACITY			
1980	128	0	0
1990	672	744	0
2000	840	816	1122
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	24	24	67

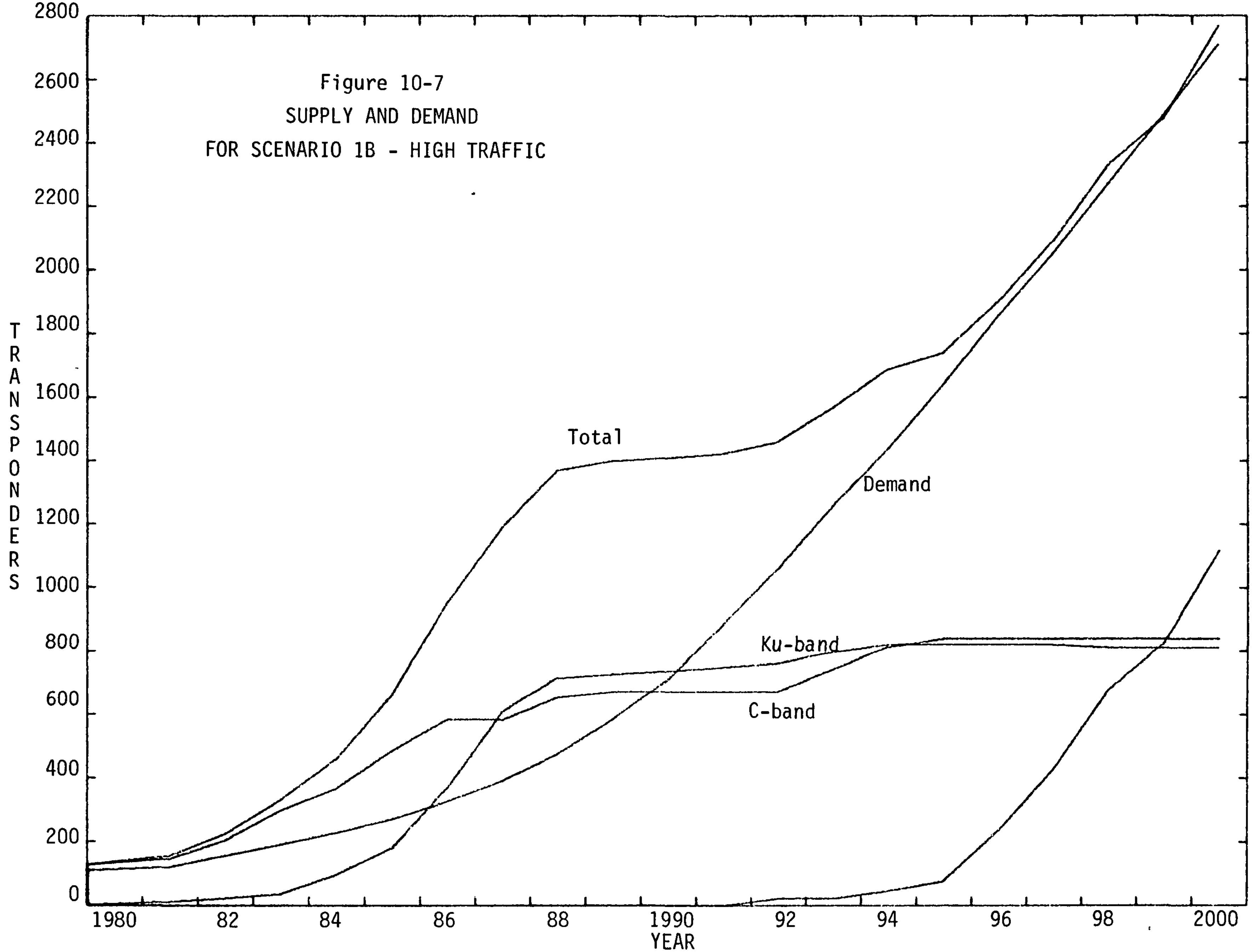
Figure 10-7
SUPPLY AND DEMAND
FOR SCENARIO 1B - HIGH TRAFFIC
Total
Demand
Ku-band
C-band
TRANSPONDERS
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
1980
82
84
86
88
1990
92
94
96
98
2000
YEAR

Table 10-19

SUMMARY FOR
CASE #2B -- TOTAL C-BAND PREFERENCE -- 24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

	FREQUENCY BAND		
	C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	24	24	77
YEAR LAUNCHED:	1986	1989	2000
FIRST MULTIBEAM SATELITE IN:	0	0	1996
GROSS CAPACITY			
1980	128	0	0
1990	720	744	0
2000	840	816	1025
NET CAPACITY			
1980	128	0	0
1990	720	744	0
2000	840	816	931
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	24	24	45

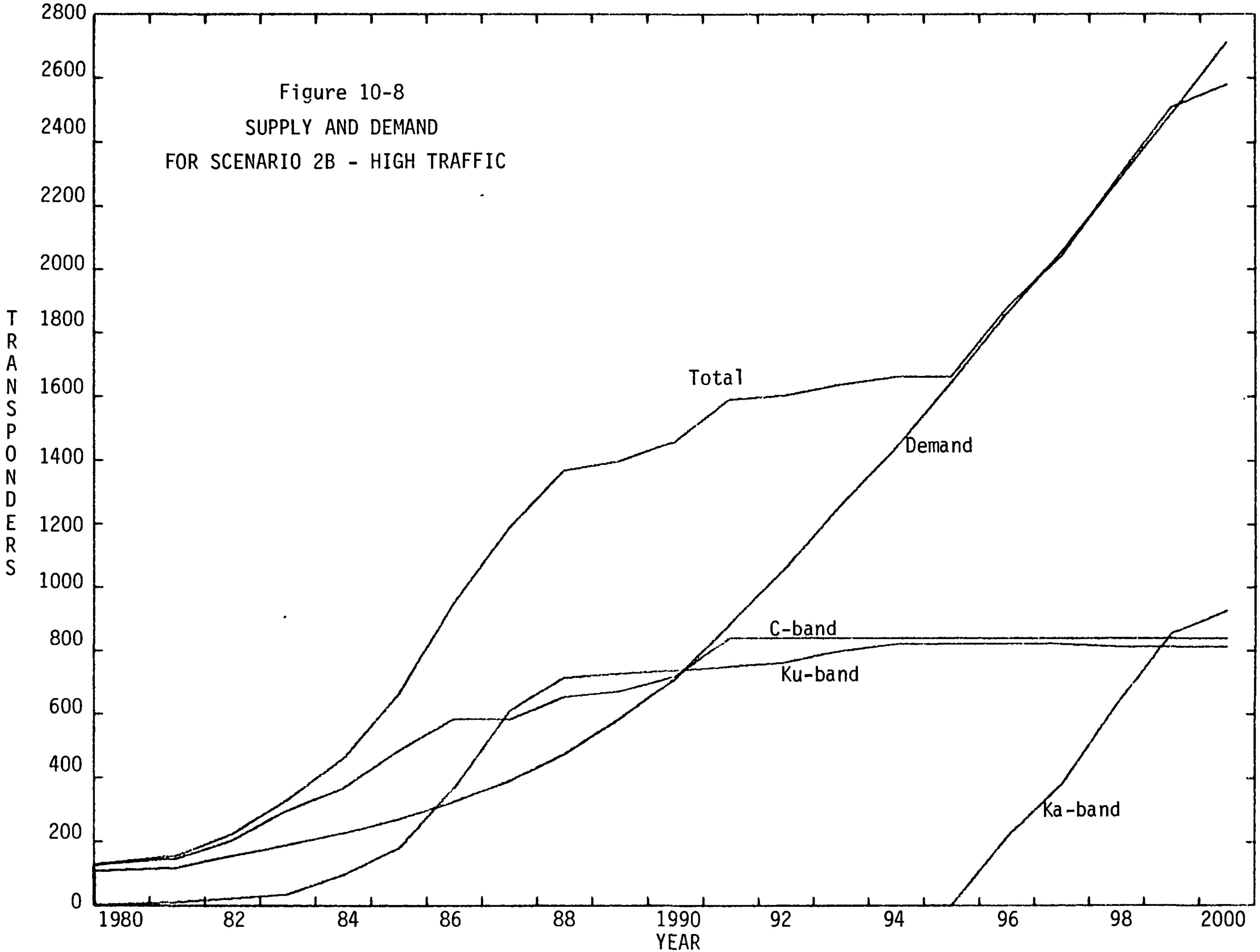

Figure 10-8
SUPPLY AND DEMAND
FOR SCENARIO 2B - HIGH TRAFFIC

Table 10-20

SUMMARY FOR
CASE #3B -- EVEN SPLIT BETWEEN C AND KU BY 2000;
24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND
HIGH TRAFFIC FORECAST

	FREQUENCY BAND		
	C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	24	24	77
YEAR LAUNCHED:	1986	1989	2000
FIRST MULTIBEAM SATELITE IN:	0	0	1996
GROSS CAPACITY			
1980	128	0	0
1990	672	744	0
2000	840	816	1025
NET CAPACITY			
1980	128	0	0
1990	672	744	0
2000	840	816	931
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	24	24	45

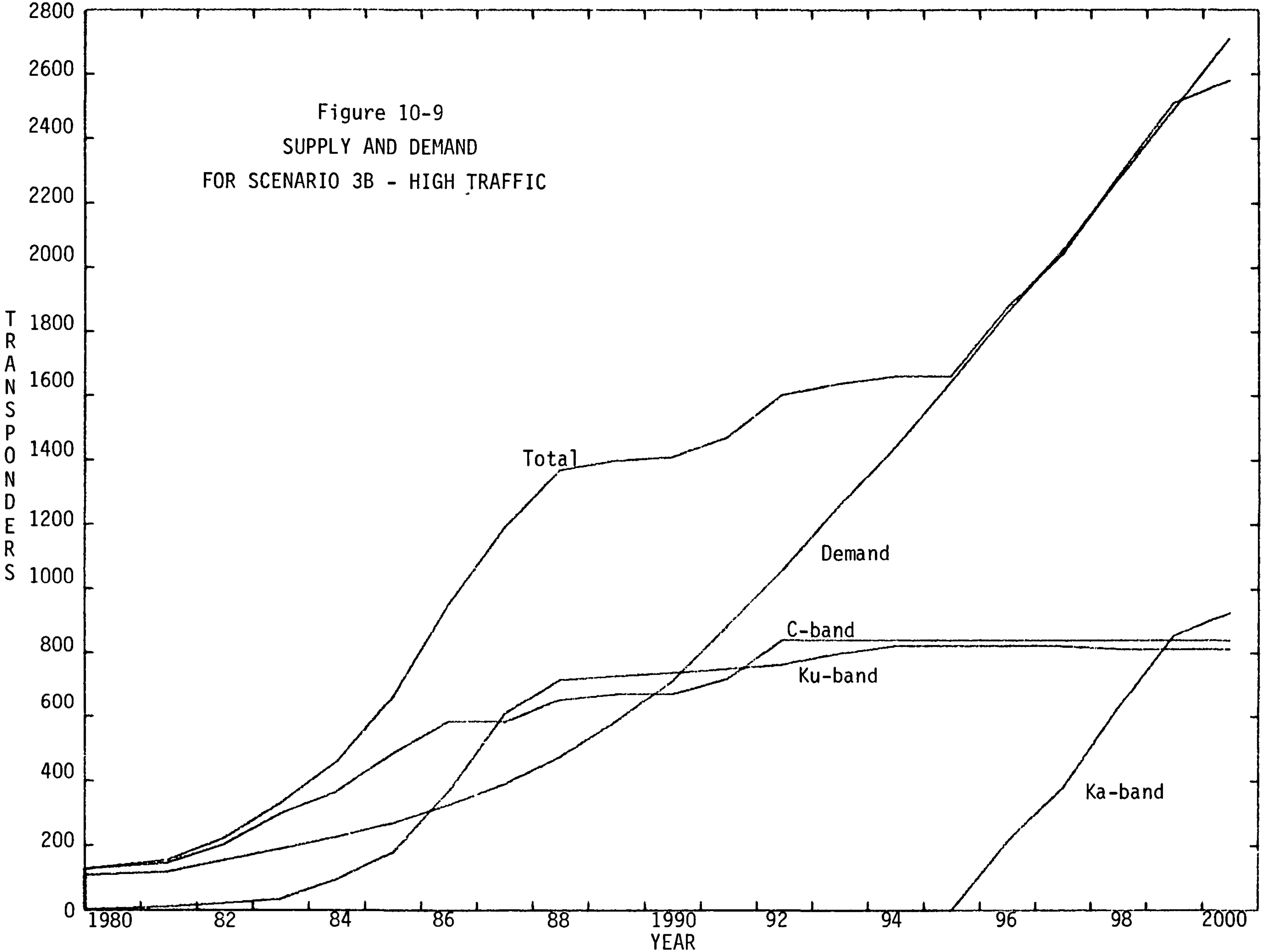

Figure 10-9
SUPPLY AND DEMAND
FOR SCENARIO 3B - HIGH TRAFFIC

SUMMARY FOR
CASE #1C -- SOME DEMAND FOR EACH BAND -- 24 TRANSPONDER LIMIT AT C-BAND
36 NET TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

	FREQUENCY BAND		
	C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	24	45*	86
YEAR LAUNCHED:	1986	1995	1998
FIRST MULTIBEAM SATELITE IN:	0	1995	1992
GROSS CAPACITY			
1980	128	0	0
1990	672	744	0
2000	840	1233	908
NET CAPACITY			
1980	128	0	0
1990	672	744	0
2000	840	1075	849
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	24	36	65

* -- GROSS CAPACITY (SEE SECTION 9)

Table 10-21

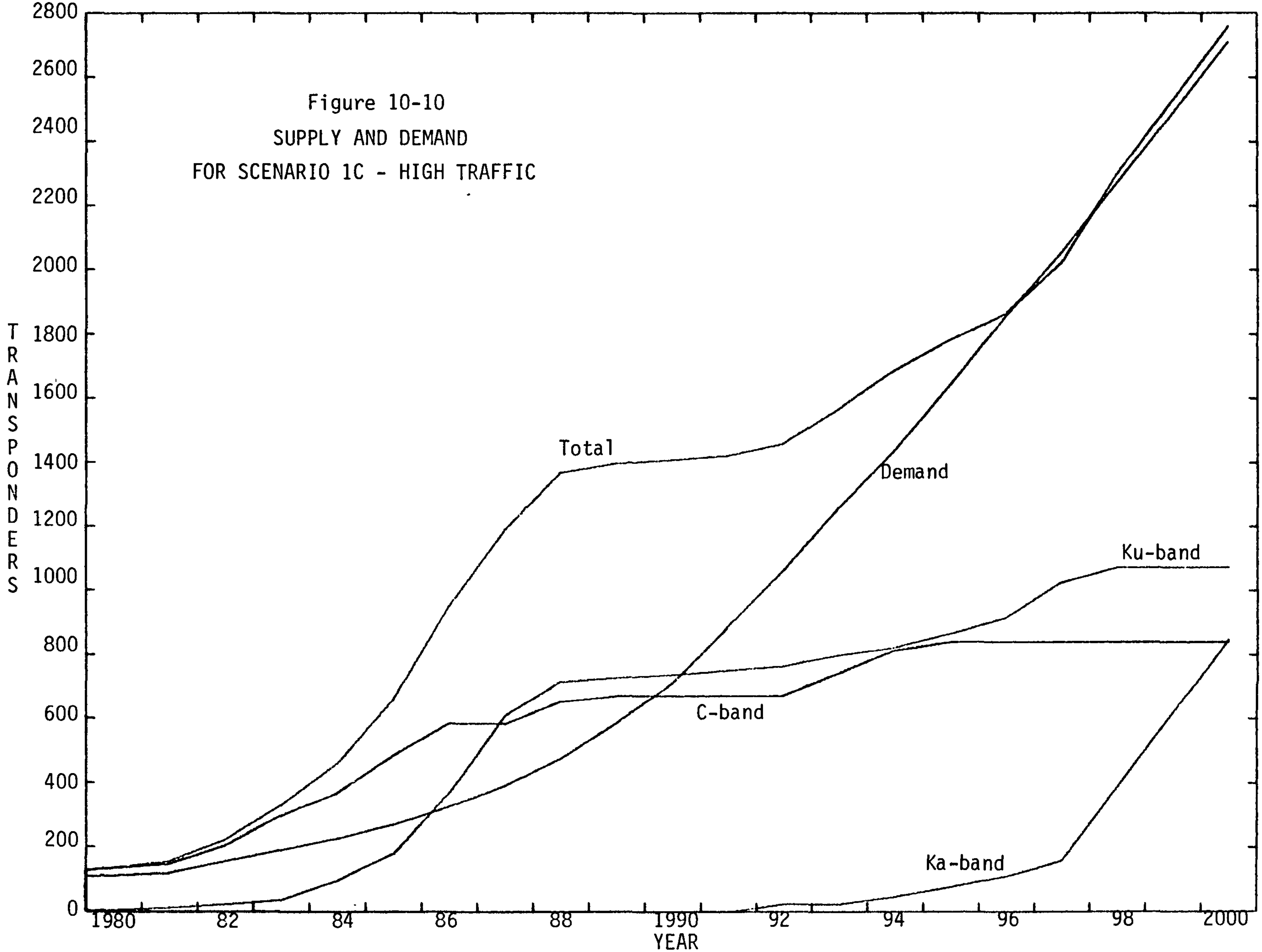
Figure 10-10
SUPPLY AND DEMAND
FOR SCENARIO 1C - HIGH TRAFFIC

SUMMARY FOR
CASE #2C -- TOTAL C-BAND PREFERENCE -- 24 TRANSPONDER LIMIT AT C-BAND
36 NET TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

	FREQUENCY BAND		
	C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	24	45*	59
YEAR LAUNCHED:	1986	1994	2000
FIRST MULTIBEAM SATELITE IN:	0	1994	1996
GROSS CAPACITY			
1980	128	0	0
1990	720	744	0
2000	840	1260	890
NET CAPACITY			
1980	128	0	0
1990	720	744	0
2000	840	1099	801
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	24	37	40

* -- GROSS CAPACITY (SEE SECTION 9)

Table 10-22

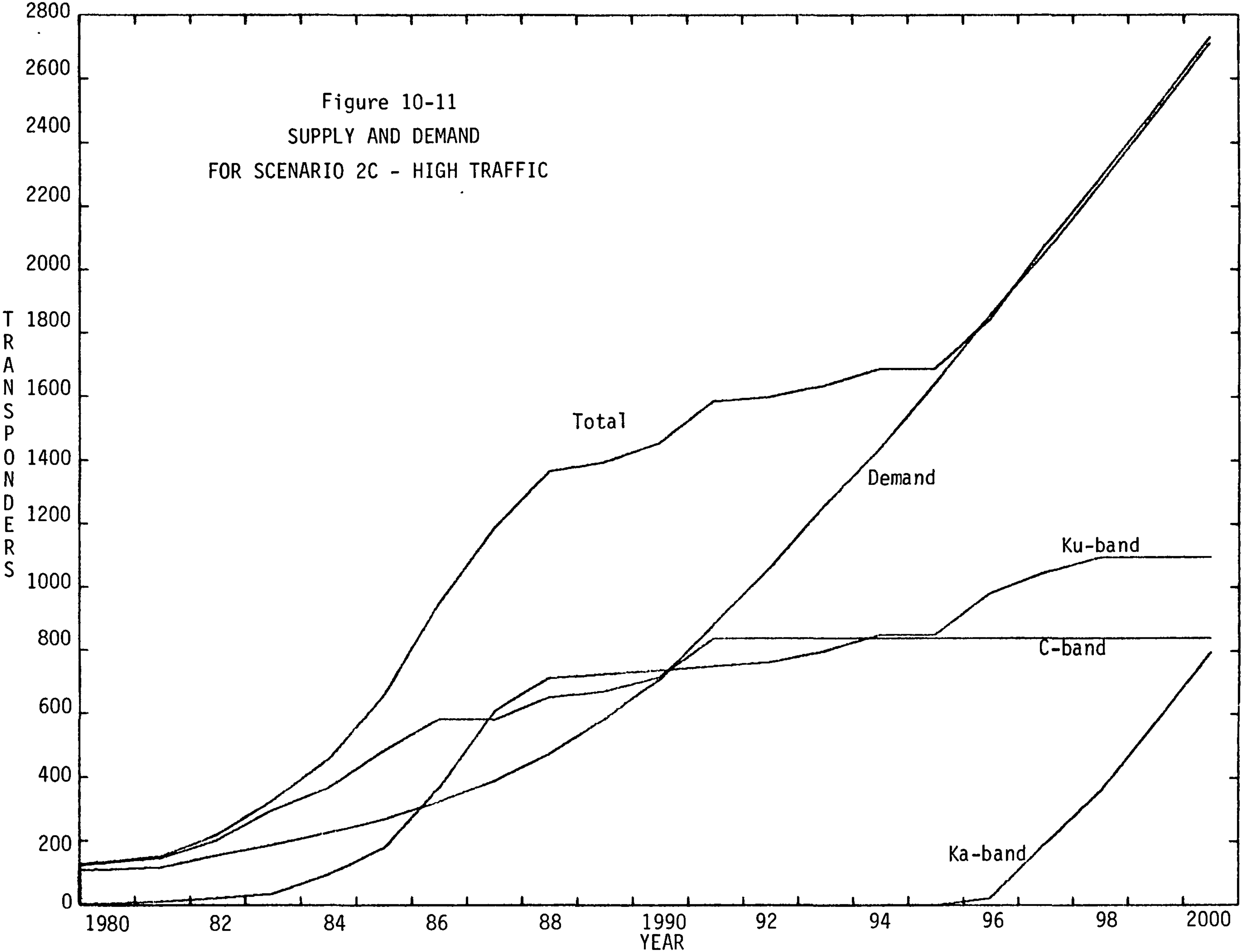

Figure 10-11
SUPPLY AND DEMAND
FOR SCENARIO 2C - HIGH TRAFFIC

SUMMARY FOR
CASE #3C -- EVEN SPLIT BETWEEN C AND KU BY 2000;
24 TRANSPONDER LIMIT AT C-BAND
36 NET TRANSPONDER LIMIT AT KU-BAND
HIGH TRAFFIC FORECAST

	FREQUENCY BAND		
	C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	24	45*	53
YEAR LAUNCHED:	1986	1993	2000
FIRST MULTIBEAM SATELITE IN:	0	1993	1997
GROSS CAPACITY			
1980	128	0	0
1990	672	744	0
2000	840	1337	794
NET CAPACITY			
1980	128	0	0
1990	672	744	0
2000	840	1144	713
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	24	39	40

* -- GROSS CAPACITY (SEE SECTION 9)

Table 10-23

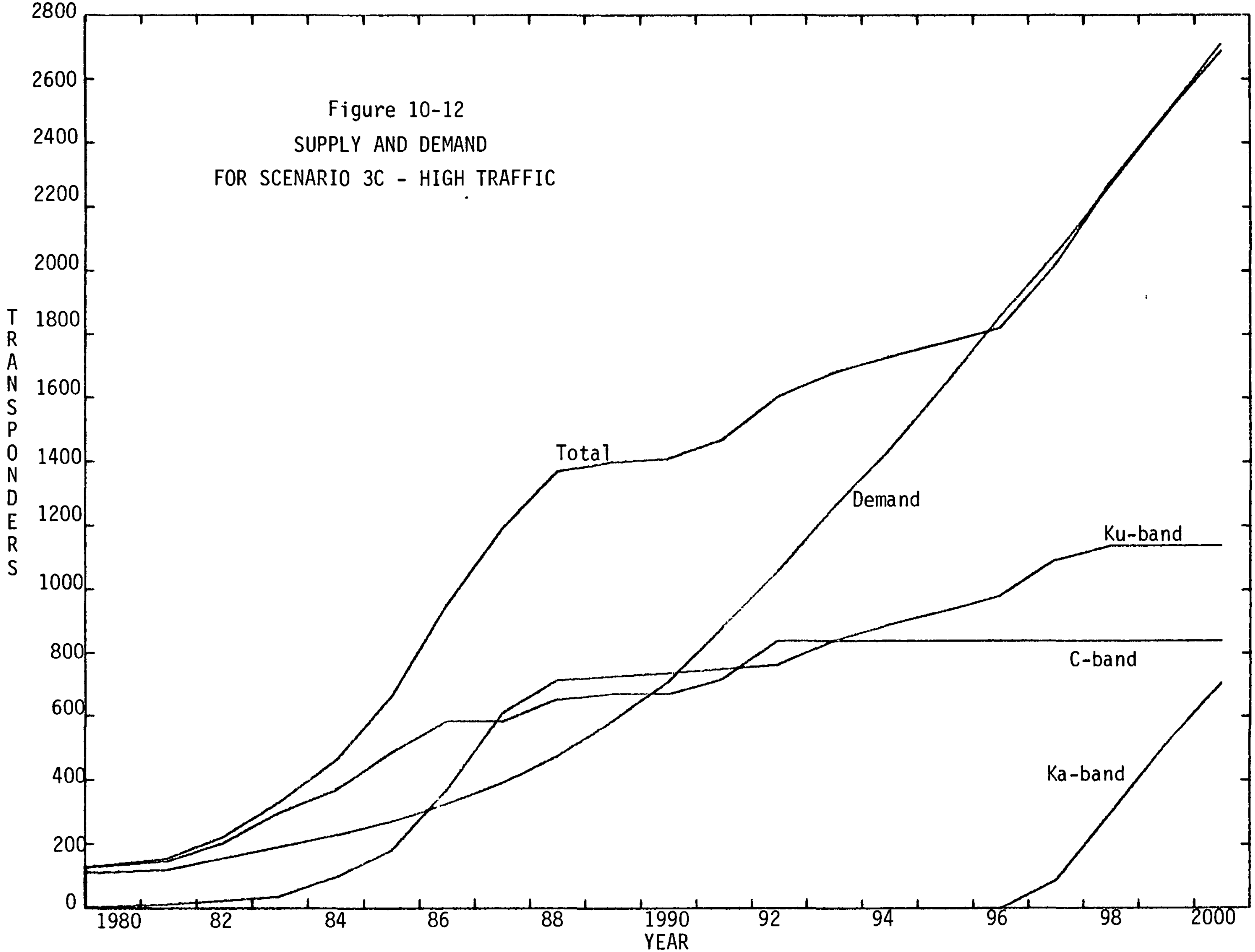

Figure 10-12
SUPPLY AND DEMAND
FOR SCENARIO 3C - HIGH TRAFFIC

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birds. However, early next year, the Spacenet satellites will be launched with 36 transponders each, an increase of 50 percent over 24. In 1988 or 1989, assuming that they are approved, the Ford satellites will be launched with 54 transponders each, an increase of 50 percent over 36. While this works out to an increase of about 75 percent in seven years, the 50 percent increase in the model is for a single-band satellite, while these increases (for actual or proposed spacecraft) include hybrid designs.

The single most significant conclusion to be drawn from these models is that something like 90 percent of the demand in both high and low traffic cases could be filled at C-band and Ku-band, provided that the necessary frequency-reuse technology is available. Since the application of 30/20 GHz seems to require roughly the same measure of frequency-reuse technology, this particular advance can be said to be absolutely necessary, whether or not it is used at C-band and Ku-band.

If 30/20 GHz proves technically obdurate, or commercially unacceptable, the frequency-reuse demands on the lower bands will be considerable in the High traffic case. In Scenario 3, which postulates no independent demand for 30/20 GHz, that band is unused in the Low traffic case, with an average capacity per slot of less than 40 transponders at C-band and Ku-band. In the High traffic cases, 30/20 GHz is unused until 1998, and the average capacity per slot is only slightly higher than in the Low traffic runs. However, in both scenarios, multiple frequency reuse is needed at the lower bands in the early 1990s. This clearly targets the multiple reuse technology as most significant. Taking into account that TV distribution comprises at most about one-third of the total after the introduction of multi-beam satellites, and less than 15 percent by the year 2000, we conclude that less than 25 percent of the total capacity will need to be CONUS or time-zone coverage. With an average capacity per slot of 40 transponders, the 75 percent of capacity subject to reuse averages less than 48 transponders per slot. This requires about 27 beams. If we consider the peak satellite sizes postulated by the model, the level of reuse is about twelve times (over and above the reuse by dual polarization). This is still feasible, but would be difficult to construct, requiring 36 beams.

10.6 Transition to New Technology

Technology improvements in communications systems have proceeded along several lines. The quality of service and transmission has been improved in fairly straightforward ways. Considerable emphasis has also been put on digitization of switching exchange and progress toward an Integrated digital system, capable of handling voice and data equally well. Increases in the efficiency with which facilities such as transmission trunks are used have also been pursued, leading to lower costs.

However, acting against these trends has been the desire to allow servicable equipment to remain in service as long as possible, in order that the cost be spread over as much time as possible. Thus, significant economies have to be available from the new technology in order for it to displace existing equipment with any rapidity. Additionally, there is the question of compatibility with existing systems, which affects the design as well as the schedule of installation.

One current example of a large system which is in transition to different equipment is INTELSAT, now in the process of procuring and installing TDMA equipment for use with INTELSAT V. With such a radical change of operations, a great deal of planning is needed to accommodate the various traffic routes. The heavier traffic routes are to be converted first, followed eventually by the lighter routes. This ensures that the TDMA equipment will be used economically almost from the start.

In the case of a centrally-organized network like INTELSAT, the conversion to more efficient transmission means can be carried out in an orderly, if lengthy, manner. For the numerous users of U.S. domestic satellites, however, any such transitions will be considerably less deterministic. Transitions are most likely to occur when existing equipment has depreciated significantly; when substantial network growth is planned; or whenever useful cost savings can result even though equipment must be written off earlier than otherwise. Since in most cases, there is no centralized organizing force, nor standardization to enable various private networks to communicate directly, these changes will be a matter of individual policy and timing.

The use of advanced technology, including both additional spacecraft complexity and new frequency bands, is prompted by pressures and capabilities. Some of the pressures are: shortage of orbital locations, increasing customer demand, inability to frequency-coordinate with new earth stations, and cost competition from other transmission media. Capabilities primarily include the ability to launch larger (more powerful, more complex) spacecraft and the availability of hardware to operate at new frequencies. On rare occasions, additional frequency spectrum is allocated by the ITU, adding to the capabilities.

A system operator who works according to the economic principle of profit maximization would strive to satisfy as much demand as possible. So long as individual satellites of relatively low capacity are used, there is little economy of scale in satellite systems. What is available comes as a result of buying a number of satellites of the same design, consolidation of spacecraft operations, and maintaining as high a fill as possible. There is no assurance that the system owners operate this way. In fact, instances can be found, such as RCA's second "auction" in which the market demand was ignored somewhat in setting a price. However, in general it is probably safe to assume that the operators will try to fill any perceived demand, as long as the technology is available at fairly low risk and at a cost comparable with competing media so as to allow a reasonable profit.

10.7 Regulatory Considerations

Reduced Spacing

The congestion of the geostationary arc above the U.S., predicted several years ago, prompted the FCC to investigate the feasibility of reducing the spacing between satellites. This investigation, Docket 81-704, resulted in a number of comments from the satellite systems operators, manufacturers, and other interested parties. The positions taken by these participants are summarized in Table 10-24.

Even though the decision to reduce spacing has been made, there are still valid concerns about the effects on system operation and introduction of innovations. These are as follows:

Table 10-24

Positions of Various Parties on 2° Spacing

	Support of FCC Proposal Yes	No	Recommendations
Mutual Broadcasting (MBS)		X	Time-Phased Orbital Spacing Policy
AT&T		X	2.5° Spacing
Western Union		X	(a) 3° Evolving to 2°
			(b) Formation of Industry Committee
Southern Pacific Communications		X	(a) 3° Preferred Evolving to 2°
			(b) Variable Spacing Policy
RCA Americom		X	3° Preferred Evolving to 2°
USSSI		X	Supports 3° Spacing
SBS		X	Prefers a Phased & Flexible Basis
Comsat		X	(a) Delay in 2° Spacing Due to Technology Requirements
			(b) Adjustments in Other Parameters Required
GSAT		X	Urged "Figure-of-Merit" Rating of Satellites
Hughes Communications		X	Supported 3° Spacing
American Satellite Co.		X	Supported 2.5° to 3° "Variable Traffic Oriented Spacing
Home Box Office		X	Supported Ku-band Reduction to 2°, but Opposed C-band Reductior to 2°
Times Mirror		X	(a) Delay 2° Implementation
			(b) 2° Satellites should Receive at 4 GHz and Transmit at 6 GHz
Wold Communications		X	Supported 3° Spacing
Westinghouse Broadcasting		X	Supported 3° but Urged Interference Study
Public Service Satellite Consortium (PSSC)	X		Supported 2° but opted for 3° if 2° is Found not Feasible

Table 10-24 (continued)

Positions of Various Parties on 2^{o} Spacing

	Support of FCC Proposal		
	Yes	No	Recommendations
Joint Council of Educational Telecommunications (JCET)	X		Urged Careful Transition and Use of Such Techniques as "Polarization Interleaving"
Wall Street Journal	X		Urged Caution in Evaluating Interference Effects
Alascom		X	Asked for Wider Separation to Prevent Destructive Interference
Satellite Syndicated Systems (SSS)	X		Supported
United Press International (UPI)		X	Opposed C-band Reduction
National Cable TV Association (NCTA)		X	3^{o} Spacing Less Disruptive
California Microwave	?	?	Urged Innovation to Curtail Interference
Scientific-Atlanta		X	3^{o} Spacing Supported with Continued Investigation
M/A-COM	X		Believed 2^{o} Can be Implemented by end of Decade
EIA		X	Supported 3^{o} Spacing
Department of Commerce	X		Supported Fully

Increased Interference — While many systems, especially those employing larger antennas, will still operate in a satisfactory manner, the total interference budget will certainly be increased. This increase will arise from two sources: first, the previously existing satellites that are now closer in angular space, and therefore on average experience higher antenna sidelobe levels, and second, the increased number of interference entries resulting from the increased number of orbital slots. This effect will occur for other satellite systems using the orbit near the U.S. arc as well, and the Canadians have specified greater separations between their satellites and ours. South and Central American systems will also be affected, albeit to a lesser extent because of the geographical distance.

Structure — The decreased separation will require greater structure to the communications satellite constellation in order to limit the increase of interference. This structure may take several forms. First, the FCC has proposed that antennas be made to conform to a more stringent sidelobe gain level, and more stringent cross-polarized response off-axis. Second, they have proposed that the polarization plans of adjacent spacecraft be opposite to one another. Both of these plans result in more structure in place of the operational flexibility that existed before. Existing equipment, both satellites and earth stations, will in some cases be obsolete under such plans.

Effects on Technology and Planning — The tolerance of system for inhomogeneity of power levels and/or certain types of spectra with pronounced peakedness would be reduced under such a plan. While this would have essentially no effect on the introduction of new frequencies such as the 30/20 GHz band (which can tolerate much smaller spacing), the use of multiple spot beams would be difficult. There would be several effects from multiple spots: 1) if the increased antenna gain (of the spots) is used to increase EIRP, G/T and transponder gain, interference to and from the spot-beam system would be increased proportionately; 2) even if no increases in EIRP or gain were employed (G/T could be increased without harm) the spot-beam satellite would increase the number of interference entries experienced by other systems.

These considerations will require careful coordination with other system operators before changes in satellite parameters can be made. The planning process will be more cumbersome and subject to bickering than now. However, the concept of implementing multiple-spot-beam satellites with homogeneous transmission parameters deserves consideration. Although larger earth stations would be needed, such a system could be integrated into the reduced-spacing environment without difficulty, and would provide a useful increase in orbital capacity through frequency re-use.

<u>Efficiency Requirements</u>

One possibility for additional regulatory constraint would be the requirement of a specific degree of spectrum/orbit efficiency for new or replacement satellites. Such a course has been urged on the FCC during the filing process for some recent applicants. These urgings were mostly from other applicants or carriers who, feeling that their particular design was more efficient than the instant applicant's, used the argument in a petition to deny. In spite of this origin, the idea has some merit. Imposition of minimum requirements consistent with the state of the art would help increase the capacity of the arc, and would also help ensure eventual lower costs to users. However, considerable controversy would probably arise over the administration of such a requirement.

Under an efficiency requirement, the specific use to which the satellite was designed would have to be specified beforehand. For example, a satellite intended for TV broadcast to CATV systems could not employ frequency re-use with any effectiveness, by the very nature of its traffic. Unless the application were accounted for, this would result in a poor efficiency evaluation relative to satellites with multiple beams and re-use.

Another factor involves hybrid versus single-band spacecraft. In a sense, the hybrid satellite is more efficient, since it achieves some sharing of the buss. However, this does not result in any spectrum/orbit efficiency relative to single band satellites, and in some circumstances (different spacing at the different bands) can add constraint to the total orbital configuration. The relative weight of such factors is very uncertain.

10.8 Division of Traffic by Frequency Bands

One result of the scenarios is an allocation of the traffic in each year into the various frequency bands. To some extent, this is a function of the preference matrices shown earlier and used to drive the model along with the traffic. However, the preferences are subsidiary to the ability of the system to provide capacity where and when desired. As far as this is concerned, this model makes these assumptions:

1. Traffic that wants to go to C-band but cannot be accommodated can be carried at Ku-band if possible.

2. Traffic that wants to use Ku-band but cannot be accommodated can use excess capacity at C-band if available.

3. If there's no space at C-band or Ku-band the traffic can be carried at 30/20 GHz if it is possible to launch a satellite in that band at that time.

To a great extent, then, the allocations among the bands are a reflection of the possibility of providing capacity in each when necessary.

Tables 10-25 through 10-27 show the year 2000 division of traffic among the bands for the various scenarios.

Table 10-25

Year 2000 Traffic Distribution

Low Traffic

(Transponders)

Scenario 1	TV	Data	Voice	Video-conferencing
C-band	185.9	383.7	151.5	65.8
Ku-band	11.2	290.5	120.3	181.0
Ka-band	0.0	40.8	33.9	40.6
Scenario 2				
C-band	185.2	627.3	191.9	218.3
Ku-band	11.9	87.7	113.8	69.1
Ka-band	0.0	0.0	0.0	0.0
Scenario 3				
C-band	195.5	492.8	197.0	190.1
Ku-band	0.6	222.2	108.7	97.3
Ka-band	0.0	0.0	0.0	0.0

Table 10-26

Year 2000 Traffic Distribution

High Traffic

(Transponders)

Scenario 1	TV	Data	Voice	Video-conferencing
C-band	261.6	442.2	330.4	98.8
Ku-band	33.3	467.9	346.6	168.2
Ka-band	28.6	201.0	256.8	77.7
Scenario 2				
C-band	228.8	580.6	317.3	194.3
Ku-band	59.7	383.6	382.6	107.1
Ka-band	35.2	146.9	233.9	43.1
Scenario 3				
C-band	228.9	508.8	283.9	161.9
Ku-band	59.6	455.2	415.4	139.5
Ka-band	35.2	147.1	234.5	43.2

Table 10-27

Year 2000 Traffic Distribution

High Traffic Modified Scenarios

(Transponders)

Scenario 1-B	TV	Data	Voice	Video-conferencing
C-band	219.8	340.9	191.5	87.7
Ku-band	30.6	405.9	243.5	135.9
Ka-band	73.2	364.3	498.7	120.9
Scenario 2-B				
C-band	188.9	355.1	167.9	128.0
Ku-band	56.5	389.6	261.7	108.3
Ka-band	68.2	330.0	440.0	97.0
Scenario 3-B				
C-band	196.6	358.9	169.8	114.7
Ku-band	48.8	385.8	259.8	121.6
Ka-band	68.2	330.0	440.0	97.0
Scenario 1-C				
C-band	219.8	340.9	191.5	87.7
Ku-band	55.5	501.2	358.2	160.5
Ka-band	48.4	269.0	384.0	96.4
Scenario 2-C				
C-band	188.9	355.1	167.9	128.0
Ku-band	74.6	505.8	381.3	137.0
Ka-band	60.2	250.2	384.5	78.8
Scenario 3-C				
C-band	196.6	358.9	169.8	114.7
Ku-band	71.8	518.2	395.3	158.3
Ka-band	55.3	234.0	368.7	71.6

10.9 Connectivity and the Role of Larger Satellite Platforms

The number of satellites in orbit by the year 2000 could be very large if relatively minimal designs are used, as in these scenarios. For example, in the High traffic runs, as many as 35 C-band, 34 Ku-band, and 7 Ka-band slots are occupied, yet average capacity per location is on the order of 30 to 40 transponders in each band. Even if we assume that all satellites are hybrid designs, each antenna would still access only about three percent of the total capacity. With such a system, connectivity would be a severe problem. It is unlikely that user communities could be segregated in such a way as to solve it. There would be a need for many intersatellite links, and considerable intra-industry structure and standardization even to approach a solution.

The postulated, multi-satellite situation is a natural consequence of the present structure of the U.S. domestic satellite industry. As satellites reach the end of their useful lives, the owner/operators will not forgo the chance to replace each one individually, with the same size or larger spacecraft. In order for satellites of considerably larger size to replace several smaller spacecraft, a significant departure from present behavior is needed. Either several operators would have to pool resources and launch a shared satellite, or an operator who is leasing (or has sold) considerable capacity on several satellites would have to aggregate this capacity on a larger, replacement satellite*.

This, of course, leads to the question of so-called "geoplatforms" and whether they will be used in this study period. Based on the results of the scenarios, and on comments by spacecraft manufacturers, and on the behavior of prospective satellite operators, we would have to say that it depends on your definition of geoplatform. Our reasoning is as follows.

First, the scenarios indicate that the forecasted demand can be satisfied using satellites with fairly modest characteristics, compared with the likely characteristics of geoplatforms. Even with combinations of the frequency bands into two or three band hybrids, the largest spacecraft launched under the

*Note that in the case of Hughes Communications, this would almost certainly be a "cluster satellite", since they hold the patent on the concept, and Hughes president Wheelon has stated that "We'll never build a bigger satellite than INTELSAT VI."

scenarios would be about 5000 kg at BOL, assuming that on-board switching provided fairly complete connectivity. This is probably a reasonable maximum single-Shuttle satellite, using a modified Centaur as the LEO to GEO vehicle. Deployables of significant complexity would be needed to fit such a satellite into the bay. This spacecraft could be said to be a geoplatform, although a firm definition might be based on other characteristics than size alone. However, it is probably at the lower limit of platform size.

Second, there are real incentives to the spacecraft manufacturers to develop and construct busses of more modest size. First, the smaller bus will be able to accommodate the payloads of more different customers, many of whom will have modest requirements and only few of whom will have larger needs. In addition, the manufacturer can spread the development cost over more customers, with the total being more than any one or few customers would pay. This commonality can be seen at work the widespread acceptance of the RCA SATCOM bus, and the Hughes HS-376 bus. In contrast, Ford and TRW, with much larger busses (from INTELSAT V and TDRS) have been unable to attract much interest. With current launch vehicles, the price differential between the smaller and larger busses is also a factor.

Third, current satellite planners are focussed on serving relatively small user communities, for which connectivity is no problem. Since, compared with terrestrial point-to-point communications, satellites are still in their infancy, the need for widespread connectivity has not arisen. Present and prospective users are still concentrating on the problems of getting their own specific communications requirements filled, and it will be some time before there is a need for widespread interconnection between user systems.

Lastly, it is likely that, considering antenna structures needed for multi-beam formation at C-band, most of the multiple-beam capacity will be provided at Ku-band or 30/20 GHz. Except for the power supply requirements, no large structure would be needed at these bands.

The year 2000 seems to be right on the threshold of requiring really large satellites. Assuming that traffic growth continues at or near the same pace, the year 2010 would certainly see geoplatforms in orbit.

SECTION 11
EARTH STATION FORECASTS

Earth station configuration changes must accommodate existing hardware as much as possible. To some extent, this can be done through user segregation. For example, specialized TV distribution satellites make a great deal of sense. The value of a particular spacecraft to both programmers and cable system operators depends in large part on the number of TV signals accessible on that satellite. Therefore it makes sense to provide satellites with a larger number of narrower transponders, and without point-to-point users on it to "waste" (from the TV viewpoint) any transponders.

Some modulation/access methods that will be coming into use in the next few years will be handled best if they can be segregated. AT&T and other long-haul carriers will be using Companded Single Sideband (CSSB) extensively, beginning soon. From the satellite system viewpoint, this is a step backwards, since it requires the use of large and expensive earth stations. However, it has the advantage of providing very high capacity (since the baseband itself is transmitted) and with proper frequency and power control, has extensive multiple-access potential. However, satellites used with such systems require low sensitivity (transponder gain) so that uplink noise contributions can be minimized. The resulting high earth station EIRP is a potential source of interference into spot-beam satellites, which will have much greater sensitivity on the uplink. This, along with the use of the large earth station antennas, suggests that satellites accessed by such methods can be segregated into a portion of the arc. These satellites could be spaced close together, since the large antennas will alleviate interference difficulties (in a homogeneous system) even with relatively small intersatellite spacing.

The growth of the earth station population is roughly proportional to the traffic, varying according to the kind of traffic (i.e. — CPS or trunking or TV, etc.). The number of earth stations per transponder of traffic has historically been an increasing function with time, and we expect this to continue within reasonable limits. For TVRO or very thin route stations, the practical limits are quite high or non-existant. However, for stations which carry a significant amount of traffic and require access to one or more transponders on a continuous basis, there are fairly low limits. The frame period limits the number of accesses in a TDMA system, since reasonable efficiency must be maintained. FDM/FM/FDMA systems are unlikely to play a significant role in the future; accesses here are limited since the carrier sizes must be pre-assigned if a reasonable level of system control is desired, and rapid re-configuration presents problems. CSSB systems allow a large degree of multiple access, but the earth stations are large and expensive.

The earth station size mix will also vary according to traffic category. This is partly an economic decision, since a smaller earth station of less complexity and lower price will be needed to make lighter traffic economical to carry. However, the consideration of physical placement is very important for CPS services. This is especially so at Ku-band and 30/20 GHz, since these stations will be located in metropolitan areas (as well as elsewhere) and hence must be as unobtrusive as possible.

11.1 Earth Station Sizes

In order to reduce things to manageable proportions, we have selected a number of "typical" earth station configurations for use in our calculations. These are shown in Table 11-1. The traffic is divided up into categories appropriate to these earth stations by means of 1) the CPS/non-CPS divisions provided by ITT and Western Union in their initial traffic forecasts, and 2) the segregation into frequency bands that was an outcome of the model scenarios. This traffic, so divided, is then used to determine the number of earth stations as described in the next subsection.

11.2 Correlation Between Traffic and Earth Station Population

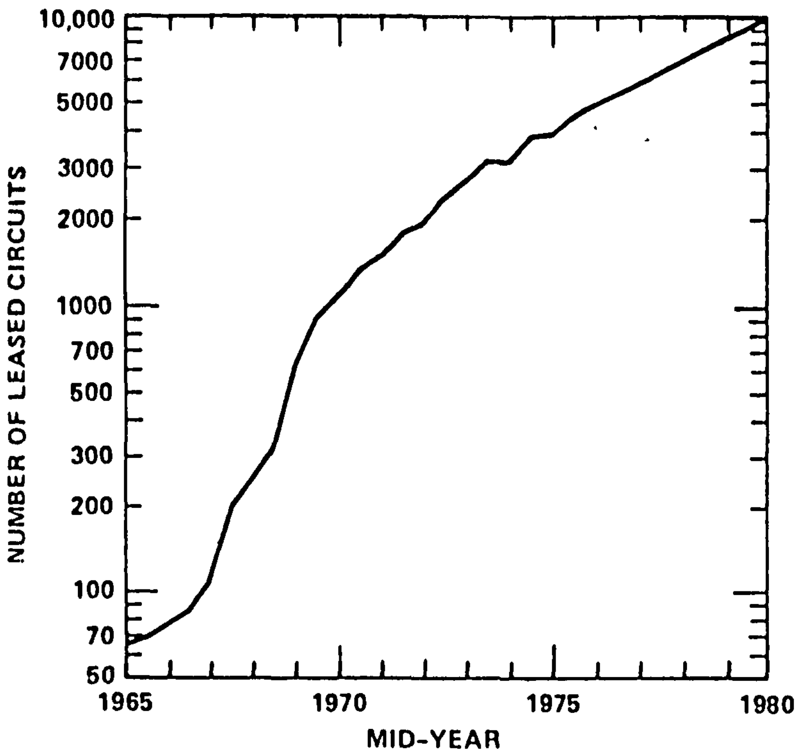
Traffic growth arises in two ways: first, new users come on line, bringing their traffic to the system, and second, the traffic of existing users increases with time. We are most interested in the first category, since the new users will in most cases require new earth stations, and we are interested in predicting the earth station population. In order to extract this component of growth, we must estimate the magnitude of the second component.

Table 11-1

Typical Earth Stations

Type	Carrier Trunking	High-Quality TVRO	Small TVRO	Shared Business	CPS Business
Antenna diameter (m)					
at C-band	11 - 30	7	5	7 - 11	4.5 - 7
at Ku-band	7 - 12	5	2	3.5 - 8	3 - 5
at 30/20 GHz	7 - 12	NA	1	3 - 7	1 - 3
Approx. Capacity	1000 - 10000 Circuits (Analog) or 12 - 60 Mbps	3 - 5 TV	1 - 3 TV	2 - 12 Mbps	0.3 - 6 Mbps

For starters, we can look at the oldest satellite communications system around, INTELSAT. Traffic in the Atlantic region of INTELSAT has been growing at a more-or-less steady pace for some years now, and can probably be considered to be in a mature state. Figures 11-1 and 11-2 show some points of interest here. In Figure 11-1, we see that intially there was a period corresponding to the classical "S" curve growth pattern, slow initial growth, followed by very rapid growth, followed in turn by a longer period of stable growth at a modest rate. Figure 11-2 compares the growth of traffic with the growth in earth stations, showing that the former is greater after about 1977, and that most of the traffic growth is just that, with relatively little contribution from added earth stations. These data indicate that the mature growth rate is about 13 percent per year.



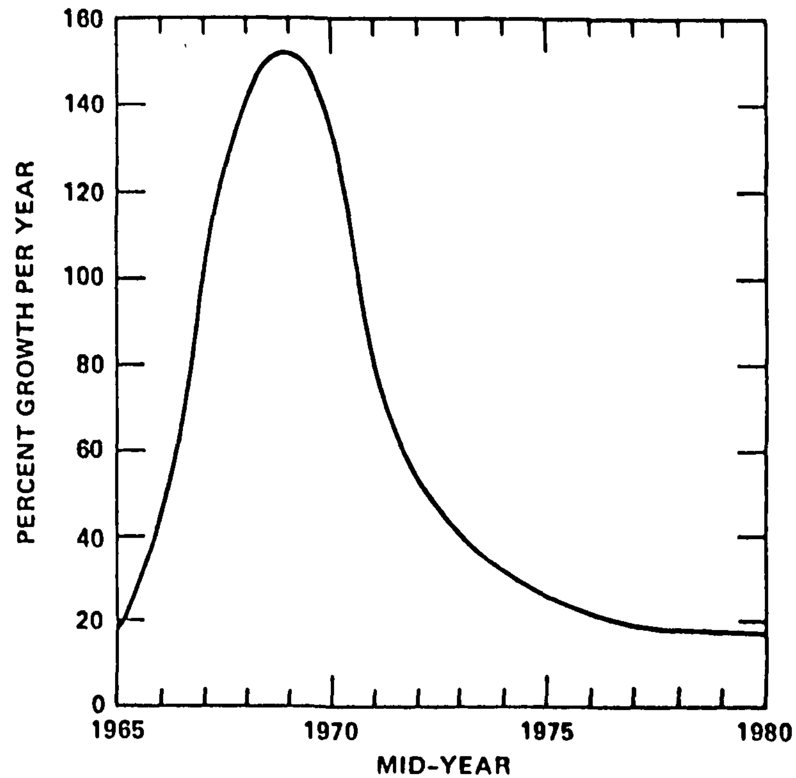


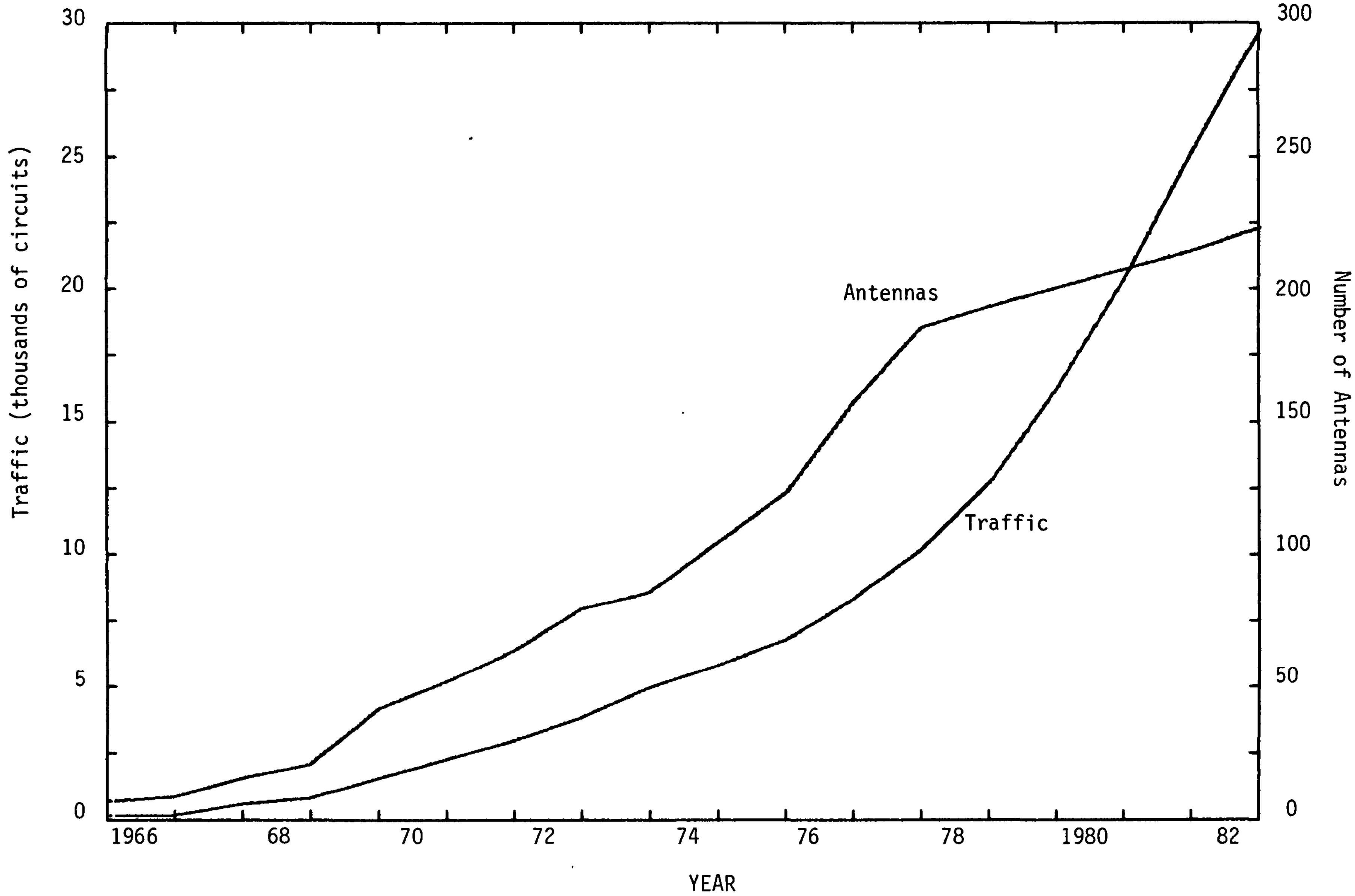
Figure 11-1

DYNAMICS OF SYSTEMS GROWTH
FOR INTELSAT ATLANTIC OCEAN TRAFFIC

PERCENT GROWTH RATE PER YEAR
FOR INTELSAT ATLANTIC OCEAN TRAFFIC

Figure 11-2

GROWTH OF TRAFFIC AND EARTH
STATION ANTENNAS IN INTELSAT



Other indications are found in the mature growth rates for telephony traffic. In the U.S., total long-haul traffic is growing at a rate of about 10 to 12 percent per year. The number of phones in service is growing at a rate of about five percent per year. This indicates a rate of growth per phone of about 4.5 to 6.5 percent per year. While this is considerably lower than the rate shown by INTELSAT, the system in the U.S. is in a more mature state than international satellite telephone traffic now is.

Since even growth through existing facilities involves additional investments for equipment, we can be conservative and estimate that traffic through such facilities grows at a rate of about 5.5 percent per year for voice, and about 10 percent per year for new services such as data and videoconferencing. If the total growth rate of the service falls below twice these rates, then the existing-facilities growth rate will be assumed to account for half the growth (that is, will be the square root of the total growth factor).

TV Distribution

This analysis falls apart if applied to TV distribution receive-only earth stations, since there is no clear relationship between the number of RO stations and the number of transponders carrying traffic. The situation is further complicated by the fact that some programs are distributed free (TV evangelists etc.), and that the number of channels that an RO can receive simultaneously is unrelated to the number that can be accessed individually. While there is probably good temporal correlation between the number of satellite video channels and the number of ROs in service, we suggest that the casual relationship is tenuous at best. Once several high-quality program channels were available, such as HBO and Showtime and the like, the attractiveness of satellite TV was probably increased only slightly by each doubling of the number of channels.

In addition, there are a great many privately-owned RO stations, and their number is growing rapidly. In a recent FCC filing, SPACE (Society for Private and Commercial Earth Stations) estimates that there are now 300,000 stations in operation, and that monthly shipments exceed 20,000!! Clearly, most of these are very-low-cost TVROs for home use. In contrast, the 1983 Satellite

Directory lists approximately 7400 licensed receive-only stations. In consequence, our estimates of the TVRO earth station installations will be based primarily on population, rather than on the number of transponders or video channels in service.

Estimated Correlation Factors

In Figure 11-3, you can see that the earth station/transponder ratio is considerably lower for those networks that service trunking type traffic primarily. Systems which address a more direct-to-user market, such as SBS and American Satellite, operate many more stations per transponder at a much lower average capacity per station.

In Section 2, we estimated an average of 1,000 circuits per station for an intertoll carrier, using a mix of satellite and terrestrial transmission. If we apply this value (assuming that it is constant with time for the moment) to the composite non-CPS transponder capacities, we get a ratio of 1.5 earth stations per transponder in 1980, 3.9 in 1990, and 5.8 in the year 2000. The increase is clearly a strong function of the dramatic improvement in transponder capacity during the period. By contrast, the transponder capacity in the INTELSAT system has remained fairly constant (on average) for the period covered in Figure 11-3.

Even though the various traffic types can be expected to occupy transmission capacity in somewhat different ways, any network must provide a reasonable set of access procedures so that users can communicate with one another. The presence of earth stations carrying more than one kind of traffic (which will be more common than not) and shared-user stations implies that an overall correlation factor is needed, which includes all traffic (excepting TV distribution, which is quite separate). Therefore, we will only differentiate between trunking and CPS categories for point-to-point traffic. These factors are developed as shown below.

CPS Traffic

As noted in the sections treating Task 1, we have postulated that CPS transponders will be accessed in such a manner as to reduce the cost of the earth station as feasible. Our assumptions about this result in a capacity per 36 MHz transponder of 24.7 Mbps, with improvements in transponder linearity, EIRP, etc. being used to enable cheaper earth stations, rather than increased capacity.

If we examine the ITT data concerning the total addressable CPS earth station population, as shown in Table 11-2, and equate this with the total addressable CPS satellite traffic, also shown, we can compute an approximate number of earth stations per transponder. This is shown in the last line of the table, based on a 24.7 Mbps transponder capacity. Since the traffic is shown as growing much faster than the earth station population, the ratio drops significantly. While this is a reasonable pattern of behavior, we think that the ratio and number of earth stations postulated is much too low for a CPS network.

Table 11-2
Calculations Based on ITT Data

	1980	1990	2000
CPS-Addressable Traffic (Mbps)	1,490	13,990	63,190
CPS-Addressable Traffic (transponders)	60	566	2,558
CPS Earth Station Addressable Market	0	3,934	4,239
Earth Stations per Transponder	0	6.9	1.7

Figure 11-4 shows our estimate of the ratio of CPS-type earth stations to transponders carrying such traffic. Dedicated and shared earth stations of very large users would probably not be included in the CPS portion, since their aggregated traffic would be larger. Such users would be able to access the satellites using relatively more expensive access techniques and earth stations, therefore, transponder capacity would be higher in such instances.

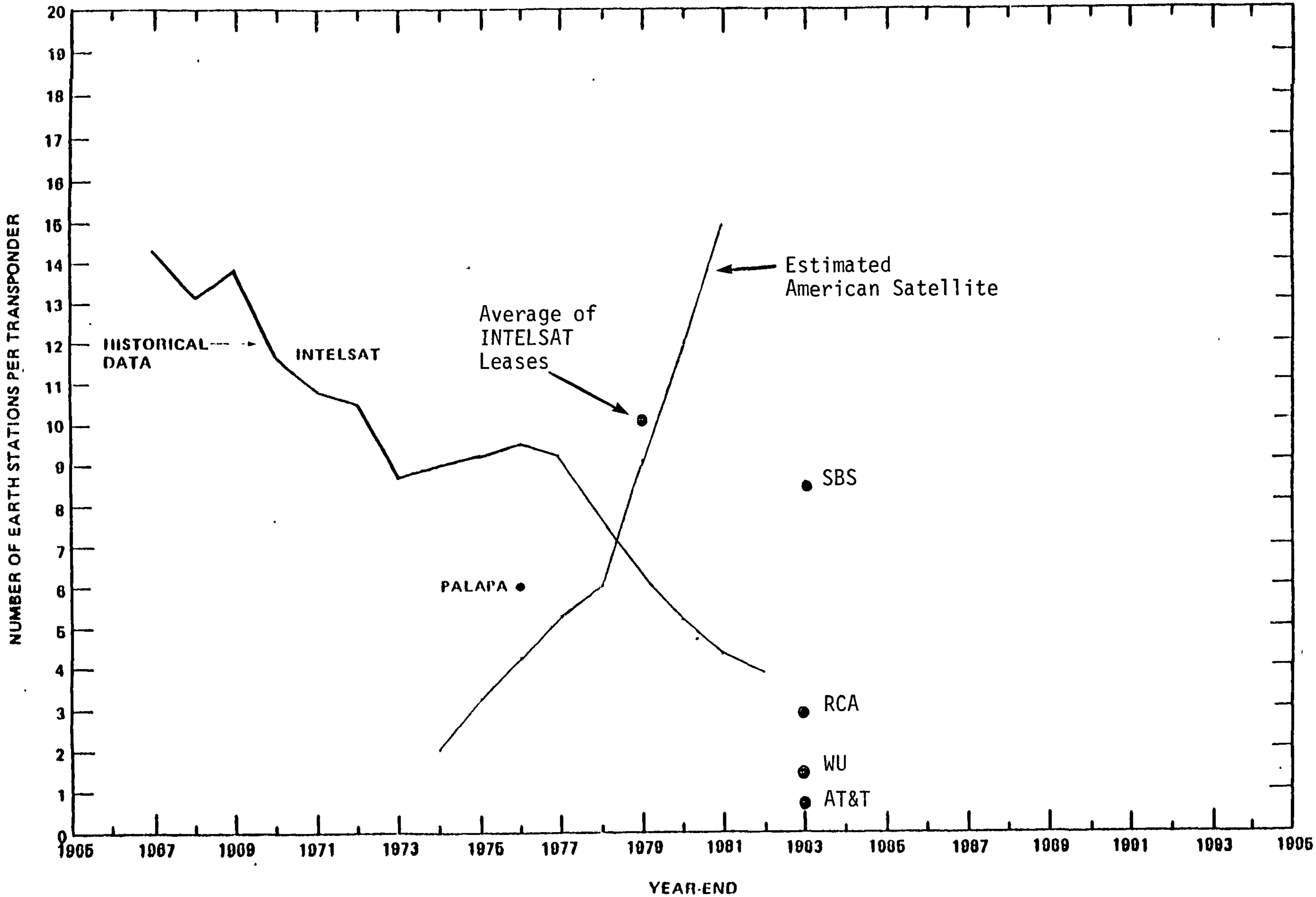


Figure 11-3

NUMBER OF EARTH STATIONS PER TRANSPONDER VERSUS TIME

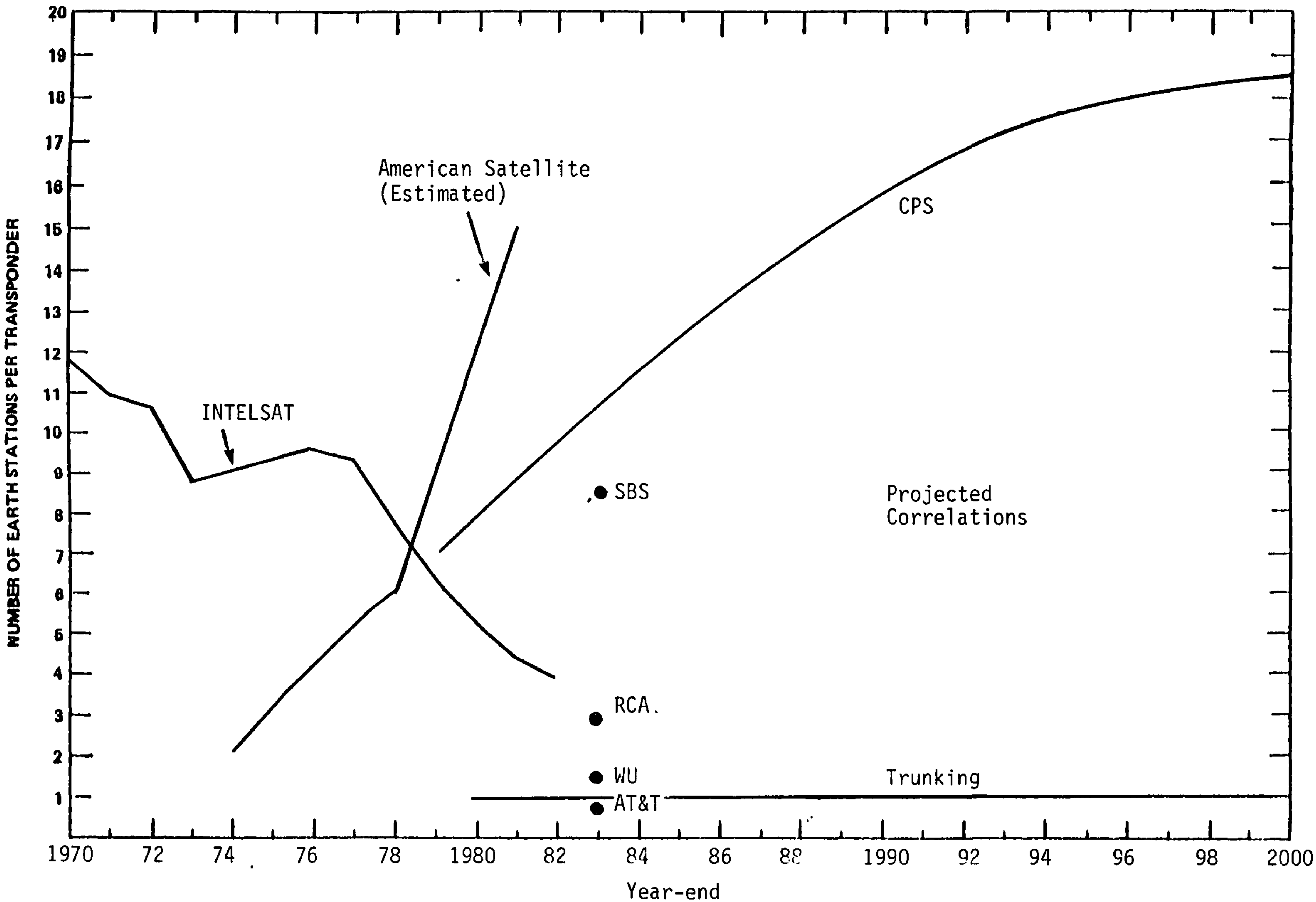


Figure 11-4
NUMBER OF EARTH STATIONS
PER TRANSPONDER VERSUS TIME

Trunking Traffic Stations

Because the earth station costs are averaged over a very large number of users, trunking systems can afford to install more costly equipment so as to get the most capacity per transponder. Such a system will probably undergo a number of transitions between various configurations, with the trend being toward more efficient use of the space segment.

Since the number of major service points is likely to be limited, eventually the network will have expanded to cover virtually all of them. At this point, the ratio of earth stations to transponders in use will begin to stabilize or decline slowly as the traffic increases. This is complicated in the U.S. by the presence of competing long-haul carriers, whose facilities will duplicate one another to some (undefined) extent. This results in the overall environment having a larger number of earth stations while the traffic base, which is controlled by the end users, remains more or less the same. However, because of the well-developed terrestrial system, and future networks using fiber optics for data transmission, the overall ratio for trunking will still fall to a low level, because the number of service points will be low.

The correlation factor for trunking stations is also included in Figure 11-4, shown previously.

TV Distribution

Amazingly, there seems to be an enormous market for TVRO stations, much larger than we thought even as recently as 1979. There is now about one licensed TVRO, generally of 4.6 meter diameter or larger, for each inhabited "place" of 2,500 persons or more (this is a Census Bureau subdivision). Of course, they are not so evenly distributed. Generally, we can conclude that the licensed TVROs serve cable systems, larger hotels, and other users who derive revenue from the programs and desire interference protection. This amounts to about 7,400 stations. The limiting number of licensed TVRO stations is likely to be much larger. According to the U.S. Industrial Outlook, there are over 50,000 hotels, motels, and similar establishments. About 70 percent of these have payrolls (that is, are more than a Mom & Pop operation). This puts the potential number of licensed TVROs at greater than 35,000. However, there is no conclusive way of knowing what fraction of this potential market would buy stations, nor how many have already purchased an unlicensed station.

Estimating the number of unlicensed stations is of course even more speculative. In theory, the number could be as large as 10 to 20 million, but is unlikely to reach that level for a number of reasons. However, if DBS and quasi-DBS systems are included, the number of installations could easily achieve the 10 to 20 million level, mainly because the stations are projected to be very expensive.

As noted above, SPACE has estimated that there are 300,000 earth stations in service in the U.S. right now. The vast majority are relatively inexpensive, unlicensed TVROs. They further estimate that shipments are running about 20,000 per month. If we assume that volume remains at this level, by 1990 there would be approximately 2 million RO stations in service.

By that time, however, DBS systems may have made significant inroads on the "conventional" TVRO market for home use. If that is the case, we would expect to see a reduction in the number of C-band TVROs being sold, with a corresponding diversion of the market into FSS Ku-band and DBS stations. Such a diversion would be hastened by the advent of 2 degree spacing at C-band, which should be complete before 1990, since this would drive up the cost of C-band TVROs because of improved performance requirements. Therefore, by 1990 we would expect that sales would have declined to the 10,000 per month level at C-band, with the remainder made up of Ku-band DBS and quasi-DBS stations.

Earth Station Installations for the Scenarios

Since the various scenarios produce somewhat different distributions of traffic among the frequency bands, we estimated the earth station requirements for each one. Division between the shared and unshared CPS stations is based on the estimates for these categories contained in the ITT and Western Union reports. Summary results of earth station requirements are shown in Tables 11-3 through 11-14.

CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

LOW TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	46.0	27.0	33.0
1981	41.0	29.0	35.0
1982	38.0	32.0	39.0
1983	39.0	41.0	50.0
1984	46.0	57.0	70.0
1985	59.0	88.0	108.0
1986	76.0	135.0	165.0
1987	100.0	207.0	253.0
1988	121.0	276.0	337.0
1989	152.0	381.0	466.0
1990	189.0	513.0	627.0
1991	211.0	616.0	753.0
1992	229.0	714.0	872.0
1993	249.0	826.0	1010.0
1994	266.0	922.0	1127.0
1995	279.0	1000.0	1223.0
1996	294.0	1094.0	1338.0
1997	305.0	1174.0	1436.0
1998	314.0	1253.0	1532.0
1999	320.0	1305.0	1595.0
2000	326.0	1376.0	1682.0

Table 11-3a

Total Earth Stations in Service

(TVROs Not Included)

CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

LOW TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	2.0	1.0	2.0
1984	6.0	8.0	10.0
1985	13.0	22.0	27.0
1986	25.0	45.0	56.0
1987	39.0	82.0	100.0
1988	65.0	151.0	185.0
1989	106.0	255.0	311.0
1990	151.0	380.0	465.0
1991	178.0	481.0	588.0
1992	205.0	586.0	716.0
1993	230.0	695.0	850.0
1994	253.0	791.0	966.0
1995	272.0	889.0	1087.0
1996	293.0	972.0	1188.0
1997	310.0	1066.0	1303.0
1998	321.0	1140.0	1394.0
1999	335.0	1192.0	1457.0
2000	346.0	1270.0	1552.0

Table 11-3b

Total Earth Stations in Service
(TVROs Not Included)

CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

LOW TRAFFIC FORECAST

YEAR	NUMBER OF KA-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	0.0	0.0
1993	1.0	5.0	6.0
1994	5.0	15.0	19.0
1995	13.0	37.0	46.0
1996	23.0	68.0	83.0
1997	32.0	108.0	132.0
1998	41.0	135.0	165.0
1999	55.0	167.0	204.0
2000	71.0	218.0	267.0

Table 11-3c

Total Earth Stations in Service
(TVROs Not Included)

CASE #2 -- TOTAL C-BAND PREFERENCE -- NO LIMIT AT C-BAND OR KU-BAND EXCEPT PURELY TECHNICAL AS ESTIMATED.

LOW TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	46.0	27.0	33.0
1981	41.0	29.0	35.0
1982	39.0	32.0	40.0
1983	42.0	43.0	52.0
1984	52.0	66.0	80.0
1985	72.0	111.0	135.0
1986	101.0	181.0	221.0
1987	139.0	290.0	354.0
1988	187.0	428.0	523.0
1989	258.0	636.0	778.0
1990	340.0	894.0	1092.0
1991	390.0	1098.0	1342.0
1992	435.0	1301.0	1590.0
1993	481.0	1527.0	1866.0
1994	525.0	1729.0	2113.0
1995	550.0	1879.0	2296.0
1996	561.0	1977.0	2417.0
1997	560.0	2070.0	2531.0
1998	581.0	2223.0	2717.0
1999	581.0	2295.0	2805.0
2000	574.0	2391.0	2922.0

Table 11-4a

Total Earth Stations in Service
(TVROs Not Included)

CASE #2 -- TOTAL C-BAND PREFERENCE -- NO LIMIT AT C-BAND OR KU-BAND
EXCEPT PURELY TECHNICAL AS ESTIMATED.

LOW TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	0.0	0.0
1993	0.0	0.0	0.0
1994	0.0	0.0	0.0
1995	15.0	48.0	59.0
1996	49.0	158.0	193.0
1997	88.0	278.0	340.0
1998	95.0	306.0	375.0
1999	130.0	369.0	451.0
2000	169.0	474.0	580.0

Table 11-4b

Total Earth Stations in Service
(TVROs Not Included)

CASE #3 -- EVEN SPLIT BETWEEN C AND KU BY 2000;
NO LIMIT AT C-BAND OR KU-BAND EXCEPT TECHNICAL AS ESTIMATED

LOW TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	46.0	27.0	33.0
1981	41.0	29.0	35.0
1982	39.0	32.0	40.0
1983	42.0	43.0	52.0
1984	50.0	61.0	74.0
1985	66.0	99.0	121.0
1986	90.0	158.0	193.0
1987	120.0	245.0	300.0
1988	152.0	342.0	418.0
1989	204.0	498.0	609.0
1990	261.0	681.0	832.0
1991	300.0	839.0	1025.0
1992	328.0	981.0	1199.0
1993	355.0	1129.0	1380.0
1994	383.0	1256.0	1536.0
1995	405.0	1379.0	1686.0
1996	427.0	1489.0	1819.0
1997	446.0	1622.0	1983.0
1998	467.0	1750.0	2139.0
1999	484.0	1829.0	2235.0
2000	497.0	1950.0	2383.0

Table 11-5a

Total Earth Stations in Service
(TVROs Not Included)

CASE #3 -- EVEN SPLIT BETWEEN C AND KU BY 2000;
NO LIMIT AT C-BAND OR KU-BAND EXCEPT TECHNICAL AS ESTIMATED

LOW TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	2.0	5.0	6.0
1985	5.0	11.0	14.0
1986	11.0	23.0	28.0
1987	19.0	44.0	54.0
1988	35.0	85.0	104.0
1989	54.0	138.0	169.0
1990	79.0	212.0	260.0
1991	89.0	258.0	316.0
1992	107.0	320.0	391.0
1993	125.0	397.0	486.0
1994	142.0	472.0	577.0
1995	160.0	548.0	670.0
1996	184.0	646.0	790.0
1997	202.0	726.0	887.0
1998	208.0	779.0	953.0
1999	227.0	836.0	1022.0
2000	246.0	916.0	1119.0

Table 11-5b

Total Earth Stations in Service
(TVROs Not Included)

CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	24.0	52.0	63.0
1981	20.0	61.0	74.0
1982	34.0	73.0	90.0
1983	43.0	107.0	131.0
1984	51.0	152.0	186.0
1985	56.0	216.0	265.0
1986	59.0	322.0	394.0
1987	62.0	475.0	581.0
1988	68.0	666.0	814.0
1989	75.0	929.0	1136.0
1990	80.0	1247.0	1524.0
1991	94.0	1668.0	2039.0
1992	103.0	2066.0	2525.0
1993	116.0	2483.0	3035.0
1994	128.0	2879.0	3519.0
1995	143.0	3239.0	3959.0
1996	157.0	3711.0	4536.0
1997	174.0	4105.0	5017.0
1998	183.0	4357.0	5325.0
1999	180.0	4425.0	5408.0
2000	174.0	4503.0	5503.0

Table 11-6a

Total Earth Stations in Service
(TVROs Not Included)

CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	3.0	4.0	5.0
1983	8.0	9.0	12.0
1984	13.0	33.0	40.0
1985	16.0	81.0	99.0
1986	21.0	150.0	184.0
1987	27.0	252.0	308.0
1988	32.0	398.0	487.0
1989	40.0	630.0	770.0
1990	49.0	949.0	1161.0
1991	69.0	1333.0	1629.0
1992	90.0	1795.0	2194.0
1993	111.0	2342.0	2862.0
1994	130.0	2765.0	3380.0
1995	147.0	3200.0	3911.0
1996	160.0	3689.0	4508.0
1997	177.0	4087.0	4996.0
1998	206.0	4692.0	5735.0
1999	222.0	5093.0	6225.0
2000	205.0	5065.0	6190.0

Table 11-6b

Total Earth Stations in Service
(TVROs Not Included)

CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KA-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	9.0	11.0
1993	3.0	51.0	63.0
1994	10.0	132.0	161.0
1995	17.0	316.0	386.0
1996	26.0	475.0	581.0
1997	32.0	645.0	788.0
1998	43.0	871.0	1065.0
1999	72.0	1461.0	1785.0
2000	133.0	2567.0	3137.0

Table 11-6c

Total Earth Stations in Service

(TVROs Not Included)

CASE #2 -- TOTAL C-BAND PREFERENCE -- NO LIMIT AT C-BAND OR KU-BAND EXCEPT PURELY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	24.0	52.0	63.0
1981	20.0	61.0	74.0
1982	37.0	78.0	95.0
1983	51.0	117.0	143.0
1984	64.0	185.0	227.0
1985	73.0	298.0	364.0
1986	81.0	473.0	578.0
1987	90.0	728.0	890.0
1988	101.0	1065.0	1302.0
1989	116.0	1560.0	1907.0
1990	130.0	2197.0	2685.0
1991	164.0	3001.0	3668.0
1992	194.0	3870.0	4730.0
1993	205.0	4340.0	5305.0
1994	217.0	4738.0	5791.0
1995	218.0	4970.0	6074.0
1996	219.0	5258.0	6427.0
1997	214.0	5378.0	6573.0
1998	219.0	5629.0	6880.0
1999	213.0	5727.0	7000.0
2000	204.0	5833.0	7130.0

Table 11-7a

Total Earth Stations in Service

(TVROs Not Included)

CASE #2 -- TOTAL C-BAND PREFERENCE -- NO LIMIT AT C-BAND OR KU-BAND
EXCEPT PURELY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	0.0	0.0
1993	25.0	536.0	655.0
1994	51.0	1038.0	1269.0
1995	90.0	1786.0	2183.0
1996	126.0	2617.0	3198.0
1997	169.0	3459.0	4228.0
1998	213.0	4275.0	5225.0
1999	204.0	4250.0	5195.0
2000	197.0	4335.0	5298.0

Table 11-7b

Total Earth Stations in Service
(TVROs Not Included)

CASE #2 -- TOTAL C-BAND PREFERENCE -- NO LIMIT AT C-BAND OR KU-BAND
EXCEPT PURELY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KA-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	0.0	0.0
1993	0.0	0.0	0.0
1994	0.0	0.0	0.0
1995	0.0	0.0	0.0
1996	0.0	0.0	0.0
1997	0.0	0.0	0.0
1998	1.0	16.0	19.0
1999	57.0	1000.0	1223.0
2000	111.0	1965.0	2402.0

Table 11-7c

Total Earth Stations in Service
(TVROs Not Included)

CASE #3 -- EVEN SPLIT BETWEEN C AND KU BY 2000;
NO LIMIT AT C-BAND OR KU-BAND EXCEPT TECHNICAL AS ESTIMATED

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	24.0	52.0	63.0
1981	20.0	61.0	74.0
1982	36.0	77.0	95.0
1983	47.0	113.0	139.0
1984	58.0	174.0	212.0
1985	65.0	276.0	338.0
1986	71.0	436.0	533.0
1987	78.0	625.0	764.0
1988	83.0	893.0	1091.0
1989	95.0	1241.0	1517.0
1990	102.0	1697.0	2074.0
1991	122.0	2268.0	2772.0
1992	141.0	2886.0	3527.0
1993	164.0	3536.0	4322.0
1994	186.0	4079.0	4986.0
1995	194.0	4414.0	5395.0
1996	190.0	4568.0	5583.0
1997	186.0	4672.0	5711.0
1998	191.0	4914.0	6006.0
1999	186.0	4999.0	6110.0
2000	179.0	5091.0	6222.0

Table 11-8a

Total Earth Stations in Service
(TVROs Not Included)

CASE #3 -- EVEN SPLIT BETWEEN C AND KU BY 2000;
NO LIMIT AT C-BAND OR KU-BAND EXCEPT TECHNICAL AS ESTIMATED

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	4.0	3.0	3.0
1984	5.0	11.0	14.0
1985	7.0	21.0	26.0
1986	9.0	37.0	45.0
1987	11.0	102.0	125.0
1988	17.0	171.0	210.0
1989	21.0	318.0	389.0
1990	27.0	500.0	611.0
1991	41.0	733.0	896.0
1992	52.0	984.0	1203.0
1993	67.0	1340.0	1638.0
1994	82.0	1698.0	2075.0
1995	114.0	2342.0	2862.0
1996	154.0	3307.0	4043.0
1997	197.0	4165.0	5091.0
1998	241.0	4987.0	6095.0
1999	231.0	4975.0	6081.0
2000	223.0	5074.0	6201.0

Table 11-8b

Total Earth Stations in Service
(TVROs Not Included)

CASE #3 -- EVEN SPLIT BETWEEN C AND KU BY 2000;
NO LIMIT AT C-BAND OR KU-BAND EXCEPT TECHNICAL AS ESTIMATED

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KA-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	0.0	0.0
1993	0.0	0.0	0.0
1994	0.0	0.0	0.0
1995	0.0	0.0	0.0
1996	0.0	0.0	0.0
1997	0.0	0.0	0.0
1998	1.0	17.0	24.0
1999	57.0	1004.0	1227.0
2000	111.0	1969.0	2407.0

Table 11-8c

Total Earth Stations in Service

(TVROs Not Included)

CASE #1B -- SOME DEMAND FOR EACH BAND -- 24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	24.0	52.0	63.0
1981	20.0	61.0	74.0
1982	34.0	73.0	90.0
1983	43.0	107.0	131.0
1984	51.0	152.0	186.0
1985	56.0	216.0	265.0
1986	59.0	322.0	394.0
1987	62.0	475.0	581.0
1988	68.0	666.0	814.0
1989	75.0	929.0	1136.0
1990	80.0	1247.0	1524.0
1991	94.0	1668.0	2039.0
1992	103.0	2066.0	2525.0
1993	116.0	2483.0	3035.0
1994	128.0	2879.0	3519.0
1995	130.0	3032.0	3706.0
1996	126.0	3100.0	3790.0
1997	123.0	3158.0	3860.0
1998	120.0	3216.0	3931.0
1999	117.0	3258.0	3982.0
2000	113.0	3314.0	4050.0

Table 11-9a

Total Earth Stations in Service

(TVROs Not Included)

CASE #1B -- SOME DEMAND FOR EACH BAND -- 24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	3.0	4.0	5.0
1983	8.0	9.0	12.0
1984	13.0	33.0	40.0
1985	16.0	81.0	99.0
1986	21.0	150.0	184.0
1987	27.0	252.0	308.0
1988	32.0	398.0	487.0
1989	40.0	630.0	770.0
1990	49.0	949.0	1161.0
1991	69.0	1333.0	1629.0
1992	90.0	1795.0	2194.0
1993	111.0	2342.0	2862.0
1994	130.0	2765.0	3380.0
1995	161.0	3407.0	4164.0
1996	174.0	3900.0	4767.0
1997	169.0	3971.0	4853.0
1998	163.0	4016.0	4908.0
1999	158.0	4075.0	4980.0
2000	152.0	4151.0	5074.0

Table 11-9b

Total Earth Stations in Service
(TVROs Not Included)

CASE #1B -- SOME DEMAND FOR EACH BAND -- 24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KA-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	9.0	11.0
1993	3.0	51.0	63.0
1994	10.0	132.0	161.0
1995	17.0	316.0	386.0
1996	45.0	874.0	1068.0
1997	91.0	1708.0	2087.0
1998	149.0	2682.0	3278.0
1999	199.0	3645.0	4455.0
2000	248.0	4668.0	5705.0

Table 11-9c

Total Earth Stations in Service
(TVROs Not Included)

CASE #2B -- TOTAL C-BAND PREFERENCE -- 24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	24.0	52.0	63.0
1981	20.0	61.0	74.0
1982	37.0	78.0	95.0
1983	51.0	117.0	143.0
1984	64.0	185.0	227.0
1985	73.0	298.0	364.0
1986	81.0	473.0	578.0
1987	90.0	728.0	890.0
1988	101.0	1065.0	1302.0
1989	116.0	1560.0	1907.0
1990	130.0	2197.0	2685.0
1991	155.0	2816.0	3442.0
1992	150.0	2940.0	3594.0
1993	146.0	3053.0	3732.0
1994	143.0	3133.0	3829.0
1995	139.0	3202.0	3914.0
1996	134.0	3278.0	4007.0
1997	130.0	3344.0	4087.0
1998	127.0	3407.0	4165.0
1999	123.0	3459.0	4228.0
2000	118.0	3524.0	4307.0

Table 11-10a

Total Earth Stations in Service
(TVROs Not Included)

CASE #2B -- TOTAL C-BAND PREFERENCE -- 24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	9.0	185.0	226.0
1992	44.0	729.0	1136.0
1993	84.0	1823.0	2228.0
1994	125.0	2644.0	3231.0
1995	169.0	3553.0	4343.0
1996	169.0	3743.0	4575.0
1997	165.0	3807.0	4653.0
1998	159.0	3848.0	4704.0
1999	155.0	3900.0	4767.0
2000	149.0	3971.0	4854.0

Table 11-10b

Total Earth Stations in Service

(TVROs Not Included)

CASE #2B -- TOTAL C-BAND PREFERENCE -- 24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KA-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	0.0	0.0
1993	0.0	0.0	0.0
1994	0.0	0.0	0.0
1995	0.0	0.0	0.0
1996	41.0	853.0	1042.0
1997	88.0	1684.0	2059.0
1998	147.0	2664.0	3256.0
1999	197.0	3619.0	4423.0
2000	216.0	4127.0	5045.0

Table 11-10c

Total Earth Stations in Service
(TVROs Not Included)

CASE #3B -- EVEN SPLIT BETWEEN C AND KU BY 2000;
24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND
HIGH TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	24.0	52.0	63.0
1981	20.0	61.0	74.0
1982	36.0	77.0	95.0
1983	47.0	113.0	139.0
1984	58.0	174.0	212.0
1985	65.0	276.0	338.0
1986	71.0	436.0	533.0
1987	78.0	625.0	764.0
1988	83.0	893.0	1091.0
1989	95.0	1241.0	1517.0
1990	102.0	1697.0	2074.0
1991	122.0	2268.0	2772.0
1992	141.0	2886.0	3527.0
1993	140.0	3039.0	3714.0
1994	137.0	3116.0	3809.0
1995	133.0	3183.0	3890.0
1996	129.0	3256.0	3980.0
1997	125.0	3319.0	4057.0
1998	122.0	3381.0	4132.0
1999	119.0	3429.0	4191.0
2000	114.0	3490.0	4266.0

Table 11-11a

Total Earth Stations in Service
(TVROs Not Included)

CASE #3B -- EVEN SPLIT BETWEEN C AND KU BY 2000;
24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND
HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	4.0	3.0	3.0
1984	5.0	11.0	14.0
1985	7.0	21.0	26.0
1986	9.0	37.0	45.0
1987	11.0	102.0	125.0
1988	17.0	171.0	210.0
1989	21.0	318.0	389.0
1990	27.0	500.0	611.0
1991	41.0	733.0	896.0
1992	52.0	984.0	1203.0
1993	90.0	1837.0	2246.0
1994	131.0	2660.0	3252.0
1995	175.0	3573.0	4367.0
1996	174.0	3766.0	4603.0
1997	169.0	3833.0	4685.0
1998	163.0	3875.0	4737.0
1999	159.0	3931.0	4804.0
2000	153.0	4005.0	4895.0

Table 11-11b

Total Earth Stations in Service
(TVROs Not Included)

CASE #3B -- EVEN SPLIT BETWEEN C AND KU BY 2000;
24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND
HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KA-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	0.0	0.0
1993	0.0	0.0	0.0
1994	0.0	0.0	0.0
1995	0.0	0.0	0.0
1996	41.0	853.0	1042.0
1997	88.0	1684.0	2059.0
1998	147.0	2664.0	3256.0
1999	197.0	3619.0	4423.0
2000	216.0	4127.0	5045.0

Table 11-11c

Total Earth Stations in Service
(TVROs Not Included)

CASE #1C -- SOME DEMAND FOR EACH BAND -- 24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	24.0	52.0	63.0
1981	20.0	61.0	74.0
1982	34.0	73.0	90.0
1983	43.0	107.0	131.0
1984	51.0	152.0	186.0
1985	56.0	216.0	265.0
1986	59.0	322.0	394.0
1987	62.0	475.0	581.0
1988	68.0	666.0	814.0
1989	75.0	929.0	1136.0
1990	80.0	1247.0	1524.0
1991	94.0	1668.0	2039.0
1992	103.0	2066.0	2525.0
1993	116.0	2483.0	3035.0
1994	128.0	2879.0	3519.0
1995	130.0	3032.0	3706.0
1996	126.0	3100.0	3790.0
1997	123.0	3158.0	3860.0
1998	120.0	3216.0	3931.0
1999	117.0	3258.0	3982.0
2000	113.0	3314.0	4050.0

Table 11-12a

Total Earth Stations in Service
(TVROs Not Included)

CASE #1C -- SOME DEMAND FOR EACH BAND -- 24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	3.0	4.0	5.0
1983	8.0	9.0	12.0
1984	13.0	33.0	40.0
1985	16.0	81.0	99.0
1986	21.0	150.0	184.0
1987	27.0	252.0	308.0
1988	32.0	398.0	487.0
1989	40.0	630.0	770.0
1990	49.0	949.0	1161.0
1991	69.0	1333.0	1629.0
1992	90.0	1795.0	2194.0
1993	111.0	2342.0	2862.0
1994	130.0	2765.0	3380.0
1995	161.0	3407.0	4164.0
1996	192.0	4299.0	5255.0
1997	221.0	4929.0	6024.0
1998	220.0	5087.0	6218.0
1999	216.0	5186.0	6338.0
2000	208.0	5285.0	6460.0

Table 11-12b

Total Earth Stations in Service
(TVROs Not Included)

CASE #1C -- SOME DEMAND FOR EACH BAND -- 24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KA-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	9.0	11.0
1993	3.0	51.0	63.0
1994	10.0	132.0	161.0
1995	17.0	316.0	386.0
1996	26.0	475.0	581.0
1997	39.0	750.0	917.0
1998	92.0	1615.0	1974.0
1999	141.0	2534.0	3098.0
2000	192.0	3535.0	4320.0

Table 11-12c

Total Earth Stations in Service
(TVROs Not Included)

CASE #2C -- TOTAL C-BAND PREFERENCE -- 24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	24.0	52.0	63.0
1981	20.0	61.0	74.0
1982	37.0	78.0	95.0
1983	51.0	117.0	143.0
1984	64.0	185.0	227.0
1985	73.0	298.0	364.0
1986	81.0	473.0	578.0
1987	90.0	728.0	890.0
1988	101.0	1065.0	1302.0
1989	116.0	1560.0	1907.0
1990	130.0	2197.0	2685.0
1991	155.0	2816.0	3442.0
1992	150.0	2940.0	3594.0
1993	146.0	3053.0	3732.0
1994	143.0	3133.0	3829.0
1995	139.0	3202.0	3914.0
1996	134.0	3278.0	4007.0
1997	130.0	3344.0	4087.0
1998	127.0	3407.0	4165.0
1999	123.0	3459.0	4228.0
2000	118.0	3524.0	4307.0

Table 11-13a

Total Earth Stations in Service
(TVROs Not Included)

CASE #2C -- TOTAL C-BAND PREFERENCE -- 24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	9.0	185.0	226.0
1992	44.0	929.0	1136.0
1993	84.0	1823.0	2228.0
1994	125.0	2644.0	3231.0
1995	169.0	3553.0	4343.0
1996	210.0	4587.0	5606.0
1997	213.0	4795.0	5861.0
1998	221.0	5090.0	6222.0
1999	217.0	5187.0	6339.0
2000	209.0	5283.0	6457.0

Table 11-13b

Total Earth Stations in Service
(TVROs Not Included)

CASE #2C -- TOTAL C-BAND PREFERENCE -- 24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KA-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	0.0	0.0
1993	0.0	0.0	0.0
1994	0.0	0.0	0.0
1995	0.0	0.0	0.0
1996	0.0	9.0	11.0
1997	40.0	697.0	852.0
1998	85.0	1422.0	1738.0
1999	134.0	2332.0	2850.0
2000	186.0	3327.0	4066.0

Table 11-13c

Total Earth Stations in Service

(TVROs Not Included)

CASE #3C -- EVEN SPLIT BETWEEN C AND KU BY 2000;
24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND
HIGH TRAFFIC FORECAST

YEAR	NUMBER OF C-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	24.0	52.0	63.0
1981	20.0	61.0	74.0
1982	36.0	77.0	95.0
1983	47.0	113.0	139.0
1984	58.0	174.0	212.0
1985	65.0	276.0	338.0
1986	71.0	436.0	533.0
1987	78.0	625.0	764.0
1988	83.0	893.0	1091.0
1989	95.0	1241.0	1517.0
1990	102.0	1697.0	2074.0
1991	122.0	2268.0	2772.0
1992	141.0	2886.0	3527.0
1993	140.0	3039.0	3714.0
1994	137.0	3116.0	3809.0
1995	133.0	3183.0	3890.0
1996	129.0	3256.0	3980.0
1997	125.0	3319.0	4057.0
1998	122.0	3381.0	4132.0
1999	119.0	3429.0	4191.0
2000	114.0	3490.0	4266.0

Table 11-14a

Total Earth Stations in Service
(TVROs Not Included)

CASE #3C -- EVEN SPLIT BETWEEN C AND KU BY 2000;
24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND
HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KU-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	4.0	3.0	3.0
1984	5.0	11.0	14.0
1985	7.0	21.0	26.0
1986	9.0	37.0	45.0
1987	11.0	102.0	125.0
1988	17.0	171.0	210.0
1989	21.0	318.0	389.0
1990	27.0	500.0	611.0
1991	41.0	733.0	896.0
1992	52.0	984.0	1203.0
1993	90.0	1837.0	2246.0
1994	131.0	2660.0	3252.0
1995	175.0	3573.0	4367.0
1996	216.0	4619.0	5646.0
1997	236.0	5140.0	6282.0
1998	234.0	5305.0	6484.0
1999	231.0	5408.0	6610.0
2000	222.0	5511.0	6736.0

Table 11-14b

Total Earth Stations in Service

(TVROs Not Included)

CASE #3C -- EVEN SPLIT BETWEEN C AND KU BY 2000;
24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND
HIGH TRAFFIC FORECAST

YEAR	NUMBER OF KA-BAND EARTH STATIONS TRUNKING	DEDICATED CPS	SHARED CPS
1980	0.0	0.0	0.0
1981	0.0	0.0	0.0
1982	0.0	0.0	0.0
1983	0.0	0.0	0.0
1984	0.0	0.0	0.0
1985	0.0	0.0	0.0
1986	0.0	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	0.0	0.0
1993	0.0	0.0	0.0
1994	0.0	0.0	0.0
1995	0.0	0.0	0.0
1996	0.0	0.0	0.0
1997	22.0	378.0	462.0
1998	76.0	1234.0	1509.0
1999	125.0	2141.0	2617.0
2000	177.0	3132.0	3828.0

Table 11-14c

Total Earth Stations in Service
(TVROs Not Included)

SECTION 12
ECONOMIC ANALYSIS

Satellite communications has developed into a rather large business, with total investment in current satellites of over $1 billion in the U.S. domestic systems alone. According to a recent article, the worldwide communications satellite market is approaching $3 billion per year, excluding ground segment. Thus it is important that we examine the effect of our postulated future satellites on the overall market, in economic terms.

The costs of satellites launched during each scenario run in Task 2 was estimated using the SAMSO cost model. Launch costs were estimated based on the weight of the satellite and the costs of known launch vehicles. All these figures were expressed in 1983 dollars to provide a common standard.

Table 12-1 shows the estimated costs for the example earth station configurations that we used. Figures are again in 1983 dollars. These costs were estimated using data of our own, plus information developed by Western Union.

Tables 12-2 through 12-13 show the costs of meeting the earth station requirements postulated in Section 11. We have not included costs for networking of trunk and shared CPS earth stations in these costs. A method of estimating the magnitude of the networking costs is described below.

Space segment costs are also shown. Investments for known satellites (i.e. - not generated by the program) are not included.

Space segment costs are also shown, but only for satellites launched by the simulation program. Thus, the cost of known satellites is not included. Space segment costs include the satellite development and unit costs, launch costs, and launch support costs. No TT&C or operations cost are included.

Table 12-1

Estimated Installed Earth Station Costs

($ millions, 1983)

	Trunking	Dedicated CPS	Shared CPS
C-band	2.0	0.40	0.50
Ku-band	2.4	0.48	0.60
Ka-band*	2.4	0.35	0.45

CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

LOW TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	119.3
1981	0.0	1.8
1982	0.0	3.2
1983	0.0	17.6
1984	0.0	48.2
1985	0.0	91.1
1986	85.0	138.5
1987	0.0	198.6
1988	0.0	258.1
1989	268.0	392.4
1990	99.0	467.7
1991	99.0	335.3
1992	329.0	326.7
1993	837.0	353.4
1994	814.0	320.7
1995	828.0	309.5
1996	1190.0	327.4
1997	1029.0	315.6
1998	907.0	260.0
1999	745.0	223.0
2000	315.0	289.3

Table 12-2

Satellite and Earth Station

Incremental Investments

CASE #2 -- TOTAL C-BAND PREFERENCE -- NO LIMIT AT C-BAND OR KU-BAND
EXCEPT PURELY TECHNICAL AS ESTIMATED.

LOW TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	119.3
1981	0.0	1.8
1982	0.0	3.7
1983	0.0	16.4
1984	0.0	43.2
1985	0.0	85.5
1986	85.0	129.0
1987	0.0	186.1
1988	0.0	235.7
1989	296.0	352.7
1990	525.0	424.2
1991	331.0	306.6
1992	573.0	295.2
1993	921.0	320.4
1994	944.0	292.3
1995	989.0	295.9
1996	1223.0	336.5
1997	732.0	333.6
1998	1005.0	247.4
1999	448.0	232.6
2000	0.0	318.3

Table 12-3

Satellite and Earth Station

Incremental Investments

CASE #3 -- EVEN SPLIT BETWEEN C AND KU BY 2000;
NO LIMIT AT C-BAND OR KU-BAND EXCEPT TECHNICAL AS ESTIMATED

LOW TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	119.3
1981	0.0	1.8
1982	0.0	3.7
1983	0.0	16.4
1984	0.0	45.0
1985	0.0	85.6
1986	85.0	136.2
1987	0.0	193.2
1988	0.0	249.9
1989	268.0	371.9
1990	99.0	448.8
1991	331.0	317.4
1992	307.0	317.8
1993	921.0	340.9
1994	814.0	316.2
1995	828.0	303.7
1996	1130.0	331.1
1997	1029.0	313.0
1998	763.0	250.6
1999	745.0	228.0
2000	149.0	290.6

Table 12-4

Satellite and Earth Station

Incremental Investments

CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	100.3
1981	0.0	9.1
1982	0.0	52.9
1983	0.0	70.7
1984	0.0	101.8
1985	0.0	140.7
1986	85.0	209.0
1987	0.0	298.5
1988	0.0	394.4
1989	268.0	580.6
1990	99.0	740.5
1991	99.0	967.0
1992	343.0	1039.5
1993	921.0	1206.9
1994	1053.0	1073.1
1995	1085.0	1144.7
1996	1469.0	1294.4
1997	1398.0	1123.8
1998	1244.0	1306.4
1999	942.0	1193.7
2000	1612.0	1220.6

Table 12-5

Satellite and Earth Station

Incremental Investments

CASE #2 -- TOTAL C-BAND PREFERENCE -- NO LIMIT AT C-BAND OR KU-BAND
EXCEPT PURELY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	100.3
1981	0.0	9.1
1982	0.0	51.3
1983	0.0	67.6
1984	0.0	95.2
1985	0.0	131.7
1986	85.0	193.0
1987	0.0	276.0
1988	0.0	362.8
1989	268.0	530.5
1990	331.0	671.8
1991	744.0	881.1
1992	1189.0	938.6
1993	1107.0	1207.8
1994	870.0	1078.0
1995	593.0	1237.3
1996	1223.0	1388.0
1997	732.0	1246.4
1998	1590.0	1375.9
1999	1213.0	1119.8
2000	1294.0	1207.9

Table 12-6

Satellite and Earth Station

Incremental Investments

CASE #3 -- EVEN SPLIT BETWEEN C AND KU BY 2000;
NO LIMIT AT C-BAND OR KU-BAND EXCEPT TECHNICAL AS ESTIMATED

HIGH TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	100.3
1981	0.0	9.1
1982	0.0	48.9
1983	0.0	71.2
1984	0.0	95.7
1985	0.0	134.6
1986	85.0	197.4
1987	0.0	289.1
1988	0.0	379.2
1989	268.0	563.8
1990	99.0	709.9
1991	198.0	933.8
1992	634.0	993.8
1993	1153.0	1171.4
1994	1015.0	1063.2
1995	1121.0	1212.6
1996	1076.0	1423.4
1997	594.0	1249.4
1998	1590.0	1376.7
1999	1213.0	1106.5
2000	1294.0	1210.7

Table 12-7

Satellite and Earth Station

Incremental Investments

CASE #1B -- SOME DEMAND FOR EACH BAND -- 24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	100.3
1981	0.0	9.1
1982	0.0	52.9
1983	0.0	70.7
1984	0.0	101.8
1985	0.0	140.7
1986	85.0	209.0
1987	0.0	298.5
1988	0.0	394.4
1989	268.0	580.6
1990	99.0	740.5
1991	99.0	967.0
1992	329.0	1039.5
1993	1092.0	1206.9
1994	1134.0	1073.1
1995	1179.0	1194.1
1996	2680.0	1268.2
1997	1587.0	1004.7
1998	2168.0	1129.3
1999	811.0	1100.5
2000	1612.0	1187.4

Table 12-8

Satellite and Earth Station

Incremental Investments

CASE #2B -- TOTAL C-BAND PREFERENCE -- 24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	100.3
1981	0.0	9.1
1982	0.0	51.3
1983	0.0	67.6
1984	0.0	95.2
1985	0.0	131.7
1986	85.0	193.0
1987	0.0	276.0
1988	0.0	362.8
1989	268.0	530.5
1990	269.0	671.8
1991	609.0	922.1
1992	619.0	1112.7
1993	837.0	1294.5
1994	650.0	1174.8
1995	505.0	1279.2
1996	2997.0	1173.2
1997	1561.0	1005.2
1998	2218.0	1137.7
1999	1304.0	1094.5
2000	365.0	655.1

Table 12-9

Satellite and Earth Station

Incremental Investments

CASE #3B -- EVEN SPLIT BETWEEN C AND KU BY 2000;
24 TRANSPONDER LIMIT AT C-BAND
24 TRANSPONDER LIMIT AT KU-BAND
HIGH TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	100.3
1981	0.0	9.1
1982	0.0	48.9
1983	0.0	71.2
1984	0.0	95.7
1985	0.0	134.6
1986	85.0	197.4
1987	0.0	289.1
1988	0.0	379.2
1989	268.0	563.8
1990	99.0	709.9
1991	269.0	933.8
1992	619.0	993.8
1993	1347.0	1281.1
1994	650.0	1175.3
1995	505.0	1280.1
1996	2997.0	1174.3
1997	1561.0	1006.4
1998	2218.0	1136.9
1999	1304.0	1095.2
2000	365.0	655.3

Table 12-10

Satellite and Earth Station

Incremental Investments

CASE #1C -- SOME DEMAND FOR EACH BAND -- 24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	100.3
1981	0.0	9.1
1982	0.0	52.9
1983	0.0	70.7
1984	0.0	101.8
1985	0.0	140.7
1986	85.0	209.0
1987	0.0	298.5
1988	0.0	394.4
1989	268.0	580.6
1990	99.0	740.5
1991	99.0	967.0
1992	329.0	1039.5
1993	1092.0	1206.9
1994	1134.0	1073.1
1995	1212.0	1194.1
1996	1103.0	1391.4
1997	1476.0	1170.3
1998	2037.0	1156.5
1999	1281.0	1106.9
2000	1291.0	1199.8

Table 12-11

Satellite and Earth Station

Incremental Investments

CASE #2C -- TOTAL C-BAND PREFERENCE -- 24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND

HIGH TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	100.3
1981	0.0	9.1
1982	0.0	51.3
1983	0.0	67.6
1984	0.0	95.2
1985	0.0	131.7
1986	85.0	193.0
1987	0.0	276.0
1988	0.0	362.8
1989	268.0	530.5
1990	269.0	671.8
1991	609.0	922.1
1992	619.0	1112.7
1993	837.0	1294.5
1994	660.0	1174.8
1995	505.0	1279.2
1996	1842.0	1437.5
1997	1581.0	1041.7
1998	1723.0	1202.1
1999	1213.0	1105.6
2000	1289.0	1202.6

Table 12-12

Satellite and Earth Station

Incremental Investments

CASE #3C -- EVEN SPLIT BETWEEN C AND KU BY 2000;
24 TRANSPONDER LIMIT AT C-BAND
36 TRANSPONDER LIMIT AT KU-BAND
HIGH TRAFFIC FORECAST

YEAR	CAPITAL INVESTMENTS ($ MILLIONS) SATELLITES	EARTH STATIONS
1980	0.0	100.3
1981	0.0	9.1
1982	0.0	48.9
1983	0.0	71.2
1984	0.0	95.7
1985	0.0	134.6
1986	85.0	197.4
1987	0.0	289.1
1988	0.0	379.2
1989	268.0	563.8
1990	99.0	709.9
1991	269.0	933.8
1992	619.0	993.8
1993	1362.0	1261.1
1994	660.0	1175.3
1995	538.0	1280.1
1996	944.0	1442.1
1997	1726.0	1136.4
1998	1972.0	1163.1
1999	1213.0	1107.4
2000	1175.0	1203.5

Table 12-13

Satellite and Earth Station

Incremental Investments

Earth Station Networking

Trunking Stations

Trunking stations take advantage of a terrestrial network, serving a relatively broad area, which collect traffic for both long and short haul. A central concentration point or points serve the earth station directly, and it may be collocated with one of these. In the carriage of telephony, and lower speed data, for which an established terrestrial network exists, the added costs for the earth station networking will consist simply of whatever high-density links are needed to transport the traffic from the collection point(s) to the earth station. In a typical case, this would be a microwave link of one or more hops, or possibly an optical fiber links (for example, as planned for the various Teleports serving larger cities). Typical costs are shown in Table 12-14 for these links. These costs vary with length and the link capacity.

Shared CPS Stations

The distinction between trunking and shared CPS may become a bit blurred, but we are not trying to define a generalized earth station taxonomy here, simply to show some useful categories. Networking costs for shared CPS stations could be minimal, as for instance when the station serves a single building or an industrial park. The same local area network that may provide communications within the service area can furnish connection with the earth station. This would involve essentially no added cost.

At the other extreme of "shared CPS" (and probably well into the blurred region) are networks such as we studied in a previous work for TRW. Figure 12-1 shows the postulated earth stations and connections for a network serving the Washington, DC metropolitan area. Such a configuration has much of the total cost concentrated in the terrestrial network. In fact, in this analysis, we assumed that the network would provide local connections at a significant level, increasing the total traffic in the system by 50 percent. Table 12-15 shows the cost allocations for this particular configuration.

Table 12-14

Sample Networking Costs Fiber Optics Costs Per Kilometer

	Transmission Rate (Mbps)			
	45	90	135	270
Number of Fibers	4	4	4	4
Cable Cost	1,700	1,700	1,700	1,700
Cable Installation	8,000	8,000	8,000	8,000
Repeater	865	1,075	1,265	2,530
Total	10,565	10,775	10,965	13,630

Summary Digital Microwave
Radio Equipment Costs

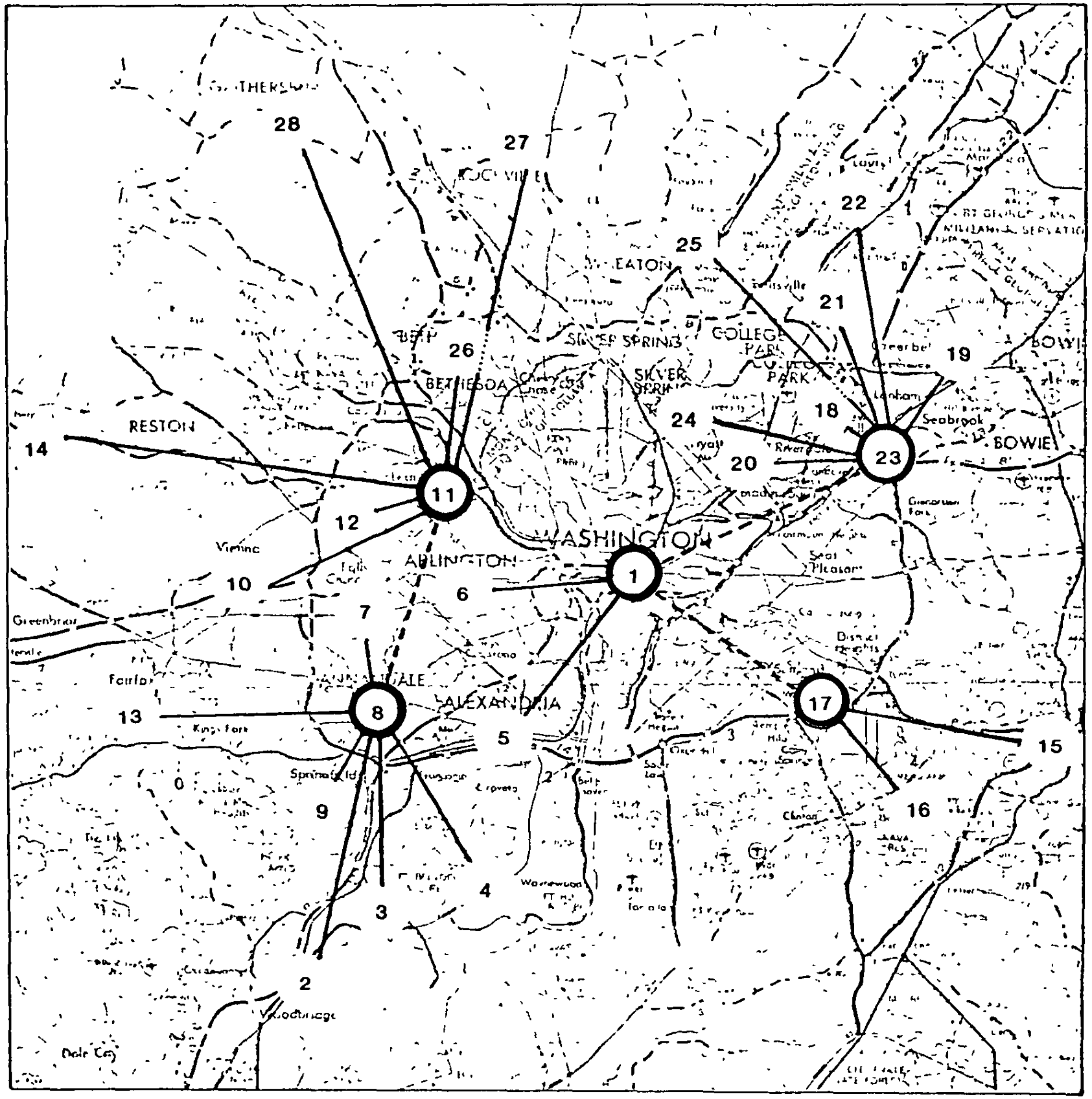
Item	Costs
Transceiver	$12,500 - 15,000
Repeater	25,000 - 30,000
Multiplexer	2,500 + $100/56k channel

Cable Coaxial Costs
($/strand mile)[1]

	Underground
Transmission Hardware	$5,000
Construction	7,800 - 27,000[2]
Total	12,800 - 32,000

[1]One cable strand mile includes all trunk and feeder cables supported by one mile of aerial messenger strand or located underground in one mile of trench or duct.

[2]Depends on nature of surface (paved or unpaved), soil type, type of conduit vs. direct burial.



1. Downtown, D.C.
2. Woodbridge
3. Ft. Belvoir
4. Hybla Valley
5. Alexandria
6. Arlington
7. Falls Church
8. Annandale
9. Springfield
10. Vienna
11. McLean
12. Tysons Corner
13. Fairfax
14. Herndon
15. Marlboro
16. Andrews AFB
17. Suitland
18. New Carrolton
19. Goddard
20. Hyattsville
21. Beltsville
22. Laurel Corridor
23. Langley Park
24. Silver Spring
25. Wheaton Corridor
26. Bethesda
27. Rockville
28. Gaithersburg

1 = Earth Station

16 = Local Node

= Diversity Link

= Node to Earth Station Trunk

Figure 12-1

WASHINGTON, D.C.: OPTIMAL TDMA SYSTEM CONFIGURATION - OPTICAL FIBER

Table 12-15

Ground Network Costs Summary - Optical Fiber

		Investment				
		Interconnect Cost ($K)	Earth Station Cost ($K)	Diversity Cost ($K)	Total Investment Cost ($K)	Annual Leased Line Cost ($K)
TDMA						
Washington		5,429	867	306	6,602	12,035
FDMA						
Washington	(W)	5,756	1,778	183	7,717	12,035
	(N)	5,521	1,508	287	7,316	12,035
HYBRID						
Washington	(W)	5,916	1,253	173	7,342	12,035
	(N)	5,265	1,370	272	6,907	12,035

(W) = wide beam (N) = narrow beam

Our inclination is to place such networks as that of Figure 12-1 in the trunking category, and to limit the shared CPS designation to less complex and geographical dispersed setups. The implication in a shared CPS arrangement is that, for a relatively small additional cost, enough users can be included in the network, sharing the capital cost of the earth station, to bring it within affordability for all of them.

Summary

Table 12-16 summarizes the investment costs for space and earth segments under the scenarios.

Table 12-16
Cumulative Investment Costs
for Scenario Runs
(millions of 1984 dollars)

Scenario	Space Segment	Ground Segment
Low Traffic		
1	7,545	4,797
2	8,072	4,576
3	7,469	4,682
High Traffic		
1	10,528	14,270
2	11,239	14,150
3	10,340	14,340
1B	13,143	13,868
2B	12,287	13,337
3B	12,287	13,330
1C	11,506	14,203
2C	11,500	14,264
3C	10,330	14,315

SECTION 13
SUMMARY AND CONCLUSIONS

This report has covered a rather wide range of topics relating to satellite communications in the U.S. To one extent or another, of course, the various results depend on one another and on assumptions that we made during the course of the study. Some of these assumptions are more arguable than others, for instance, our selection of data rate for a CPS transponder, and our speculations about the courses of action of the several long-haul carriers using satellite transmission. Given the traffic forecasts that we began with, however, we are of the opinion that no reasonable variation of assumptions would change the magnitude of either the high or low traffic forecast by more than a factor of about two.

Historical Perspective

From the beginning of the concept of the large (perhaps multi-purpose) satellite, there has been an implicit assumption, by ourselves as well as others, that the advantages were compelling enough that industry would be drawn to use such spacecraft. We are now at a stage where we can see that, while there are advantages, there are drawbacks as well, and logistical difficulties. There are probably economies of scale available, at least on two fronts: sharing of the housekeeping functions, and connectivity. However, there are drawbacks of scale as well: the need to aggregate considerable traffic, the specialization required of the satellite design, and the increased exposure to single-point failures, which can probably never be completely eliminated.

The investigation of the 30/20 GHz band shares some of these difficulties, but has some counterbalancing advantages. There has always been a need, eventually, for additional frequency space. This is the single largest factor that argues for 30/20 GHz development. The technology developments that have been included in that program, such as multi-beam antennas and on-board switching, have applications at the other bands as well. However, the assumption that a 30/20

GHz satellite would necessarily be large, heavy, and complex is not entirely justified. Simpler designs are possible, and in the time frame encompassed by this study, seem to offer quite useful service (see, for instance, the Hughes concept designs based on FDMA).

Industry Views

The advantages of the current class of domestic satellites are well known. Lovell & Fordyce point out that: "The North American Domsats have been standardized around the Delta and Shuttle/SSUS-D launch vehicles. As a result of this standardization, these domsats have enjoyed a relatively long production run.* Part of the superior figure-of-merit of these designs can be attributed to the economics of production and part to the lower cost of the Delta class launch vehicle system." Since every operator wants to get the most satellite for his money, this cost advantage is a compelling one. Competing designs will have to prove that they can achieve the same level of effectiveness.

That new designs involve new risks has been clearly shown by the recent troubles of INSAT A and B during deployment, and of the IUS during transfer of TDRS. It is clear that larger spacecraft will involve both more complex deployable mechanisms, and new launch vehicle systems. Even though the operator is (or can be) insured against such problems, the premiums and indeed the viability of the launch insurance business depend on the probability of failure remaining relatively small and consistent.** In addition, while an established operator could weather a failure, using existing (if aged) spacecraft, substantial delays of startup could be a complete disaster for a new entrant. (In spite of this, new entrants have tended to propose the more ambitious designs, presumably for reasons of product differentiation and new marketing approaches.)

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* - as have the Delta Class vehicles as a consequence.

** - launch insurance premiums have not covered losses over the past few years.

Hughes, while disavowing increased buss size, has unveiled a design recently that employs a despun solar array attached to a spin-stabilized buss. This gives a considerable increase in power, with a modest increase in complexity, mostly in deployables.

American Satellite's Otto Hoernig commented recently that his firm sees the three-band hybrid as the satellite of the 1990s. The reasons are of note: that an interconnected hybrid allows easy incorporation of existing earth stations into a network expanded in frequency coverage. However, Amersat's next generation satellite is postulated to be more modest than that, with 44 to 48 transponders and C-band/Ku-band coverage like the Amersat birds now under construction.

Market Stability

Current satellites are beginning to depart from the "standard" 36 MHz transponder, but primarily for reasons of weight and power constraint, rather than a desire to serve specialized markets. The relative instability of the market is probably somewhat to blame for this. Take the TV market as an example. This market has been populated with many users whose financial stability is unknown, as well as with profitable programmers. It would have been a somewhat risky step to pioneer the use of narrower transponders, say, 24 MHz, for TV distribution when the size and stability of that market segment was uncertain. In addition, one would have required many cable systems and other users to change their receiving equipment to accommodate the different bandwidth and channel centers.

While there may be some specialization of transponder characteristics to serve certain markets, there will be every incentive to maintain as much flexibility as possible, in order that other markets may also be tapped. To the extent that markets become more stable, as TV distribution promises to do, the satellite operators may find it desirable to invest in some specialization in order to reduce costs or improve performance. However, the nature of the satellite industry tends to discourage this somewhat. Satellites typically serve emerging market areas, because a satellite system can provide economical connectivity even when the users are few and far between, too sparse for cost-effective terrestrial connections. Thus the satellite operators will often be providing capacity to communications technologies that are changing rapidly and market segments that are far from stable. In such an environment, the best approach is to remain flexible and attempt to satisfy as many different kinds of users as possible. This tends to militate against more specialized designs.

Conclusions from the Scenarios

With the currently-mandated 2 degree spacing at C-band and Ku-band, the scenario runs clearly indicate that the average capacity needed at each band is relatively modest for the Low traffic cases, and feasible, but rather advanced for the High traffic. It's worth noting that the 2B and 3B scenarios used every slot, even at 30/20 GHz. However, it would be instructive to investigate different ways in which this capacity might be provided. The scenario runs present one way, but not the only way, in which satellites might be launched to satisfy demand. The various possibilities might be loosely classified as: Multiple Small Satellites (as in the scenarios); Multiple Hybrids of modest specific capacity; Rapid Transition to Large Satellites.

Multiple Small Satellites

This approach is explicitly taken by the scenario program, mainly because of the complexity of trying to form appropriate hybrid satellites. The result is a skyfull of spacecraft, with all C-band and Ku-band slots used up. Of course, "small" as used here is relative -- these satellites are in many cases considerably larger than current spacecraft.

We don't really think that actual developments will follow this line. For one thing, a number of system operators have stated their express intention to continue using hybrid spacecraft or to change to hybrids. For another, the use of completely separate satellites would worsen the interconnectivity problem compared with hybrids. Finally, the use of the same spacing interval at both (or all) bands makes for an easy transition to having all slots able to accommodate a hybrid spacecraft.

Multiple Hybrids

This is a more likely path of development, and could result in some satellites of considerable size. These would certainly occupy the full Shuttle bay (along with their upper stage) and could be considered to be "platforms". However, if all slots are utilized, the average capacity could be modest, and an average satellite, if launched as a hybrid using two bands, would have a total capacity of about 75 transponders in the year 2000. Satellites launched in the last two or three years of the period (again, as two-band hybrids) would be in the 100 to 150 transponder range — quite large by today's standards. A hybrid design including all three bands would be around 175 to 200 transponders, and interconnections would present a challenge. While this would certainly be considered a "platform", the average satellite by the year 2000 would still be considerably below this capacity.

The interesting thing that results from thinking about this alternative is that it very clearly leads into the use of platforms (or possibly larger cluster satellites) because the year 2000 seems to be right on the threshold of necessity. In most of the runs, 30/20 GHz has just come into significant use, and the sizes of satellites at the other bands are all such as to require many spot beams. The connectivity —both in frequency and in spatial terms — will have become a sore spot with many users. In addition, the technology should certainly be ready.

Other Factors

The two scenario realizations discussed above have one thing in common: many, many satellites, with all slots full at C and Ku-band. One significant result is that this will be an interference-dominated environment. As noted earlier this causes significant reductions in the capacity per transponder compared with a predominantly thermal-noise dominated environment. One response to such constraints will be an increased use of interference-tolerant modulation schemes. Error-correcting coding and spread-spectrum modulations are possibilities, both of which result in a loss of some spectral efficiency. There will also be difficulties associated with polarization plans, transponder bandwidths, and EIRP inhomogeneities.

Rapid Transition to Large Platforms

This realization implies that the satellite operators make a fairly fast transition to large platforms, rather than having a very large number of smaller satellites filling all available slots. Such a transition might occur in response to the pressures noted above, and as a way to preserve the trend toward smaller earth stations. The resulting satellite configurations would feature multiple frequency bands with on-board interconnection, probably intersatellite links, and would quite possible be segregated in the orbit from satellites providing point-to-multipoint distribution, such as for TV. Such segregation would allow considerable inhomogeneity between spot-beam and area coverages, without interference.

Given the technology that will be likely to be available during the study period, such spacecraft might begin to appear after some of the concepts have been proven operationally. Initial designs, launched in the first half of the 1990s, would be of sufficient size to occupy the entire Shuttle bay, together with upper stage, and would probably have a total capacity of 150 to 200 transponders. This could (and probably would) be a two- or three-band hybrid payload. However, we think that a wholesale transition to large platforms is unlikely for several reasons, in spite of its technological feasibility.

First, there is a considerable incentive for the satellite operators to file applications for replacement satellites for all of their current operating satellites. If they were all replaced with considerably larger spacecraft, a large oversupply would develop. Second, the FCC has already made it clear that the potential problems with 2 degree spacing — and the resulting large number of satellites — are, in its opinion, solvable. Therefore, even if the existing system operators decided in mass to use fewer slots and higher capacity, the FCC could turn around and award the slots so vacated to still other, newer, entrants. This could worsen the interference problem, cause oversupply, and create other difficulties.

Sensitivity to Traffic Variations

Reduced Low Traffic

If the Low Traffic forecast were reduced to one-half its present value, little or no advanced technology would be needed to satisfy demand through the year 2000. At the time, the average capacity per slot needed would be 24 transponders; this could obviously be supplied by C-band and Ku-band satellites of conventional design. However, we think the probability of traffic being this low is quite small.

Increased High Traffic

Increasing the High Traffic forecast to twice its current value would have profound effects on the satellite requirements. Table 13-1 shows a scenario summary for Case 1 run with twice the High Traffic values, but otherwise unchanged. Table 13-2 reproduces the "normal" Case 1 for comparison.

The surprising thing is that there is relatively little difference in the average satellite capacity for the two runs. However, this arises because when the traffic is higher, the high capacity satellites are launched sooner. In fact, the majority of the satellites that are launched early in the period are replaced prematurely because of the need for added capacity. Of course, another major difference is that all the 30/20 GHz orbital slots are filled in the double-traffic case, and that demand outstrips supply by 1996.

The Role of Satellites in the Overall Communications Structure

Satellites are, and will remain, ideally suited for broadcast applications. It is hard to conceive of a development in terrestrial communications technology that would undermine this advantage, at least in the United States. There are a number of countries whose physical extent is limited enough that it is actually less expensive for them to install a terrestrial broadcast system (for TV and radio) than to launch a satellite or even share a satellite for DBS purposes. However, our large

SUMMARY FOR
CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

DOUBLED HIGH TRAFFIC FORECAST

	FREQUENCY BAND C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	112	61	117
YEAR LAUNCHED:	1990	1998	1996
FIRST MULTIBEAM SATELITE IN:	1988	1991	1992
GROSS CAPACITY			
1980	128	0	0
1990	1096	744	0
2000	1690	1360	1452
NET CAPACITY			
1980	128	0	0
1990	1015	744	0
2000	1410	1180	1360
AVERAGE CAPACITY			
1980	19	0	0
1990	31	22	0
2000	48	41	67

Table 13-1

SUMMARY FOR
CASE #1 -- SOME DEMAND FOR EACH BAND -- NO LIMIT ON C-BAND OR KU-BAND CAPACITY EXCEPT STRICTLY TECHNICAL AS ESTIMATED.

HIGH TRAFFIC FORECAST

	FREQUENCY BAND C-BAND	KU-BAND	KA-BAND
MAXIMUM SATELLITE (TRANSPONDERS):	58	61	84
YEAR LAUNCHED:	1996	1999	2000
FIRST MULTIBEAM SATELITE IN:	1992	1996	1992
GROSS CAPACITY			
1980	128	0	0
1990	672	744	0
2000	1329	1148	641
NET CAPACITY			
1980	128	0	0
1990	672	744	0
2000	1133	1016	595
AVERAGE CAPACITY			
1980	19	0	0
1990	24	22	0
2000	38	34	58

Table 13-2

land area and common interests, along with our seemingly inexhaustible appetite for programming, will ensure a continuing role for satellites in broadcast. But what of point-to-point communications?

In point-to-point communications, satellites have been used mainly to enable the "great leap" whereby new communications modes are offered, or conventional modes expanded or opened to competition. This leap is generally necessary because terrestrial communications systems suffer from a "critical mass" or "critical density" syndrome. Until and unless the density of users becomes relatively high, the distance-sensitivity of terrestial links makes the cost of the system exorbitant. An added user is likely to cause the system to incur a very high added cost. Once the density of users is high enough, the incremental cost per user drops and continues to drop as the user base expands. In a satellite system, different rules prevail.

An additional satellite user always incurs (roughly) the same incremental cost no matter where he is located. The network can therefore add service points and grow without penalizing any particular users with high costs. This feature makes satellites ideal for new systems or modes of communications, where users are initially few and far between. This is why satellites have been used for trans-oceanic communications, greatly expanding the available facilities and improving quality, and for new services such as wideband data communications and videoconferencing.

As such services become better established, and the density of users increases, terrestrial technologies begin to encroach. This process can readily be seen at work today. It is our view that several factors will keep satellites viable for many years. Among these are: the continuing existance of remote users, the competitive environment in the U.S., and the economic advantage of existing facilities.

Remote Users

Despite the fact that a large fraction of the U.S. population lives and works in areas of high population density, there are and will increasingly be users in remote areas. Some of this will arise from moving the workplace to the home in information-intensive industries. Some will arise from information needs to the job. Just as there are still places where it is uneconomical to extend the power grid, there are places where it will be too expensive to extend the information grid except via satellite.

Compeititive Environment

With a monopoly service, use of satellite to access areas already served by terrestrial systems would be foolish. However, in the current competitive environment in the U.S., each entity which wishes to offer service to an area in competition with those already serving that area has the possibility of establishing a competitive beachhead by satellite. New services may be different in various ways from existing ones; there may be certain value-added features, for example. Re-selling transmission capacity acquired from existing carriers may be uneconomical, or the new entrant may simply desire to garner all the potential profit for itself. Thus, there are many possibilities for continued use of satellites for new applications. These will almost always begin as low-density services, well-matched to satellite carriage.

Another outgrowth of competition will be the offering of services not traditionally identified with the Fixed Services bands. For example, given the necessary technology development, mobile services could be offered using Ku-band or Ka-band. If the U.S. should decide that competition with INTELSAT in some areas is permissable, service to offshore mineral exploration units could be offered. We anticipate that use of satellites will evolve away from simple duplication of terrestrial facilities and services, and toward the provision of services that satellites can do better than terrestrial systems can, along with services that simply cannot be offered terrestrially.

Existing Facilities

Even though advances in terrestrial transmission techniques, such as the current installation of optical fiber systems, will tend to compete very effectively with satellite transmission for newer forms of traffic (such as data and videoconferencing), satellite facilities will also continue to be installed apace. By the time that an alternative system becomes widely available for a particular set of users, they may already have a substantial investment in the satellite facilities, which they would be loath to discard. Their equipment and operating procedures will have been tailored, to some extent, to the satellite link, and it may very well offer them service far superior to that which they had received in the past. Thus, there will be a large established base of satellite users, and very substantial incentives would have to be offered to induce them to change systems again.

This "inertia" factor will be aided and augmented by the growing trend toward integrated digital facilities. Eventually, there will be virtually transparent interconnection among different types of transmission media, with proper flow and error control so that the end user doesn't have to bother with specifying particular arrangements. Except for this transmission delay, satellite facilities will be indistinguishable from terrestrial ones.

In addition, with competition will come cost-allocated services. This will tend to provide incentive for lower-density and remote users to use satellite links, because the possible cost advantages of terrestrial systems will not be realized for them.

Footnote: The Year 2000

The year 2000 has become something of a touchstone for long-range planning. Indeed, one sometimes gets the impression that there is a veil drawn across time which prevents us from seeing beyond that date. The usual short-term focus of commercial firms, for whom five years is "long-range", probably causes some of the reluctance to look beyond the end of the century.

However, it's our opinion that some interesting things will just be beginning to happen by the year 2000, in communications and in space generally. We are already in a position where the firm plans of communications carriers today will affect the actual events of the early 1990s. This leaves relatively little scope for action if we limit our future vision to the year 2000. To alter the course of events requires either enormous power acting in a short time, or a long time for moderate influence to be effective. We respectfully note that we (and NASA) are more likely to be in the latter position than the former. Therefore, we need to look further and identify decision points that are within the range of our influence.

APPENDIX A
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APPENDIX B
MASS AND POWER MODEL

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B.1 Antenna System

The antenna system model has two major elements: feeds and reflector. Seven feeds are assumed for each beam, and their mass is modeled by using Table B-1.

Table B-1
Assumed Mass per Feed Horn (kg)

	Downlink	Uplink
C-band	0.16	0.08
Ku-band	0.025	0.019
Ka-band	0.01	0.005

The reflector diameter is scaled from an approximate CONUS-coverage diameter (ignoring the asymmetry of the coverage area). Scaling is:

$$D_N = 3 \times D_1 \times \sqrt{N}$$

where N = number of beams.

The factor of 3 allows for scanning. Reflector diameter at Ka-band is constant, since the spot-beam size is assumed to be a constant 0.35°. The basic sizes are shown in Table B-2.

Table B-2

Reflector Sizes for N = 1 (meters)

	Downlink	Uplink
C-band	0.74	0.5
Ku-band	0.25	0.22
Ka-band*	5.25	3.85

*for N $\doteq$ 136

Reflector mass was approximated from Figure B-1 by two simple relationships:

For $D \leqslant 4.6$ meter:

$$\text{mass} = 2.3\ D^{1.95}\ \text{(kg) (solid reflector)}$$

For $D > 4.6$ meter:

$$\text{mass} = 182\ D^{2.4}\ \text{(kg) (deployable reflector)}$$

The dividing line was based on Shuttle bay diameter; another figure could just as well have been used as a crossover point. Note that the SAMSO model doesn't account for the increased complexity of the deployable reflector.

B.2 Communications Electronics

B.2.1 Receivers

These are assumed to be installed 4 per beam at C-band and Ku-band, to handle dual-pol and 4-for-2 redundancy. At Ka-band, single-pol and 2-for-1 redundancy is assumed. Masses and power consumption are shown in Table B-3.

Table B-3

Receiver Mass and Power

(each)

	Mass (kg)	Power (watts)
C-band	1.1	5.0
Ku-band	1.5	5.0
Ka-band*	2.0	4.5

B.2.2 Power Amplifiers and Drivers

Driver amps were modeled using the values in Table B-4; redundancy was incorporated by increasing the mass and power by 20 percent. There are thus 1.2 drivers per transponder.

Table B-4

Driver Amplifiers

(each)

	Mass (kg)	Power (watts)
All bands	0.5	1.0

Power amplifiers were modeled using Tables B-5 and B-6. Redundancy was again at 1.2 amplifiers per transponder.

Table B-5

Power Amplifier Specifications

Base RF output power (1980) and efficiency	
C-band:	8.5 watts for CONUS coverage (increases 0.25 dB per year)
Ku-band:	20 watts for CONUS coverage (increases 0.25 dB per year)
30/20 GHz:	20 watts per beam (increases 0.25 dB per year)

Table B-6

Power Amplifier Mass and Power

(Y = Year - 1980, N = Number of Beams)

C-band (SSPA)

P_o = Output power per transponder = $\dfrac{8.5 \text{ W} \times 1.06^Y}{N}$

η = efficiency = $0.40 \times (0.307 \log P_o + 0.58) \times (1.024^{(Y-3)})$

Mass = 1.4 kg

Ku-band (TWTA)

P_o = $\dfrac{20 \text{ W} \times 1.06^Y}{N}$

η = $0.40 \times (0.307 \log P_o + 0.58) \times (1.019^{(Y-3)})$

Mass = $2.35 \log P_o - 0.278$

Ka-band (TWTA)

P_o = $\underline{20 \text{ W} \times 1.06^{(Y-8)}}$

η = $0.25 \times (0.307 \log P_o + 0.58) \times (1.028^{(Y-3)})$

Mass = $2.35 \log P_o - 0.278$

B.2.3 Other Items in the Payload

Multiplex

C-band	0.7 kg/transponder
Ku-band	0.5 kg/transponder
Ka-band	0.3 kg/transponder

Matrix Switching for Multibeam

Mass: $\dfrac{N^3}{1122}$ kg

Power: $\dfrac{N^3}{25.7}$ watts

Miscellaneous

5 percent additional mass

B.3 Electrical Power

B.3.1 Solar Arrays

The array must supply power to run all subsystems, as well as charge batteries during eclipse season. The charge cycle efficiency is 90 percent. Charging is assumed to take 22.8 hours maximum. Array degradation is:

0 - 7 years	3.5% per year
7 - 20 years	2.0% per year

Summer solstice requires 14 percent margin. Basic array power density is 18 W/kg; this is assumed to improve 9 percent per year. We have also allowed an adjustment in density which varies with total power:

$$\text{factor} = \frac{\text{Log}^{P}}{2} - 0.5$$

The array drive is sized at 0.01 kg/watt.

B.3.2 Batteries

Advanced batteries are used; the basic density is (by coincidence) 18 w-hr/kg at 60 percent DOD. We assume a 5 percent per year improvement. There is an allowance of 10 percent for redundant cells, and 17 percent for mounting, connectors, and diodes. Maximum eclipse is 1.2 hour.

B.3.3 EPC Subsystem

The EPC was sized as follows:

mass = 6.8 kg + 0.00682 kg/watt

B.4 Other Subsystems and Parts

Other systems modeled include Reaction Control, TT&C, Attitude Control, Thermal Control, Harness, and Structure. Structure was approximated by the larger of:

36.7% of the mass of the payload, or

28.8% of the mass of (payload plus electric power system)

TT&C, ACS, Thermal and Harness are as shown in Table B-7.

Table B-7

Some Subsystem Relationships

M_R = Communications Subsystem Mass

(mass in kg, power in watts)

TT&C:

mass	=	$0.0394\ M_R + 21$ kg
power	=	$0.0488\ M_R + 27$ W

Attitude Control:

mass	=	$0.093\ M_R + 37$ kg
power	=	$0.665\ M_R + 4$ W

Thermal Control:

mass	=	$0.135\ M_R$

Harness:

mass	=	$0.26\ M_R - 9.5$ kg (minimum 5 kg)

PROPULSION (RCS)

RCS is used for initial corrections, and stationkeeping. Typical budgets are as follows:

Initial	60 m/sec
N-S	50 m/sec/year
E-W	1.5 m/sec/year
Repositioning	15 m/sec

The current hydrazine thrusters provide a specific impulse of 200 - 220 sec. Expected technology will give an I_{sp} = 300 sec. with reliable hardware. To compute the needed propellant mass, first calculate the total ΔV:

$$\Delta V = 60 + 15 L (50 + 1.5)$$

$$L = \text{life in years}$$

then:

$$\frac{W_{BOL}}{W_{dry}} = e^{\left\{\frac{\Delta V}{g I_{sp}}\right\}}$$

where

W_{BOL} = spacecraft BOL mass, kg

W_{dry} = spacecraft dry mass, kg

$W_{BOL} - W_{dry}$ = propellant mass, W_p

I_{sp} = thruster specific impulse, see

g = 9.8 m/sec^2

$\therefore$

$$W_p = \left[e^{\left\{\frac{\Delta V}{g I_{sp}}\right\}} - 1 \right] W_{dry}$$

Propellant tanks, plumbing and thrusters were included as follows:

max. 136 kg propellant per tank
(integral number of tanks)

mass per tank = $0.238\ M_p^{0.72}$
where M_p = mass of propellant per tank (up to 136 kg)

thrusters, plumbing = $0.023 \times$ (spacecraft mass)