

UNCLASSIFIED

AD 296 068

*Reproduced
by the*

ARMED SERVICES TECHNICAL INFORMATION AGENCY
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

296068

63-2-4

MEMORANDUM

RM-3487-RC

FEBRUARY 1963

AS AD NO. _____

COMMUNICATIONS SATELLITES:
TECHNOLOGY, ECONOMICS,
AND SYSTEM CHOICES

S. H. Reiger, R. T. Nichols, L. B. Early and E. Dews

The RAND Corporation

SANTA MONICA • CALIFORNIA

MEMORANDUM

RM-3487-RC

FEBRUARY 1963

**COMMUNICATIONS SATELLITES:
TECHNOLOGY, ECONOMICS,
AND SYSTEM CHOICES**

S. H. Reiger, R. T. Nichols, L. B. Early and E. Dews

Permission to quote from or reproduce portions of this Memorandum must be obtained from The RAND Corporation.

The **RAND** *Corporation*

1700 MAIN ST • SANTA MONICA • CALIFORNIA

PREFACE

This Memorandum was prepared as part of The RAND Corporation's program of self-sponsored research in the public interest. In addition to its work for the United States Air Force and other government agencies, The RAND Corporation regularly sponsors, with its own funds, research projects in areas of importance to national security and public welfare. Such research is considered to be fundamentally the responsibility of the individuals involved in the project, and the conclusions are not necessarily endorsed by RAND. The results are published in the hope that they may contribute to wider understanding of important national problems.

The present study focuses on the possible system choices implied by United States policy to establish a commercial communications satellite system as promptly as possible and to extend it to provide global coverage at the earliest possible date. The international political implications of this policy are discussed in the companion study RM-3484-RC, Foreign Participation in Communications Satellite Systems: Implications of the Communications Satellite Act of 1962, by Murray L. Schwartz and Joseph M. Goldsen. And background information on conventional systems is given in RM-3472-RC, Submarine Telephone Cables and International Telecommunications, by R. T. Nichols.

The key technological problem is that of satellite reliability, for without sufficiently long operating lifetimes in orbit, replacement costs would make any satellite system too expensive. The key economic problem is that of demand, for the minimum costs of a satellite system will be large, and the circuit capacities provided will represent a large increment over existing capacities. Cost estimates are made for representative stationary and nonstationary active satellite systems, and an evolutionary approach is suggested. With the expectation that stationary satellites would be adopted when they are sufficiently reliable, an early regional and limited global system could begin with simple random satellites in mid-altitude

orbits using currently available launch vehicles. If such a system were put in operation in the next few years, it could begin to earn some revenues almost immediately: at first mainly for transatlantic services, and later world wide. By 1970 reliable stationary satellites might be already phasing into the system, and by that year, certainly by 1975, revenues should be substantial. Possible locations for the ground stations in early regional and global networks are shown in Fig. 1.

This study draws to a considerable extent upon earlier research undertaken by RAND for the National Aeronautics and Space Administration, and we are grateful to NASA for permission to use our previous work in this way. The views here expressed should, of course, in no way be interpreted as reflecting the official opinion or policy of NASA or any of the other sponsors of RAND research.

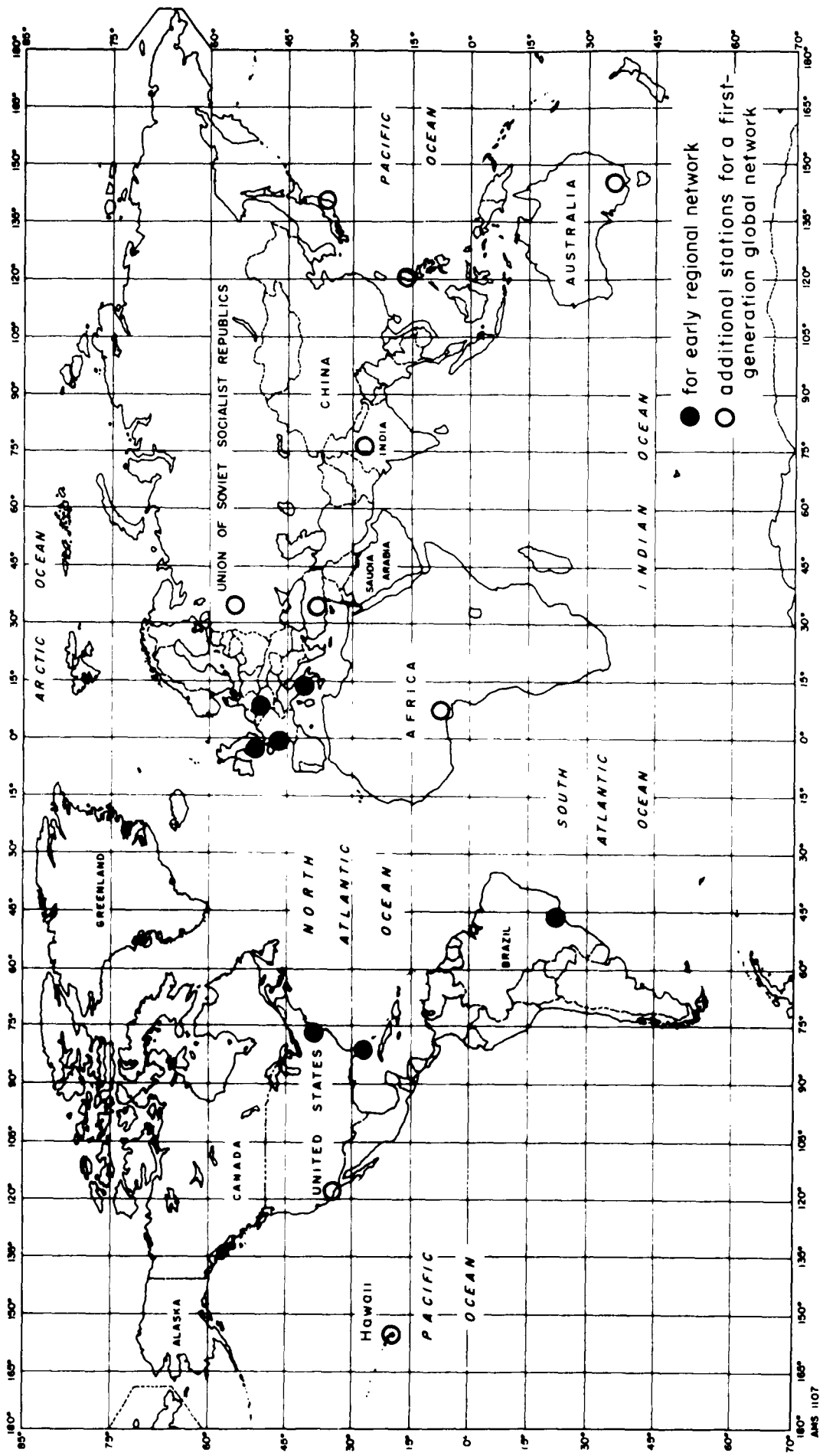


Fig. 1 — Possible terminal locations for early networks: regional and global

ACKNOWLEDGMENTS

The authors acknowledge with gratitude the assistance and critical comments of many RAND colleagues, particularly C. M. Crain, J. M. Goldsen, M. A. Margolis, G. Northrop, and R. L. Slighton, and of RAND consultant Murray L. Schwartz (Professor of Law at the University of California, Los Angeles).

We have also benefited from discussions with members of government departments and officials of the communications industry. But the views expressed here are our own.

CONTENTS

PREFACE	111
ACKNOWLEDGMENTS	vi1
LIST OF FIGURES	xi
LIST OF TABLES.	xiii

Section

I. INTRODUCTION.	1
Purpose of the Study	1
The Key Technological Problem: Satellite Reliability	1
Problems of International Coordination	3
System Characteristics and the Basic Choices.	5
Active Versus Passive Satellites.	5
Orbits, Altitudes, and Ground Stations.	5
Number of Satellites and Continuity of Service.	7
Regional and Global Networks.	12
Satellite Channel Capacity.	16
R&D Needs and Costs	18
II. SATELLITE TECHNOLOGY.	20
Satellite Design.	20
The Communications Repeater	20
Power Supply.	21
Satellite Orientation	22
Position Control.	25
Command and Telemetry	25
Temperature Control	26
Satellite Reliability	26
Orbital Configurations.	27
Some Special Topics	30
Time Delay and Echo	30
Active and Passive Systems.	31
System Choices.	33
III. SYSTEM COSTS.	37
Aims and Method of the Analysis	37
System Parameters and Specifications.	37
How the System Costs are Expressed.	39
Cost Implications for System Choices.	50

CONTENTS (continued)

IV. DEMAND AND REVENUES.	57
What is the Normal Rate of Growth of Telecommunica-	
tions Demand?	57
What Will be the Demand for Overseas Telecommunica-	
tion Service, 1962-1970?	59
What Revenues Could a Communications Satellite	
System Earn?	62
V. SYSTEM COST VERSUS SYSTEM REVENUE.	72

Appendixes

A. MILITARY USE OF COMMUNICATION FACILITIES	75
B. WORLD OVERSEAS TELEPHONE TRAFFIC IN 1960	83
C. OVERSEAS TELEPHONE TRAFFIC TO AND FROM THE UNITED	
STATES IN 1961	91
D. NUMBER OF TELEPHONES IN SERVICE BY CONTINENTAL AREAS,	
JANUARY 1, 1961.	95
E. INTERNATIONAL TELEX AND DATA SERVICE	97

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Possible Terminal Locations for Early Networks: Regional and Global	v
2. Relative Circuit Capacities of Satellites for Various Types of Orientation Subsystems	24
3. Number of Satellites Required in Various Orbital Configurations, New York to Paris Circuit	28
4. Estimated Level Annual Costs of Various Orbiting Systems, Successive Technologies.	52
5. Estimated Level Annual Costs for Early Regional Systems, by Number of Terminals	54
6. Estimated Level Annual Costs for Early Global Systems, by Number of Terminals	55
7. Increase Over 1965 of Worldwide Annual Overseas Telecommunication Revenues, 1965-1975	69

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Actual Lifetimes of Communications Satellites.	2
2. Continuity of Service versus Number of Satellites in Polar Orbit: Random Systems	11
3. Communications Satellite Terminal Stations, 1962 . . .	14
4. Random versus Stationary Systems: Advantages and Disadvantages.	34
5. Specifications of a Random Satellite System	40
6. Specifications of a Stationary Satellite System. . . .	41
7. Estimated Costs of Launched Satellites	42
8. Types of Random and Synchronous Satellites: Assumptions as to Lifetimes and Launch-success Probability . . .	43
9. Estimated Costs for Various Orbiting Systems	44
10. Estimated Costs of Individual Terminal Stations and Data Centers	46
11. Estimated Costs of Terminal Stations and Data Centers for Regional and Global Networks.	47
12. Revenue Estimate, 1965, 1970, 1975	67

I. INTRODUCTION

PURPOSE OF THE STUDY

The Communications Satellite Act of 1962 states that "... it is the policy of the United States to establish ... as expeditiously as practicable a commercial communications satellite system...." This system is "to be made available as promptly as possible and ... to be extended to provide global coverage at the earliest practicable date."¹

The purpose of the present study is to throw light on what may be "practicable" in terms of (1) communications satellite technology, (2) system costs, and (3) telecommunications demand and system revenues. These three related aspects of the problem are considered separately in Sections II, III, and IV of this Memorandum.

THE KEY TECHNOLOGICAL PROBLEM: SATELLITE RELIABILITY

If cost and continuity of service could be ignored, it might be possible in a physical sense to go ahead almost at once with the procurement and launching of communications satellites and the establishment of one or more satellite communication links. Communication links to and from spacecraft have already been employed successfully in a large number of cases; and, as shown in Table 1, five U.S. satellites have been placed in orbit with the specific purpose of providing experimental point-to-point communications between locations on the earth's surface. These communications satellites have, however, all been strictly experimental in purpose. The four active satellites died or suffered malfunctions and interrupted service in a matter of weeks or months.

With satellite lifetimes of weeks or months, the cost of regular service would be high out of all reason: not only too

¹Section 101 (a) and (b).

Table 1

ACTUAL LIFETIMES OF COMMUNICATIONS SATELLITES

<u>Satellites</u>	<u>Description and Remarks</u>	<u>Effective Lifetime in Orbit</u>
<u>Active Satellites</u>		
Score	A low-altitude active repeater launched on Dec. 15, 1958. Effective lifetime limited by battery power.	30 days
Courier	A low-altitude active repeater launched on Oct. 4, 1960. Effective lifetime limited by failure of command link. Repeater could not be turned on again.	18 days
Telstar	A mid-altitude active repeater launched on July 10, 1962. Failure of command link after about 120 days, later corrected.	
Relay	A mid-altitude active repeater launched on Dec. 14, 1962. Failed to operate initially because of power subsystem malfunction, later corrected.	
<u>Passive Satellite</u>		
Echo I	A spherical passive reflector, launched on Aug. 12, 1960, and still in orbit. The surface is now wrinkled and has lost some effectiveness as a reflector but is still usable.	2+ years

Note:

The meteorological satellites in the Tiros series have about the same complexity of design as the active communications satellites and have displayed about the same reliability: one subsystem or another failed to operate effectively after a few months in orbit.

high in relation to competing telecommunications systems, but too high to be "practicable" judged by almost any criteria. At the present time it is impossible to say with confidence exactly what a minimally acceptable standard of reliability would be, for there are many other technical and economic variables to be considered. But it seems clear that we are talking about a requirement for satellites with an effective lifetime measured in years rather than weeks or months.

PROBLEMS OF INTERNATIONAL COORDINATION

Even if the outstanding problems of communications satellite design were solved and reliable on-board components were already production items, there might conceivably be delays of several years in negotiating the international agreements necessary for a regional or global commercial network. These problems are being studied by others,¹ and we will not discuss them in detail, but their existence should be recognized here because they could affect the date of initial operations.

First, there are problems connected with the international allocation of the radio frequency spectrum. The allocation of frequency bands for operational communications satellite systems will be governed by international agreement. The subject will be considered at the Extraordinary Administrative Radio Conference for Space Communication to be held in Geneva in October 1963. There is general agreement that on technical grounds frequencies between 1000 mc/s and 10,000 mc/s are most advantageous for communications satellite systems. Frequencies above 10,000 mc/s will be of interest later on.

The United States has been preparing proposals to be presented as the basis of agreement, and these proposals may be summarized as follows:

¹For example, Murray L. Schwartz and Joseph M. Goldsen, Foreign Participation in Communications Satellite Systems: Implications of the Communications Satellite Act of 1962, RM-3484-RC, The RAND Corporation, February 1963.

(1) Recognizing that communications facilities have been rapidly expanding, and that communications satellite services are likely to do so, the United States considers it important to allocate adequate spectrum space to communications satellites to meet foreseeable needs up to the year 1975 at least.

(2) The necessary spectrum space can and should be allocated without waiting for full knowledge of all the system design parameters that may be employed in future operational systems.

(3) The United States is expected to propose that 2975 mc/s of spectrum space in the interval between 3700 and 8400 mc/s should be allocated to the communications satellite service, principally on a shared basis with existing services. A set of sharing criteria will also be proposed.

A second type of international problem concerns the general nature and characteristics of a world-wide satellite communications system intended ultimately to serve the needs of all countries. There are competing views especially about the best method of ownership and control of such a system. Some countries may desire their own national systems in competition with a U.S. system. Some may favor a truly international agency rather than a corporation established under U.S. legislation and intended to serve both U.S. and international purposes. Some may hope to transform an American corporation into an international organization, or to subordinate it to an international consortium. The course of negotiation may not be easy and could be time-consuming.

Third, and quite apart from the more general international problems hinted at above, there will be specific problems requiring negotiation with foreign corporations and agencies of foreign governments, particularly the governments of countries in which terminal stations would be located initially. While bilateral agreements for experimental stations have not been difficult to achieve, on an interim basis, the more permanent and detailed technical and financial agreements needed to support a full-time regional or global service may

require considerable effort to achieve.

SYSTEM CHARACTERISTICS AND THE BASIC CHOICES

The major technological problem is the problem of satellite reliability--of sufficiently long working lifetimes in orbit so that the satellite replacement rate is acceptably low. This is the key problem whatever the other characteristics of the system may be, and therefore in Section II we fix our attention on the reliability problem and related aspects of satellite technology. Here we will briefly outline the general characteristics of the various satellite communications systems.

Active Versus Passive Satellites

The role of the satellite in the communications link is the basis of a fundamental distinction. If the satellite receives radio signals from one station and merely reflects them back toward other stations, its role is passive, and the satellite and system are said to be "passive." An "active" satellite, on the other hand, receives, amplifies, and sends radio signals; and for this purpose it possesses a more or less complex electronic mechanism and possibly other components. Although the Echo passive satellite was successful in several respects, it is generally assumed that the future lies with the active systems. In our opinion the issue should not be foreclosed, and in Section II we return to it briefly.

Orbits, Altitudes, and Ground Stations

While any number of orbital configurations can be imagined, from the point of view of terminal-station design the important distinction is between "stationary" satellites and other satellites. Stationary satellites occupy a fixed point in the sky as seen from a particular ground station, and the station antennas can therefore be designed for fixed rather than moving mounts. Satellites in other types of orbits move from horizon to horizon as seen from a ground station, and for these the station antennas must be designed for tracking the satellites across the sky. Other things being equal,

tracking antennas are more costly to construct and install than fixed antennas. But tracking antennas have the advantage that they can be used for all types of satellites, including stationary satellites. They are thus more flexible in use, and this flexibility may be worth paying for in the early years of communications satellite development.

The orbit for stationary satellites is uniquely defined: it lies in the earth's equatorial plane at an altitude (19,300 nautical miles) such that the satellite moves with the same angular speed as the earth's surface, and thus makes one revolution about the earth's axis every 24 hours.¹ Compared with most alternatives, this is a high-altitude orbit, and as a stationary satellite must be placed in orbit with a high degree of accuracy with respect to altitude, speed, and direction, a large booster and first-class guidance are required. Moreover, to overcome the effects of natural perturbations, location-keeping devices are required on board stationary satellites, and these devices increase satellite weight and complexity. No satellite of any kind has yet been placed in stationary orbit.

For nonstationary satellites many different orbital configurations have been proposed. In general these provide in one way or another for a succession of satellites to pass through the space simultaneously visible from each of two ground stations, so that there will almost always be at least one satellite that is "mutually visible" from the two stations and therefore available to relay signals from one to the other.

Proposals for nonstationary satellite systems usually provide for orbital altitudes considerably lower than the 19,300 nautical miles required for stationary satellites, and can permit greater

¹Sometimes stationary satellites are referred to as "24-hour" or "synchronous" satellites, but we prefer the term "stationary" because it suggests more clearly the relationship between the satellite and its ground stations.

margins for error in their orbital placement. Thus, they make less rigorous demands on rocket and guidance technology, and cost less per pound of satellite placed in orbit.

Number of Satellites and Continuity of Service

Generally speaking, a satellite provides less coverage at low than at high altitudes. In all nonstationary systems, however, a number of satellites are required to perform the functions of a single, functioning, stationary satellite. As a nonstationary satellite moves away and ceases to be visible from a given pair of terminal stations, another satellite must come over to replace it.

The number of satellites required in nonstationary systems depends upon several factors:

- (1) the orbital altitude of the satellites and the latitudes of the ground stations and the distances between them;¹
- (2) the configuration of the orbits, for example, whether equatorial or polar;
- (3) the distribution of satellites within the orbits, that is, whether random or controlled by on-board, position-keeping devices; and
- (4) the continuity of service or percentage of in-service time required.

In general it can be said that the number of nonstationary satellites required varies within wide limits depending on the characteristics of the system, ranging from four to forty or more satellites.

Within the area of its coverage, a single stationary satellite can provide continuous service between any two stations but for

¹The number of ground stations and their longitudes are of secondary importance in determining the number of satellites required in nonstationary systems, and in general a nonstationary satellite system that serves one region can serve other regions simultaneously without requiring additional satellites.

systems with lower (or higher) orbital altitudes, a number of satellites must be kept simultaneously in orbit to provide something like continuous station-to-station service. One of the great advantages of the stationary satellite concept is that only one functioning satellite is needed to provide broad regional coverage, and three could serve a world-wide network of stations covering the whole globe except for the polar regions.

In what follows we have chosen as a typical first-generation nonstationary system one with satellites randomly distributed in polar orbits¹ of about 6000-nautical-mile altitude. This is not offered as being necessarily a single best choice, but we believe it is a reasonable choice if one is seeking an early operational system, and we use it as one of the basic systems in the cost comparisons given in Section III. The 6000-nautical-miles altitude gives good coverage and this altitude should be easy to attain with present booster technology;² and the satellites themselves are relatively simple, without the complication of on-board position-keeping equipment. This system, which we will refer to from now on as the random system, makes much less severe demands on technology than would a stationary system, and might therefore be brought into operation a number of years earlier.

¹In this orbital configuration, the satellites are initially placed in orbit in planes perpendicular to the earth's equatorial plane. To a first approximation, these orbital planes remain fixed in inertial space, but because the earth rotates underneath the satellites, some satellites in each orbit become visible from every point on the earth's surface during the course of the day.

²If the Atlas-Agena or a more powerful booster is used, a number of satellites (perhaps three or four) can be launched with the same vehicle.

Satellite reliability, we have said, is the key technological problem. For stationary satellites, it is also the key to the number of satellites required in orbit. If only a single stationary satellite is in place and it stops functioning, service comes to an end throughout the whole region, and other regions will also suffer in so far as they depend on the failed satellite to relay signals from one region to another. As all the steps necessary to put a replacement in orbit would take days if not weeks to accomplish, a failure of this kind would be little short of catastrophic: it would impose unacceptably long (although perhaps infrequent) discontinuities in service.

For this reason, nearly every proposed stationary system provides for spare satellites to be constantly in place in orbit. The number of spares in orbit varies with the system designer's estimate of satellite lifetimes and his assessment of the standard of continuity required. One current design calls for 15 satellites for a global network. But this design is intended to provide for a higher standard of service continuity than would be generally required for commercial telecommunications. For commercial purposes, at least 1 spare per region would certainly be required, and possibly (if satellite lifetimes are short) 2. Thus, depending on satellite technology, it would appear that a global system using stationary satellites would require 3 satellites in service plus an additional 3 or 6 as orbiting spares.

One important difference between random and stationary systems is that in the random system the same number of satellites will serve both regional and global networks. That is, with random satellites, a regional network can be expanded to encompass the globe without requiring more satellites in orbit; all that is needed is the installation of additional ground stations.

For the random system, the problem of service continuity is not a matter of long and sudden outages; it is a question of short delays occurring predictably several times a day. These delays would be somewhat like the delays encountered in making a radiotelephone call or in placing a transatlantic telephone call during a busy period. But these delays with the random system would be precisely predictable,¹ and this suggests that they could be handled in such a way as to reduce the delay apparent to the customer. Table 2 shows how these delays would be related to the number of random satellites in orbit. The question, How many satellites are needed? then resolves itself into a question of the percentage of in-service time required. It is readily seen that in the random system the failure of a single satellite (or even of several satellites) produces only a slight degradation of service, easily tolerated until a replacement could be put in orbit.

We do not know how to decide in the abstract what minimum percentage of in-service time would be required for successful commercial operations, but we are inclined to think that predictable outages of 20 or 25 per cent would be acceptable at the beginning. Over heavily traveled routes the system would initially be used to supplement submarine telephone cables and other existing means of telecommunications. The cables could continue to handle high-priority telephone conversations and other messages for which delays would not be acceptable, while record and data messages (both commercial and military) and other traffic that routinely queues for transmission could be economically diverted to the satellite system. As traffic increased over the satellite system and the need for greater continuity and more channels made itself felt, the number of satellites could be increased. And this might become increasingly more economical as advances in technology made longer satellite lifetimes possible.

In short, we think a random system could begin with as few as 6 to 9 satellites in orbit (73.7 to 86.5 per cent in-service time). As demands arise for more continuous service, the system

¹Except, of course, for those due to satellite failures.

Table 2
CONTINUITY OF SERVICE VERSUS NUMBER OF SATELLITES IN POLAR ORBIT:
RANDOM SYSTEM^a

Number of Satellites ^b	In-Service Time ^c (per cent)	Two or More Satellites Visible (per cent)	Expected Interval Between Outages of Durations Exceeding			Mean Duration of Outages
			0	15 min.	30 min.	
6	73.7	34.5	3.2 hrs.	4 hrs.	5 hrs.	50 min.
9	86.5	56.4	4.2	6	10	33
12	93.1	72.5	6	11	20	25
15	96.5	83.3	9	20	42	20
18	98.2	90.0	15	38	93	17
21	99.1	94.2	26	3 days	9 days	15
24	99.5	96.7	43	6	21	12 ^m 30 ^s
27	99.8	98.1	3 days	12	49	11 ^m 10 ^s
30	99.9	98.9	6	25	120	10 ^m
33	99.94	99.4	10	52	~ 300	9 ^m 05 ^s
36	99.97	99.7	18	110	~ 1200	8 ^m 20 ^s

Notes:

- ^aIn-service time has been calculated for terminal stations located near New York and Paris, about 40-50 degrees north latitude. For links of the same distance outages would be slightly more frequent toward the equator and less frequent toward the pole.
- ^bThe numbers are shown as multiples of three, because it is expected that three satellites can be orbited simultaneously by the same launch vehicle.
- ^cOne or more satellites simultaneously visible from both terminal stations.

might increase the number of satellites to 12 or 18 (93.1 or 98.2 per cent in-service time). With in-service times of 90 per cent or over we think the satellite system might compete very effectively with submarine cables even for voice traffic. But for certain types of priority telephone calls and military command and control traffic, even 18 random satellites might not provide sufficiently continuous service: 30 or even 36 satellites might be required. This requirement would double, triple, or even quadruple the satellite component of the system cost, and for this reason, among others,¹ we have not considered traffic of this kind as playing a role in the initial commercial operations of the system. In Section III we offer cost estimates for the random system employing 6, 9, 18, and 36 satellites.

Regional and Global Networks

The Communications Satellite Act of 1962 states that a global communications system is desired at the "earliest practicable date." But the Act clearly envisions an evolutionary development: a partial or regional system will be made available "as promptly as possible," and then "extended to provide global coverage."

Where should the first regional network be established? The answer to this seems clear. The first regional system should serve the Atlantic community--North America and Western Europe and probably part of South America also. There are two reasons for this conclusion:

First, the Atlantic region is already provided with a number of satellite terminal stations. These were built primarily for testing experimental satellites, but the ground equipment needed for satellite communications is technologically straightforward in character, and

¹There would probably be little foreign opposition to the carrying of routine military traffic of the kind now handled commercially; but military command and control traffic could raise international problems. See Schwartz and Goldsen, op. cit., pp. 21-26.

the experimental stations should be convertible for routine operational use without much difficulty. All these existing stations incorporate tracking antennas, and they could therefore be used with either stationary or nonstationary satellite systems.

Second, according to the evidence given below in Section IV, the traffic on the North Atlantic route will be pushing capacity by 1965 or 1966, and additional channels will be needed there before the need arises elsewhere. Moreover, this route appears to have the greatest telecommunications revenue potential for many years to come. It brings together the two areas with the most highly developed internal communications facilities; North America and Europe together possess nearly 90 per cent of the world's telephones.

As shown in Table 3, there are now two stations on the eastern seaboard of the United States, four in Western Europe, and one in South America. Without committing ourselves to these particular locations¹ or station characteristics, we think that two U.S. and five foreign stations constitute a suitable nucleus for the Atlantic region, and in Section III we offer cost estimates for a seven-station regional network. To bring it into operation the main thing needed is the orbiting elements of the system--the communications satellites themselves. This conclusion emphasizes again that the key problem is satellite technology.

In going from a regional to a world-wide system, it seems desirable to distinguish between a first-generation global network on the one hand and more extended networks on the other. A first-generation or minimum global network need not have a large number of stations, but it seems reasonable to expect it to provide service around the globe and to include at least one terminal station in Africa, Asia,

¹We should, for example, prefer to have one of the U.S. stations farther south, possibly in Florida. In Europe perhaps three stations would be enough at present, and two (rather than one) might be desirable in South America.

Table 3

COMMUNICATIONS SATELLITE TERMINAL STATIONS, 1962^a

Location	Antenna Size
<u>Eastern United States</u>	
(1) Andover, Maine	horn 60 ft by 60 ft
(2) Nutley, New Jersey	dish 40 ft diameter
<u>Western Europe</u>	
(3) Goonhilly Downs, England	dish 85 ft diameter
(4) Pleumeur-Bodou, France	horn 60 ft by 60 ft
(5) Raisting, West Germany	dish 85 ft diameter
(6) Fucino, Italy	dish 30 ft diameter
<u>South America</u>	
(7) Rio de Janeiro	dish 30 ft diameter
<u>Western United States</u>	
(8) Mojave, California	dish 40 ft diameter

Note:

^aThe stations listed here were intended primarily for testing and vary somewhat in a number of characteristics; the antenna size is probably the most important characteristic, for it primarily determines the bandwidth capacity of the station.

Plans are underway for the construction of a station in Japan, and in the United States several agencies of the Department of Defense possesses stations (not listed here) for use with communications satellites.

Australia, and the Near East, as well as in Europe and North and South America. A hypothetical system of this kind is shown in Fig. 1 (Preface, p. v). To the initial seven-station regional network serving the Atlantic area, there would be added two more U.S. stations (West Coast and Hawaii) and seven more foreign stations (Japan, the Philippines, Australia, India, Turkey, Africa, and either Scandinavia, Eastern Europe, or the Soviet Union) making a total of four U.S. and twelve foreign stations. For the cost comparisons in Section III, we define these sixteen stations as constituting a first-generation global network. Obviously, we might have chosen a number slightly larger or smaller or varied the locations of the stations, but differences of this kind would not significantly change the result.

We will not attempt to describe a second-generation or extended global network in detail, for there are too many uncertainties about the number and location of ground stations. Even before the first-generation system is fully in operation, we expect new stations to be planned, and the total linked into the system may rise fairly rapidly. It would be rash to set anything like an upper limit to the number of stations ultimately included, for political considerations overseas may be as influential as economic ones; and foreign aid to the emerging nations may make it possible for them to acquire their own terminal stations before they might otherwise do so.

As pointed out elsewhere, the location of terminal stations is potentially a very sensitive international issue.¹ By means of ground lines and existing cables, all the world's populated areas might be linked into global satellite system with relatively few satellite terminal stations. A limited system of this kind might make the most economic use of the world's resources; but, primarily because of political considerations in the various countries concerned, the number of stations built is likely to exceed the economically efficient number.

¹Schwartz and Goldsen, op. cit., p. 54.

These problems are outside the scope of the present study, which focusses on the initial regional and first-generation global systems. However, the size of the global network (in terms of numbers of terminal stations) could be one of the important factors affecting the choice of system. There are two somewhat opposing considerations:

(1) As already pointed out, with a random satellite system the same number of satellites would serve both a regional and a global network of terminal stations. Thus the transition from regional to global service would require only the construction of additional terminals.

(2) For the random system, however, each terminal station is considerably more expensive than for the stationary system. As shown in Section III, the relative cost of the two systems (including the orbiting satellites and all the domestic and overseas terminal stations) would be dominated by the relative costs of the stations if they became sufficiently numerous.

Satellite Channel Capacity

In comparing the costs of submarine cables with various satellite systems, the basis of earlier comparisons was annual cost per channel of service provided. But relative to cables the cost advantages of satellites can now be taken as generally accepted in principle, and the question is not how satellites compare with conventional systems, but how one satellite system compares with another.

In comparing the various satellite systems realizable in the near future, we doubt that circuit capacity as such should be a dominating criterion of choice. Any commercial satellite system that comes into operation in the next few years is likely to possess excess capacity. And whatever the type of system, its capacity can be expected to increase fairly rapidly as a result of advances in satellite technology. For the next 10 years at least, we expect that sufficient demand rather than sufficient capacity will be the relevant problem. If this is so, we are justified in fixing attention directly on system

cost (rather than cost per channel) as the important cost criterion. Moreover, the estimated system costs are probably much more reliable figures than the estimated costs per channel, for there are very large uncertainties (as large as factors of two or three or four) about the circuit capacities that will be possible with some electronic components under development.

Apart from the technological uncertainties, there are considerable difficulties in comparing the station-to-station circuit capacities of different systems, for these capacities depend upon the type, number, and location of the terminal stations as well as the characteristics of the satellites themselves. Multiplying satellite capacity by the number of working satellites in orbit sets an upper limit to the quantity of station-to-station channels conceivably available from the orbiting elements of a system. Thus, a system with 12 random satellites of 240 voice channels each would have 2880 as the maximum number of station-to-station voice channels; and a system with one stationary satellite of 2000 voice channels would have 2000 as the maximum. But with the random system the maximum number could be approached only with a widespread global network of many terminals so located as to allow full time use of all satellites. Whereas with the stationary system the maximum could be attained within a single regional network or even with a single pair of terminals. Therefore, to speak precisely about the capacity of two systems it is necessary to specify the terminal network in considerable detail.

In general it can be said that, for anything like full utilization of satellite capacity, the stationary system would allow for greater flexibility in the number and choice of terminal stations, as well as for heavier traffic between any pair of stations. For a first-generation global network, however, these considerations would not appear to weigh seriously against the random system, for it would probably have adequate capacity even for the routes with heaviest traffic. The evolutionary approach would seem to be called for. If a random system is chosen at the beginning because of earlier availability and lower system cost, it could be supplemented later on by stationary satellites: in the first instance, by

stationary satellites serving the region with heaviest station-to-station traffic.

The U.S. proposals for the international allocation of frequency bands for communication satellite systems were referred to earlier. An estimate of the number of channels that would be provided by the proposed 2975 megacycles of spectrum space may be of interest. An upper limit could be obtained with a modulation technique in the communication satellite system which uses frequency spectrum most efficiently (single sideband transmission to and from the satellite). In this case, approximately 200,000 duplex voice channels could be accommodated. But in early systems, modulation methods are likely to be employed that make most efficient use of the satellite power. This consideration leads to wideband modulation, that is, the occupied bandwidth may be about 20 times larger than the minimum required. On this basis, implementation of the U.S. proposal would allow for as many as about 10,000, station-to-station duplex voice channels in any given geographical region (say the Atlantic), and an equal number in other regions (say the Pacific) sufficiently remote so that there would be no mutual interference.

R&D NEEDS AND COSTS

Research and development in space communications in the United States has hitherto been supported by the National Aeronautics and Space Administration (mainly through R&D contracts) and by the Department of Defense, as well as directly by industry, for example, by AT&T. There is nothing in the Communications Satellite Act of 1962 that requires a major change in this pattern of support. The communications satellite corporation established under the Act is authorized to engage in R&D,¹ and the Act directs NASA to cooperate in R&D to the extent deemed by NASA to be in the public interest.² Presumably NASA's support in this way will not be charged to the

¹Sections 305(a), (b)(1).

²Section 201 (b)(2).

Corporation, although it appears that satellite launchings requested by the Corporation for its own R&D program will be furnished by NASA on a reimbursable basis.¹

We assume that the major burden of R&D expenses in the space communications field will continue to be carried by government agencies, at any rate during the immediate future, and in the cost estimates presented in Section III, R&D is not included as an element of system cost. This does not imply that the cost of future R&D in this field will be negligible; on the contrary, much remains to be done and it will be costly. Nor does it imply that R&D will be equally costly for all systems. But it does seem probable that for the time being most of the R&D needed will be accomplished as part of continuing programs conducted in the public interest for one reason or another by NASA and the Department of Defense.²

Although the Corporation benefits in this way, it seems clear that it will find it necessary to maintain an R&D effort concerned with system and component design to meet its own needs.

¹Section 201 (b) (2) and (3). See the discussion in Schwartz and Goldsen, op. cit., pp. 7-8.

²Of course, the Corporation may benefit substantially also from R&D done abroad.

II. SATELLITE TECHNOLOGY

Whether a profitable satellite communications system can be placed in operation depends on the useful lifetimes of the satellites in orbit. This is the key technological problem, as suggested by Table 1, and as will appear more clearly from the cost estimates given below in Section III. Because the answer to the problem lies in the satellites themselves, this section focuses on satellite design.

SATELLITE DESIGN

In addition to the communications repeater itself, an active communications satellite contains several subsystems. These provide for:

- power supply
- orientation control
- position control
- telemetry and command
- temperature control.

Some types of satellites do not contain all of these subsystems; and the presence or absence of a subsystem determines how a satellite can be used and in what types of orbital configuration.

The Communications Repeater

The communications repeater consists of a receiver, a frequency translator, and a transmitter. In its operation it is equivalent to repeaters employed in line-of-sight microwave links, and most of its components are well within the present state of the art. One possible problem area is the power output device, which must be

efficient and long-lived. In all satellites now under development, this device is a traveling wave tube with a power output in the range from about 1 to 10 watts. It appears that some of the tubes now in existence will meet at least the minimum requirements for efficiency and long life.

Power Supply

Early communications satellites will derive their electrical power from solar cells, which are solid-state devices that convert intercepted solar radiation into electrical energy. Approximately 8 to 10 watts of prime power can be obtained per square foot of solar cell surface.

Solar cells are subject to damage from impact by high energy particles in space, particularly from solar flare activity and Van Allen radiation. Degradation of solar cell output can be reduced by shielding the solar cells with a layer of optically transparent material. Only particles of sufficient energy to penetrate the shield can damage the solar cells. At orbital altitudes of about 6000 nautical miles and above, a thin Sapphire shield such as used on Telstar is expected to reduce the damage caused by Van Allen radiation so that it is a very small hazard. Solar flare radiation, however, does contain very high energy particles, but large flares capable of causing significant damage to satellite solar cells appear to be rare; the three most recent occurred in November 1949, in February 1956, and in May 1960. As the total radiation caused by these large flares is not well understood, it is difficult to estimate the damage that they might cause in satellite power supplies.

Aside from shielding, another means of increasing the life of the power supply would be "overdesign," for example, by doubling the number of solar cells. The characteristics of the radiation damage are such that a doubling of this kind may increase the lifetime of the power supply by as much as a factor of a hundred. If the precise nature of the space environment were known, one could arrive at an optimum combination of shielding and overdesign so as to assure a

given power level for a prescribed lifetime in orbit. But even in the absence of precise knowledge about the environment it is believed that solar power subsystems can be designed so that power supply will not be the limiting factor for satellite lifetime.

The solar cells do not supply power when the satellite is in the earth's shadow. When satellite operation is required during such periods, storage batteries are needed and are, like any additional complexity, an element of potential unreliability. Omission of the storage batteries impairs the communication capability of most satellite systems to only a small degree,¹ for in many situations while one satellite is in shadow another that is still illuminated by the sun will be available for use.

Satellite Orientation

The orientation or attitude of the satellite is important in two ways: (a) relative to the sun, so as to maximize the power supplied by the satellite's solar cells, and (b) relative to the earth, so as to maximize the energy transmitted from the satellite to the ground stations. In practice the latter is the more important. Generally, three types of satellite orientation relative to the earth can be distinguished:

- (1) Unoriented satellites, that is, with orientation changing relative to the earth.
- (2) Spin-stabilized satellites, with their spin-axis oriented perpendicular to the orbital plane of the satellite.
- (3) Fully oriented satellites, with a predetermined part of the satellite pointing toward the earth at all times.

For each of these a basically different antenna pattern can be employed to radiate energy toward the earth. The unoriented satellite can at best have an antenna that radiates equally well in all

¹For stationary satellites this impairment would occur only near the spring and autumn equinoxes, and would amount to a maximum outage of about 70 minutes near local midnight.

directions. With this pattern a large part of the satellite's power is radiated into space and is lost. A spin-stabilized satellite with the spin-axis perpendicular to the satellite's orbital plane can radiate more of its power toward the earth than an unoriented satellite can. An antenna pattern that is a figure of revolution about the spin-axis can be employed with the spin-stabilized satellite, and the beamwidth in any plane containing the spin-axis would theoretically be equal to the angle subtended by the earth as seen from the satellite. A fully oriented satellite can utilize a pencil-beam pattern designed to radiate all its energy toward the earth.

In cases (2) and (3) the ideal antenna pattern depends on the orbital altitude of the satellite. A fully oriented satellite at the altitude of a stationary orbit (19,300 nautical miles) can radiate its power toward the earth about one hundred times more effectively than an unoriented satellite at the same altitude. Thus, for the same radiated power the fully oriented satellite can provide about a hundred times as many channels.

The relative circuit capacities of the three types of satellites are shown as a function of altitude in Fig. 2.

Present satellite programs fall into these categories:

- (1) Telstar and Relay: unoriented relative to the earth; Telstar is spinning but oriented relative to the sun.
- (2) Syncom: spinning and oriented relative to earth.
- (3) Advanced Syncom: oriented relative to the earth, partly by means of electronic antenna-beam switching.

It is clear from Fig. 2 that, for circuit capacity, the fully oriented satellite is to be preferred. But however it is achieved, the orientation control mechanism contributes greatly to the complexity of the satellite. Ideally, one wants an orientation-control subsystem that consumes no energy and is simple in design and construction. Theoretically, it could be obtained through exploitation of the gravitational gradient, but there has been little experimentation along these lines and further work is very much needed. In short, reliable, long-lived orientation control seems to be a matter of

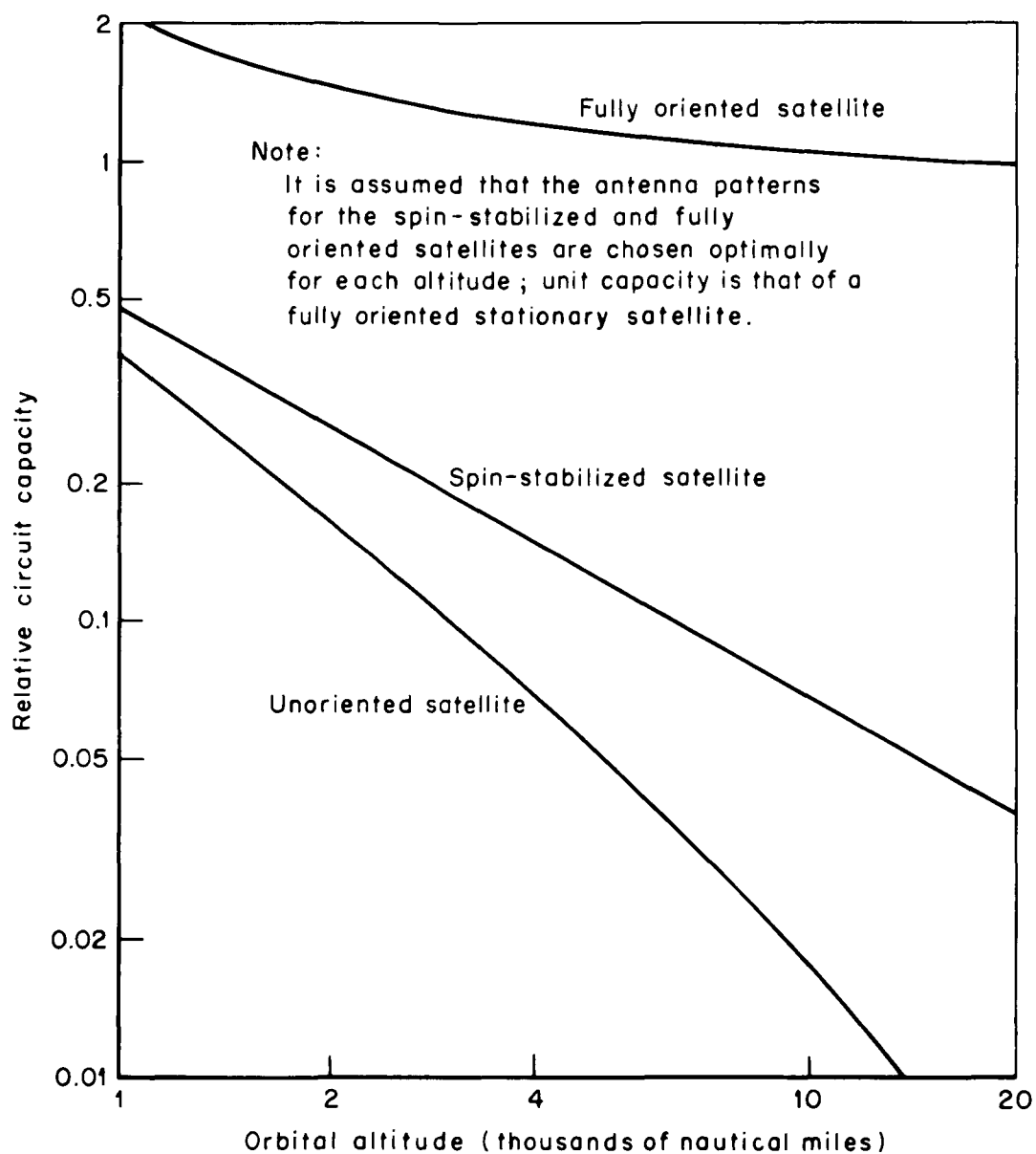


Fig.2 — Relative circuit capacities of satellites for various types of orientation subsystems

considerable difficulty and has been a troublesome problem in several space programs.

Position Control

On-board subsystems for position control or location control, sometimes referred to as station keeping, are needed in systems in which the satellites are required to remain in certain fixed orbital patterns with respect to each other. The position of a satellite can be changed by applying thrust corrections in predetermined directions to produce slight changes in orbital velocity.

Stationary satellites require a position-control system that is operative during their entire lifetime, for natural orbital perturbations will cause them to drift with respect to the earth regardless of how accurately they are initially placed in orbit. Although the amount of fuel needed is not very great (a few per cent per year of satellite weight), a sensitive position-control propulsion subsystem capable of operating over a period of years without failure is necessarily a considerable addition to satellite complexity, and compounds the problem of satellite reliability. Random satellites are, of course, free from this problem.

Command and Telemetry

Command links are used to perform certain switching functions in the satellite. When a position-control subsystem is present, a command link is necessary to adjust the satellite position, which is monitored by ground observations. In principle, a satellite without position control can function without a command link. In any case the dependence of the satellite on a command link should be minimized, for it is a potential source of satellite failure. The Courier and Telstar satellites both suffered from malfunctions in the command link. In addition to its use for position control in some systems, a command link or some other means of preventing unauthorized use of satellites may be necessary under some circumstances.

Experimental satellites are equipped with extensive telemetry

subsystems to provide for the monitoring of various aspects of satellite performance, such as power supply output and temperature. It can be expected that, once a particular satellite design has proved reliable, its telemetering functions can be reduced considerably.

Temperature Control

Some means of temperature control is needed to insure that the satellite and its components operate at all times within the designed temperature limits. However, experience to date indicates that temperature control should not be an area of major difficulty, although careful design is required.

SATELLITE RELIABILITY

None of the satellite subsystems discussed above requires what is sometime called a technological breakthrough. In each case, specific designs are readily available, some have been built and tested, others are contained in numerous proposals. No active communications satellite, however, has yet demonstrated a continuous lifetime in orbit that could make any system commercially attractive. Thus, the key problem of reliability remains.

The magnitude of this problem can be readily illustrated. Consider a satellite that requires the functioning of 1000 components of equal reliability. If such a satellite is to have a lifetime (mean time to failure) of five years, components are needed whose failure rate is no more than about 20 per billion component hours. However some of the high-quality components needed in some satellite designs are below this standard of reliability at present, having failure rates more than ten times this number, even when operated at a small fraction of nominal capacity.

Predicted or calculated reliability estimates for satellites are helpful but they are unverified and therefore uncertain. Actual performances in orbit have been quite disappointing when compared to the mean-time-to-failure values normally used in system cost estimates. The road to success promises to be long, full of frustrations, and expensive.

What can be done to solve the problem of poor reliability?

(1) Most important of all, simplicity in every subsystem must be pursued as an end in itself, and the satellite should contain only those subsystems absolutely necessary. A component or subassembly that is not there cannot fail.

(2) Margins of extra strength, capacity, and so forth must be incorporated in all subsystems, and components must be operated at only a small fraction of their nominal capability.

(3) Spare ("redundant") components must be included where the pay-off in reliability is greatest. All subsystems should be designed to have approximately the same reliability; it would be absurd, for example, to have a satellite with a highly reliable communications package and an orientation-control subsystem of low reliability.

(4) Quality control of satellite components and testing at the component, subsystem, and system level are of the utmost importance. Prolonged testing of the fully assembled satellite is necessary to identify weak components that must be replaced.

Progress is being made along these lines, and we believe that if sufficient attention is given to the problem of reliability, the improvements postulated in the cost estimates in Section III (see Table 8) can be realized.

ORBITAL CONFIGURATIONS

With the problems of satellite design and reliability in mind, we can now re-examine the various orbital configurations in terms of the demands they make on the satellite itself. As Fig. 3 shows, the basic trade-off in the orbiting elements of a system is between satellite complexity and satellite numbers.

Random configurations can accept very simple satellites, without position-control and command subsystems, and even without orientation control. High orbits are not required, and the accuracy of placement in orbit is not critical. Because they do not contain position-control devices, random satellites will drift with respect

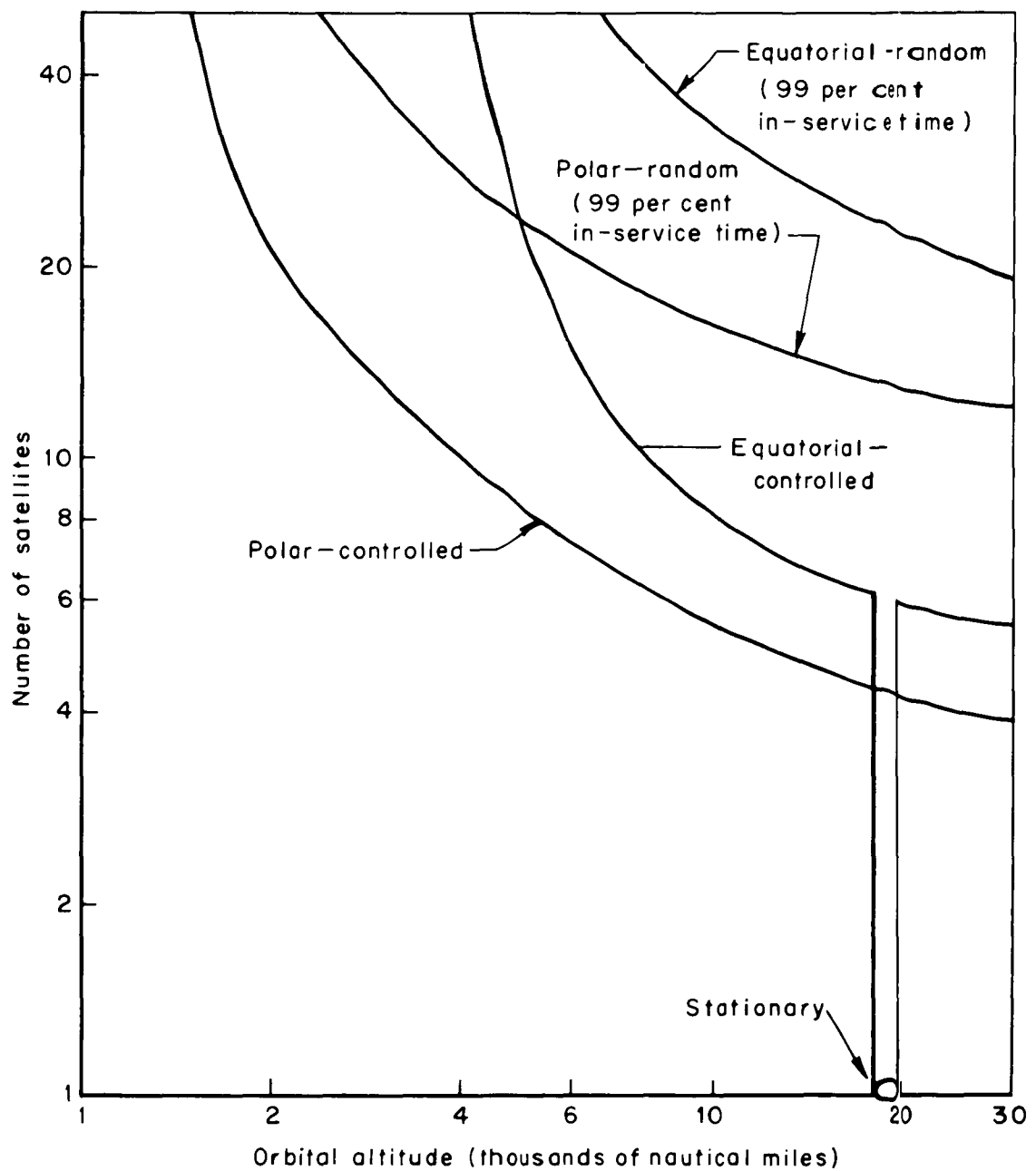


Fig. 3 — Number of satellites required in various orbital configurations, New York to Paris circuit
(5° minimum ground terminal antenna elevation)

to each other. In a random system there will therefore be outages when no single satellite is simultaneously visible from both stations in a given link, but the duration and frequency of outages can be decreased by increasing the number of satellites. Figure 3 shows the numbers required at various altitudes for 99 per cent in-service time (1 per cent outage rate).¹

Controlled configurations require satellites with position-control subsystems that enable them to remain in fixed patterns with respect to each other, so that at all times at least one satellite is mutually visible from each pair of terminal stations. As a result, continuity of service is established so long as all satellites are operating. Under fairly typical conditions, the number of satellites needed to provide continuous service with position-controlled satellites is only one-third to one-half the number of satellites needed to provide 99 per cent in-service time in a random system.

The stationary satellite is a special case of a controlled configuration: it has a unique orbital altitude in the equatorial plane. It requires a precise position-control subsystem and probably, because of its high altitude, an orientation-control subsystem as well. It is therefore the most complex type of satellite and is likely to be the heaviest. Because of its weight and its high orbit, it makes the greatest demands on launch vehicle performance; and precise guidance is needed for putting it initially into orbit.

The outstanding property of the stationary configuration is that the satellite appears to remain fixed with respect to points on the earth's surface. Thus, in principle, only one satellite is needed for a given region, and three such satellites, properly located and operating, could provide continuous world-wide coverage except for the polar caps. However, because of its complexity it is likely to pay a price in reliability, and to avoid the long outages that would occur with satellite failure, more than three satellites are likely to be needed for a

¹Cf. Table 2 for 18 and 21 satellites.

world-wide system: probably six and perhaps even nine.

Of the satellites now under development, Telstar and Relay are limited by their design to use in random configurations, whereas the Syncom series is designed for controlled configurations.

SOME SPECIAL TOPICS

Time Delay and Echo

There has been considerable discussion concerning the effects on two-way voice communication of propagation-time delay and echo, particularly in the stationary and other high altitude systems. Results of limited tests are not conclusive and reliable data are difficult to obtain, for the effect is subjective.

The nature of the difficulty is as follows: when using a short line, a speaker does not notice echoes of his own voice, but the return to his ear of words he has spoken a half-second or a whole second after he has spoken them can be annoying. Also, the delay between the words of one speaker and the response of the other speaker can be psychologically disastrous to a conversation between people accustomed to face-to-face speech, frequent interruptions, and rapid give and take. One speaker, learning after a half-second that he has been interrupted, may halt, while simultaneously the other speaker, regretting his rudeness, may also halt. After a second's pause both begin again, stop, start and, in short, have some difficulty in communicating.

Tests to date indicate that people adjust very rapidly to the delay in the absence of echo. No echo is generated in the satellite system itself because it is what is called a "four-wire" line. Echoes do originate at various points in the local telephone system, and echo suppressors have been installed in long-distance telephone circuits for a number of years. With the greater delay times involved in satellite transmissions, the existing suppressors may be inadequate, and the installation of new types of echo suppressors may be necessary in communications systems employing satellites.

In any event the combined effect of time delay and echo is a significant factor that must be considered in the choice of orbital altitude for a communications satellite system providing commercial telephone service. Quantitative tests are needed urgently to determine how significant the problem is. On the other hand, it is quite clear that one-way communications (television, data messages, etc.) will not be affected.

Active and Passive Systems

The first artificial satellite whose primary function was to serve as a reflector for communication signals was Echo I, a spherical balloon 100 feet in diameter launched in August 1960.

Echo I was in some respects an unqualified success:

- o It proved that deployment of very large structures after orbit injection is feasible.
- o The initial communication capability proved to be almost precisely as calculated and predicted.
- o Even after more than two years in orbit the reflecting cross-section has degraded only moderately and Echo I is still usable.

A passive satellite only reflects electromagnetic energy which it intercepts while an active satellite receives, amplifies, and transmits energy. The amplification in early active-satellite designs (such as Telstar) is typically of the order of 10 billion times. But a passive satellite such as Echo I intercepts about 10 million times as much energy as is received and amplified in an active satellite of the same weight. The difference is a factor of about one thousand. For a passive system to achieve equal energy at the receiving terminal (and therefore equal bandwidth), this difference must be made up either by increasing the size of the ground terminals (transmitter power and antenna size) or the size of the passive satellite or both.

A passive satellite has two outstanding features which make it technically appealing:

(1) Simultaneous use of the same passive satellite in many different communication links presents no problem. Moreover, the modulation methods, the bandwidths utilized, and even the frequency allocations can be changed after the passive satellite has been placed in orbit, and it will remain as useful as before. This flexibility is not shared (except to a very limited degree) by active satellites.

(2) A passive satellite does not require the on-board operation of active electronic components and has, therefore, a potentially longer lifetime.

An attempt to compare the costs of active and passive systems is obviously very difficult because of the sensitivity of the results with respect to the operating assumptions and the detailed system parameters chosen. In both types of system the number of variables is very large, and a reasonable comparison can only be made when systems of equal capability and similar properties are chosen. If it is assumed that the orbital configuration of the satellites is identical in the two systems, and that the circuits are the same in number and quality of channels, it turns out that the two systems differ significantly only in their orbital lifetimes and in the size of ground transmitters and antennas. What could be saved in the passive system because of longer satellite lifetimes in orbit (lower satellite replacement cost) could be used to purchase and operate larger transmitters and antennas. We have studied these tradeoffs elsewhere,¹ on the basis of present technology, and the results show that a passive system can be competitive only when the useful life of the active satellite is less than a few years and the number of terminals in the system is small. However, if R&D made it possible to construct a satellite with a much greater reflecting cross-section per unit weight than Echo I (of the order of 100 times greater), then systems employing such reflectors would appear to compare very favorably with active systems.

¹S. H. Reiger, A Study of Passive Communication Satellites (forthcoming).

SYSTEM CHOICES

Clearly the future presents a wide choice of possible communications satellite systems, differing in satellite design, orbital configuration, terminal station design, network location, and other respects. In selecting one particular system and placing it in operation, one would ideally choose the system that could provide the required service at the lowest cost. But both the nature of the required service and the magnitude of the system cost are subject to very large uncertainties. The difficulty is compounded because at the present time experience is limited to experimentation with only a very small number of satellites. And considerations other than cost will influence the choice: for example, the timing of operational availability, and problems of international coordination.

The problems that arise in the selection of a system can best be illustrated by comparing two representative systems of different types: a random system consisting of a number of relatively simple active satellites in polar orbits of about 6000-nautical-miles altitude, and a stationary system consisting of relatively complex active satellites in equatorial orbits of 19,300-nautical-miles altitude. Components for these systems are being developed in the United States at the present time.

Each of these systems has features and limitations that may be characterized qualitatively as "advantages" and "disadvantages." These advantages and disadvantages are summarized in Table 4. And in Section III an attempt is made to give quantitative estimates of the costs of the two systems.

The table indicates clearly that the random system makes its greatest demands on the ground subsystem, while the stationary system makes its greatest demands on the orbiting subsystem. It is for this reason that most engineers agree that a random system could be placed in operation at an earlier date than a stationary system. There is wide disagreement, however, about the number of years separating the operational dates of the two systems. The estimates

Table 4

RANDOM VERSUS STATIONARY SYSTEMS: ADVANTAGES AND DISADVANTAGES

<u>Random System Advantages</u>	<u>Stationary System Advantages</u>
- o Simple satellite is possible - o Orbital placement not critical - o Gradual degradation of service if satellites fail - o Use of existing launch vehicles - o Early world-wide limited capability possible	- o Simplicity of ground equipment - o Minimal tracking and acquisition - o Flexibility in arranging multi-station networks - o Relatively small number of satellites - o No outages for normal operation
<u>Random System Disadvantages</u>	<u>Stationary System Disadvantages</u>
- o Complexity of ground equipment - o Less flexibility in arranging station networks - o Large number of satellites needed for near-continuous service - o Temporary outages will be normal	- o Complex satellite - o Orbital placement critical - o Complete failure of service if satellite fails without operable spare in place - o Transmission delay and echo - o Limited system will not offer world-wide service

vary depending on one's judgment concerning the difficulty of achieving a reliable stationary satellite with all its necessarily complicated subsystems.

The Telstar and Relay designs could be used as the basis for a random system. The first stationary satellite design of interest for commercial purposes is the advanced Syncom satellite, now under limited development. The first launching of this satellite could be reasonably programmed for late 1964 or early 1965, assuming that the soundness of the basic design is demonstrated before then.

There is general agreement that in the long run the stationary satellite concept offers the greatest promise and growth potential, provided the transmission-delay and echo problems do not introduce a major roadblock in voice transmission.

Much of the controversy seems to have been based on the assumption that an either-or choice must be made now or in the near future, that is, in the absence of really adequate information. We do not think that the either-or choice is required by technological considerations, for existing ground stations (and any future stations intended for use with nonstationary satellites) could be employed in either system. Choice is foreclosed only if the first generation of operational ground stations is limited to use with stationary satellites.

An entire communications system does not come into existence overnight; it evolves. Adopting the evolutionary approach, and assuming that an early operational date is desired, we think the following course would involve the fewest risks for a commercial satellite enterprise:

- (1) Initiate limited (regional) operations with relatively simple satellites and existing launch vehicles. This will provide valuable operational experience, reveal unanticipated problem areas, and bring in some revenue.

(2) Incorporate progressively more advanced satellites when replacements and additions become necessary or possible, and use more advanced launch vehicles.

This course of action will enable the enterprise to develop in the directions indicated by actual experiment. It will avoid the serious consequences that might follow from a full commitment to either a random or a stationary system. For with the random system, whatever its short-term attractions, there may be awkward and expensive problems of long-term growth. And with the stationary system, there may be unforeseen difficulties in achieving sufficient satellite reliability, with the result that an operational communications system would be long delayed.

III. SYSTEM COSTS

AIMS AND METHOD OF THE ANALYSIS

The main purpose of this analysis is to assess the relative costs of representative random and stationary satellite communication systems for a range of system parameters expected to be relevant during the next five to ten years. Both systems are expected to provide sufficient station-to-station circuit capacity during the early years of operation; moreover, the circuit capacity estimates for both systems would be subject to considerable uncertainties. We therefore compare the system costs directly, without attempting to compare costs per channel. Another purpose of the analysis is to provide system cost estimates that can be confronted (very tentatively) with the system revenues estimated below in Section IV. The estimates have been prepared following standard RAND cost methodology.¹ For the reasons explained earlier in Section I, R&D costs are not included in these estimates.

SYSTEM PARAMETERS AND SPECIFICATIONS

For each of the two basic systems--random and stationary--we consider a range of values for the following parameters:

- o Number of satellites in orbit
- o Effective lifetime of satellites in orbit (mean time to failure)
- o Satellite launch-success probability
- o Number and type of terminal stations

The number of satellites simultaneously in orbit affects fundamentally both the cost and the continuity of service provided (see Table 2 and the related discussion, pp. 10-12). The cost of keeping an adequate number of satellites in orbit depends upon

¹See David Novick, System and Total Force Cost Analysis, Air Force Project RAND, RM-2695, April 1961.

(1) the costs of the individual satellites, (2) their launch costs, and (3) their replacement rates. The launch costs in turn depend on the cost of an attempted launching and the probability that the attempt will be successful. The satellite replacement rates depend on the mean time between satellite failures. The elements of greatest uncertainty are the lifetime of the satellites and the launch-success probability, and we therefore treat these as variables in the analysis.

The number and type of terminal stations vary according to (1) the geographical area served, (2) the number of channels provided, and (3) the type of satellite employed, whether random or stationary. As a basis for costing the terminals, we have designed simple regional and first generation global networks of ground stations for both random and stationary satellites, for the locations indicated in Fig. 1 at the beginning of this report.

To simplify the exposition we describe the systems in a series of tables organized as follows:

<u>Table</u>	<u>Contents</u>
5 & 6	basic physical specifications of the random and stationary satellites and their terminal station antennas
7	estimated costs of attempted launchings for random and stationary satellites
8	assumptions as to random and stationary satellite lifetimes and launch-success probabilities
9	estimated costs for various orbiting systems, random and stationary, based on Tables 7 and 8
10	estimated costs of various types of individual terminal stations, for random and stationary satellites
11	estimated costs of various networks of terminal stations, based on Table 10

Thus Tables 7, 8, and 9 deal with the orbiting elements of the systems, and Tables 10 and 11 with the ground elements.

The reader may wish to pursue the discussion before studying these tables (which begin on the next page), but we call attention now to Table 8. The basic technological uncertainty is that of satellite reliability, and we must relate this uncertainty to the cost estimates in a meaningful way. The probability of success in launching and guiding a satellite into orbit is also uncertain. We attempt to deal with these two technological uncertainties as follows: we assume that, as technology advances, both the satellite lifetime and the launch-success probability will improve, and in Table 8 we define a series of model years A, B, and C, with progressively longer satellite lifetimes and higher launch-success probabilities. Year A may be thought of as some year in the relatively near future (perhaps 1964 or 1965) when the state of the art has advanced to the point where random satellite models of that year are characterized by mean times to failure of 12 months or so. Year B is a later year (1967? 1968?) with satellite models of greater reliability; and Year C is a still later year (1969? 1972?) with models of even greater reliability. We use letters to designate the model years because the actual dates are extremely uncertain, although we have no doubt that the better satellite reliabilities will eventually be attained. A roughly parallel improvement in launch-success probabilities is also to be expected.

HOW THE SYSTEM COSTS ARE EXPRESSED

For cost purposes, it is convenient to think of a complete satellite communications system as made up of three parts:

- (1) the ground system (the terminal stations)
- (2) the system Data Control and Management Center
- (3) the orbiting system (the satellites in orbit)

The ground system consists of terminal stations with electronic equipment of a lifetime of 15 years or so; accordingly, it is convenient when we sum costs to deal with 15-year periods.

Table 5

SPECIFICATIONS OF A RANDOM SATELLITE SYSTEM^a

System Element	Description					
<u>Launch Vehicle</u>	Atlas-Agena (3 satellites per launch)					
<u>Satellite</u>	<u>Early Design</u>			<u>Later Design</u>		
Weight	250 pounds			250 pounds		
Orientation	Spin stabiliza- tion			Passive (gravita- tional gradient)		
Power output	2 x 2.5 watts			2 x 2 watts		
Antenna gain	3 decibels			12 decibels		
<u>Terminal Stations</u>						
Antenna diameter (feet)	85	60	30	85	60	30
Noise (degrees Kelvin)	100	100	250	100	100	250
<u>Circuit Capacities</u>						
Approximate number of duplex voice channels per satellite	240	120	12	1800	900	90

Note:

^aThis satellite design is based on the state of the art represented by Telstar and Relay; in the later design, an orientation subsystem is included, with the result that the circuit capacity is greatly increased.

Table 6

SPECIFICATIONS OF A STATIONARY SATELLITE SYSTEM^a

System Element	Description
<u>Launch Vehicle</u>	Atlas-Agena plus upper stage
<u>Satellite</u>	
Weight	500 pounds
Orientation	Spin-stablization plus electronic antenna phasing
Power output	4 x 2.5 watts
Antenna gain	17 decibels
<u>Terminal Stations</u>	
Antenna diameter (feet)	85 60 30
Noise (degrees Kelvin)	100 100 250
<u>Circuit Capacities</u>	
Approximate number of duplex voice channels per satellite	2000 1000 100

Note:

^aThis satellite design is based on the technology represented by the advanced Syncom now under limited development.

Table 7

ESTIMATED COSTS OF LAUNCHED SATELLITES^a

<u>Stationary Satellite</u>		
Satellite ^b (1 per launch vehicle)		\$ 2,000,000
Booster		
Basic vehicle, including launching	\$7,000,000	
Special modification & engineering	\$1,500,000	\$ 8,500,000
		<u>\$10,500,000</u>
<u>Random Satellite</u>		
Satellite ^c (3 per launch vehicle)		\$ 2,400,000
Booster		
Basic vehicle with special modification	\$5,200,000	
Launching costs	\$2,300,000	\$ 7,500,000
Cost per launching		<u>\$ 9,900,000</u>
(Cost per random satellite launched)		(\$ 3,300,000)

Notes:

^aThis table gives the cost per attempted launching; the cost per placement in orbit depends on the launch success probability, values for which are estimated in Table 8. As indicated in Tables 5 and 6, we base the launch-vehicle costs on the Atlas-Agena, but if bigger boosters are available the cost per pound placed in orbit would be considerably reduced.

^bThe stationary satellite consists of four 2.5-watt communication repeaters (plus power supply) at a unit cost of \$250,000. The sub-systems for position- and attitude-control together with the structure and other components add to \$1 million, for a total of \$2 million per satellite.

^cThe random satellite consists of two 2.5-watt repeaters for a total of \$500,000. Including structure and system check out and testing, the cost per satellite is \$800,000.

Table 8

TYPES OF RANDOM AND SYNCHRONOUS SATELLITES: ASSUMPTIONS
AS TO LIFETIMES AND LAUNCH-SUCCESS PROBABILITY

Type ^a	Symbol	Mean time to failure (years)	Launch-success Probability
<u>Random</u>			
Year A	RA	1	0.7
Year B	RB	2	0.8
Year C	RC	5	0.9
<u>Stationary</u>			
Year B	SB	1	0.5
Year C	SC	3	0.8

Note:

^aYear A may be thought of as a year in the near future (perhaps 1965) when the effective lifetime (mean time to failure) of a simple random satellite attains a minimum of one year. In Year A, the more complex stationary satellite is expected to have an effective orbital lifetime of less than one year, and is therefore not considered here as a practicable alternative. By Year B (some years later than A) the lifetimes and launch reliabilities of both random and stationary satellites should have improved; Year C represents a later year with further improvements. It is assumed that satellite cost, weight, etc. remain essentially unchanged as satellite lifetime and launch reliability progressively improve; but increased channel capacities for the random satellites may be achieved through orientation control in later designs (see Table 5), possibly by Year C.

Table 9
ESTIMATED COSTS FOR VARIOUS ORBITING SYSTEMS

Number and Type of Satellite in Orbit (1)	Model Year ^a (2)	System Symbol (3)	In-service Time (per cent) ^b (4)	Cost of Initial Set of Satellites Placed in Orbit (\$ millions) (5)	Annual Steady-state Satellite Replacement Cost ^c (\$ millions) (6)	Level Annual Costs for Satellites in Orbit ^d (\$ millions) (7)
6 Random	A	6RA	73.7	28.3	28.3	32.8
9 Random	A	9RA	86.5	42.4	42.4	49.2
18 Random	A	18RA	98.2	84.9	84.9	98.4
36 Random	A	36RA	99.97	169.7	169.7	196.9
6 Random	B	6RB	73.7	24.8	12.4	15.4
9 Random	B	9RB	86.5	37.1	18.6	23.1
18 Random	B	18RB	98.2	74.3	37.1	46.2
36 Random	B	36RB	99.97	148.5	74.3	92.4
6 Random	C	6RC	73.7	22.0	4.4	6.7
9 Random	C	9RC	86.5	33.0	6.6	10.1
18 Random	C	18RC	98.2	66.0	13.2	20.2
36 Random	C	36RC	99.97	132.0	26.4	40.3
2 Stationary	B	2SB	100.0	42.0	42.0	48.7
3 Stationary	B	3SB	100.0	63.0	63.0	73.1
6 Stationary	B	6SB	100.0	126.0	126.0	146.2
9 Stationary	B	9SB	100.0	189.0	189.0	219.2
2 Stationary	C	2SC	100.0	26.3	8.8	11.7
3 Stationary	C	3SC	100.0	39.4	13.1	17.5
6 Stationary	C	6SC	100.0	78.8	26.3	35.1
9 Stationary	C	9SC	100.0	118.1	39.4	52.6

Notes: See next page.

Notes to Table 9:

^aFor the differences between model years, see Table 8.

^bPercentages of in-service time for random satellites are taken from Table 2; these are calculated without taking into account the gradual degradation produced by satellite failures. For stationary satellites, if failures are ignored the in-service time would be 100 per cent as shown here; but the outages due to failures would be much more serious than with random satellites. For this reason spares are provided, and (taking failure into account) the continuity of service provided by 3 stationary satellites serving a given region (9 serving a global system) would be superior to that provided by 2 serving a region (6 serving a global system).

^cThe steady-state replacement costs are the expected costs per year after the system has been in operation for a few years. For satellites with a mean time to failure of n years, the steady-state costs are the product of the cost of the initial set of satellites placed in orbit and $1/n$.

^dBased on 15-year period, 16 per cent interest rate.

Table 10

ESTIMATED COSTS OF INDIVIDUAL TERMINAL STATIONS AND DATA CENTERS

(1) Station Type Symbol	(2) Number Communications Links	(3) Antenna Diameter (feet)	(4) Number Antennas	(5) Initial Investment Costs (\$ millions)	(6) Annual Operating Costs ^a (\$ millions)	(7) Level Annual Costs ^b (\$ millions)
<u>Random Systems</u>						
TR(1/85')	1	85	3	6.1	1.52	2.61
TR(2/85')	2	85	4	7.9	1.98	3.40
TR(3/85')	3	85	5	9.7	2.43	4.17
TR(4/85')	4	85	7	13.8	3.45	5.93
TR(1/60')	1	60	3	4.5	1.13	1.94
TR(2/60')	2	60	4	5.8	1.45	2.49
TR(3/60')	3	60	5	7.1	1.78	3.05
TR(4/60')	4	60	7	10.2	2.54	4.37
TR(1/30')	1	30	3	3.2	0.80	1.37
TR(2/30')	2	30	4	4.0	1.00	1.72
TR(3/30')	3	30	5	4.9	1.23	2.11
TR(4/30')	4	30	7	7.0	1.75	3.01
<u>Stationary Systems</u>						
TS(1/85')	-	85	1	1.4	0.35	0.60
TS(1/60')	-	60	1	1.2	0.30	0.52
TS(1/30')	-	30	1	1.0	0.26	0.44
TS(2/85') ^c	-	85	2	2.8	0.70	1.20
TS(2/60') ^c	-	60	2	2.4	0.60	1.03
TS(2/30') ^c	-	30	2	2.0	0.52	0.88

Random System Data Control and Management Centers						
Early Regional				6.0	1.5	2.58
First-Generation Global				10.0	2.5	4.29
Stationary System Data Control and Management Centers						
Early Regional				3.0	0.8	1.29
First-Generation Global				6.0	1.5	2.58

Notes:

- Not applicable.

^a Annual operating costs tend to run about period at 16 per cent interest.^c 25 per cent of initial investment costs.^b Level annual costs are computed for a 15-year period at 16 per cent interest.
^c Relay stations for a global system.

Table 11

ESTIMATED COSTS OF TERMINAL STATIONS AND DATA CENTERS
FOR REGIONAL AND GLOBAL NETWORKS^a

	(1) Initial Investment Costs (\$ millions)	(2) Annual Operating Costs (\$ millions)	(3) Level Annual Costs ^b (\$ millions)
<u>Early Regional System, Random Satellites</u>			
1 Terminal TR(4/85')			
3 Terminals TR(3/85')			
2 Terminals TR(3/60')			
1 Terminal TR(1/60')			
7-terminal total	61.6	15.41	26.46
1 Data and Management Center	<u>6.0</u>	<u>1.50</u>	<u>2.58</u>
Total ground installations	67.6	16.91	29.04
<u>Early Regional System, Stationary Satellites</u>			
4 Terminals TS(1/85')			
3 Terminals TS(1/60')			
7-terminal total	9.2	2.3	3.95
1 Data and Management Center	<u>3.0</u>	<u>0.8</u>	<u>1.29</u>
Total ground installations	12.2	3.1	5.24

Table 11 (continued)

	(1) Initial Investment Costs (\$ millions)	(2) Annual Operating Costs (\$ millions)	(3) Level Annual Costs ^b (\$ millions)
<u>First-Generation</u>			
<u>Global System,</u>			
<u>Random Satellites</u>			
4 Terminals TR(4/85')			
3 Terminals TR(3/85')			
3 Terminals TR(4/60')			
2 Terminals TR(3/60')			
2 Terminals TR(2/60')			
2 Terminals TR(1/60')			
16-terminal total	149.7	37.5	64.35
1 Data and Management Center	<u>10.0</u>	<u>2.5</u>	<u>4.29</u>
Total ground installations	159.7	40.0	68.64
<u>First-Generation</u>			
<u>Global System,</u>			
<u>Stationary Satellites</u>			
1 Terminal TS(2/85')			
4 Terminals TS(1/85')			
6 Terminals TS(1/60')			
5 Terminals TS(1/30')			
16-terminal total	20.6	5.2	8.90
1 Data and Management Center	<u>6.0</u>	<u>1.5</u>	<u>2.58</u>
Total ground installations	26.6	6.7	11.48

Notes:

^aThe terminals are identified here by the symbols used in Table 10, where the costs of individual terminals are estimated.

^bBased on 15-year period at 16 per cent interest.

When a ground station is installed there is an initial investment cost, and in subsequent years there are annual operating costs. In Table 10, cols. (5) and (6) give the estimated investment and annual operating costs for various types of terminal stations. In comparing one system with another it is helpful to combine the investment and annual operating costs into a single figure, and for this purpose we make use of the level annual cost extending over the system's lifetime. The level annual cost is defined as the annual operating expenses plus the level annual payments on a 15-year mortgage covering the initial investment cost. The terminal-station level annual costs are given in col. (7) of Table 10. In computing the level annual costs we have used an interest rate of 16 per cent, rather than a lower rate, as representing an upper bound to the rates normally relevant to public utility enterprises.¹

Like a terminal station, the system Data Control and Management Center can be regarded as an initial investment with a relatively long lifetime, and in Table 10 we estimate the investment, annual operating, and level annual costs for system Centers for random and stationary systems, both regional and global.

For the orbiting system, it seems somewhat artificial to refer to initial investment and annual operating expenses, for we are concerned basically with the costs of placing a certain number of satellites in orbit each year: initially a full set of satellites, and in subsequent years the number of satellites necessary to replace those that have failed. In Table 9, col. (5) gives the cost of a complete initial set of satellites in orbit. Col. (6) gives the expected cost per year of maintaining the system's operating capability after the system has been in service long enough so that the number of satellites that must be replaced is nearly the same from year to year. Col. (7) gives the level annual costs for the various orbiting systems for a period of 15 years, calculated from the initial placement costs on the assumption that an orbiting

¹This 16 per cent rate includes provision for payment of Federal Corporation income taxes. We have examined a range of interest rates from 8 to 16 per cent, and it appears that system choices are not sensitive to the rate selected.

system of lifetime n years would be replaced in entirety each n years. We therefore have the following sets of comparable costs:

Terminal Station	initial investment	annual operating	→ level annual
Data and Manage- ment Centers	initial investment	annual operating	→ level annual
Satellites in Orbit	initial placement	periodic replacement	→ level annual

In what follows we fix our attention on the level annual costs, for these make it possible to compare all the resources required for one system with all those required for another, even though the expenditures for the two systems may be distributed quite differently over the system lifetimes.

COST IMPLICATIONS FOR SYSTEM CHOICES

When will the various satellite systems be available for operational use? And what percentage of in-service time should be required? These are important questions that bear on the initial choice of a communications satellite system, and at least qualitatively they involve tradeoffs with cost. In this analysis we have therefore attempted to indicate what these tradeoffs might be, as well as to compare the costs of random and stationary systems.

For this purpose we identify the various satellite systems by referring to (1) the number of satellites in orbit; (2) the type, whether random or stationary, and (3) the model year, representing in a rough way the state of technology. Thus 18RA refers to a system with eighteen random satellites of Year A (early technology), and 6SB refers to a system with six stationary satellites of Year B (somewhat later technology), and so forth. A list of the systems and their symbols is given in Table 9, together with their estimated level annual costs.

Cost estimates for orbiting systems alone would be of particular interest to a corporation or international consortium that planned to provide circuits (satellite links) between terminals owned by others, for example, by AT&T, the British Post Office, etc. Figure 4 summarizes graphically the cost estimates of interest to a corporation operating in this way. Based on Table 9, it shows the level annual costs of a selection of orbiting systems of various technologies.¹ The first thing to notice in Fig. 4 is that, as expected, cost is critically dependent on reliability. The three parts of Fig. 4 show strikingly different cost pictures, and the differences are due almost entirely to the progressively better reliabilities postulated for the three model years. The effect of longer satellite lifetime is dominant, but improved launch-success probabilities also contribute.

The next thing to notice is the high price one would have to pay (especially in the early time period) to achieve even a small increase in in-service time by increasing the number of satellites in orbit. Raising the number of satellites of Year A from 9 to 36 (from 9RA to 36RA) would raise in-service time less than 14 per cent, but would raise costs by nearly \$150 million a year.

Turning to Figs. 5 and 6, we consider the costs for complete systems, including orbiting satellites, terminal stations, and a Data and Management Center for each system. These "complete system" costs are the level annual costs taken from Tables 9, 10, and 11; and Figs. 5 and 6 may be regarded as graphical summaries of these tables. The "complete system costs" are the costs that would be of interest to a single corporation or consortium of corporations that planned to finance the total space communications system, including the terminal stations (not simply the orbiting satellites).

¹A corporation operating in the way just mentioned would also be interested in the costs of the system Data Control and Management Center. These costs are given in Table 10, but they are so small compared with the costs of the orbiting systems that they would scarcely affect the curves shown in Fig. 4, and for simplicity we have omitted these system Center costs in this figure.

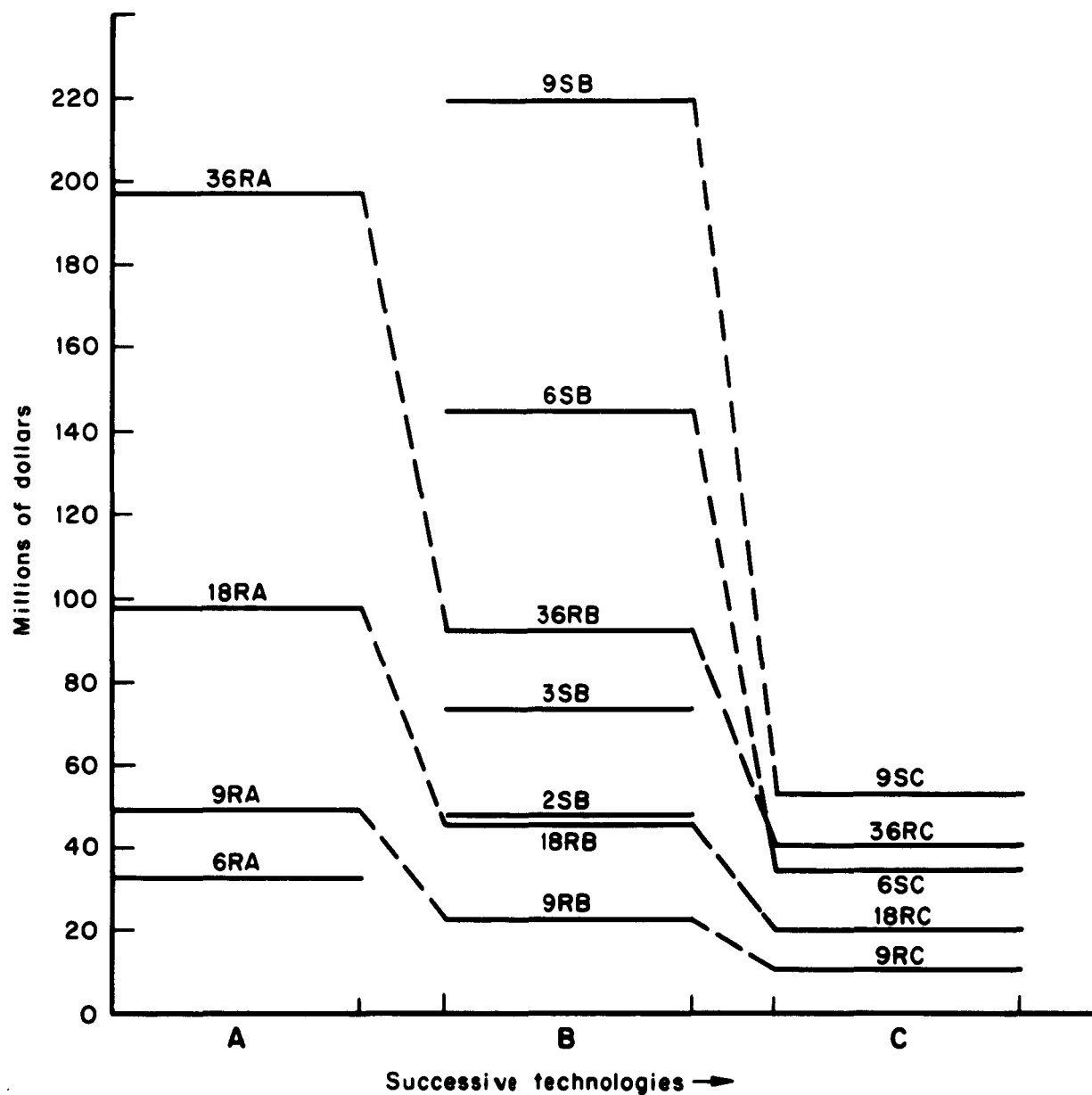


Fig. 4 — Estimated level annual costs of orbiting systems, successive technologies

Table 11 should be mentioned here, for it gives the costs of the 7-station regional and 16-station global networks of terminal stations the locations of which are indicated in Fig. 1 at the beginning of this report. Figures 5 and 6 are based on the assumption that the same "mix" of stations (and therefore the same average cost per station) will hold for larger and smaller numbers of stations as well as for the particular networks costed in Table 11. This is, of course, only an approximation, but it is sufficiently accurate for the purpose of showing the sensitivity of system cost to the number of stations in the network.

Figures 5 and 6 display two families of curves: (a) curves for various stationary systems, sloping gently upward to the right as the number of stations is increased, and (b) curves for random systems, sloping upward more steeply. The difference in slope is due to the greater cost of the terminals in the random systems. It is clear that for both regional systems (Fig. 5) and global systems (Fig. 6), the year-C stationary satellite systems will be cheaper, when available. But in earlier years the random systems with small numbers of satellites are generally less costly than the stationary systems, particularly for networks with a relatively small number of stations.

For regional systems of year B (see Fig. 5),

6RB is cheaper than 2SB for 9 stations or fewer
9RB is cheaper than 2SB for 6 stations or fewer
18RB is costlier than 2SB for any number of stations

For global systems of year B (see Fig. 6),

6RB is cheaper than 6GB for 36 stations or fewer
18RB is cheaper than 6GB for 28 stations or fewer

Thus if a satellite corporation wished to begin operations earlier than year C, it might find it attractive to begin as early as year A with a random regional system with relatively few stations, possibly extending it to a small global network after year B, and by year C beginning to phase stationary satellites into the system. It

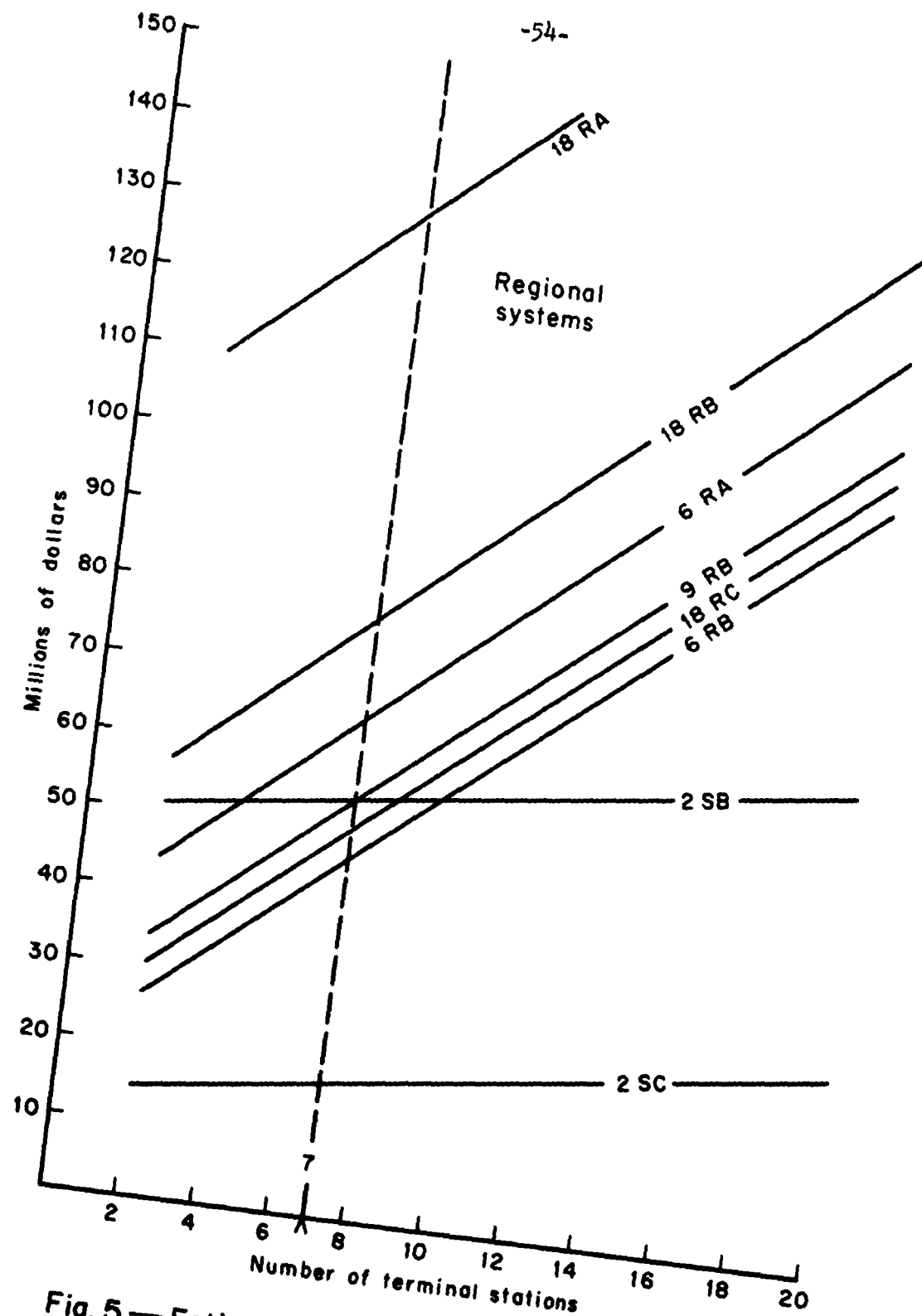


Fig. 5—Estimated level annual costs for early regional systems, by number of terminals (includes satellites, terminal stations, and Data and Management Center)

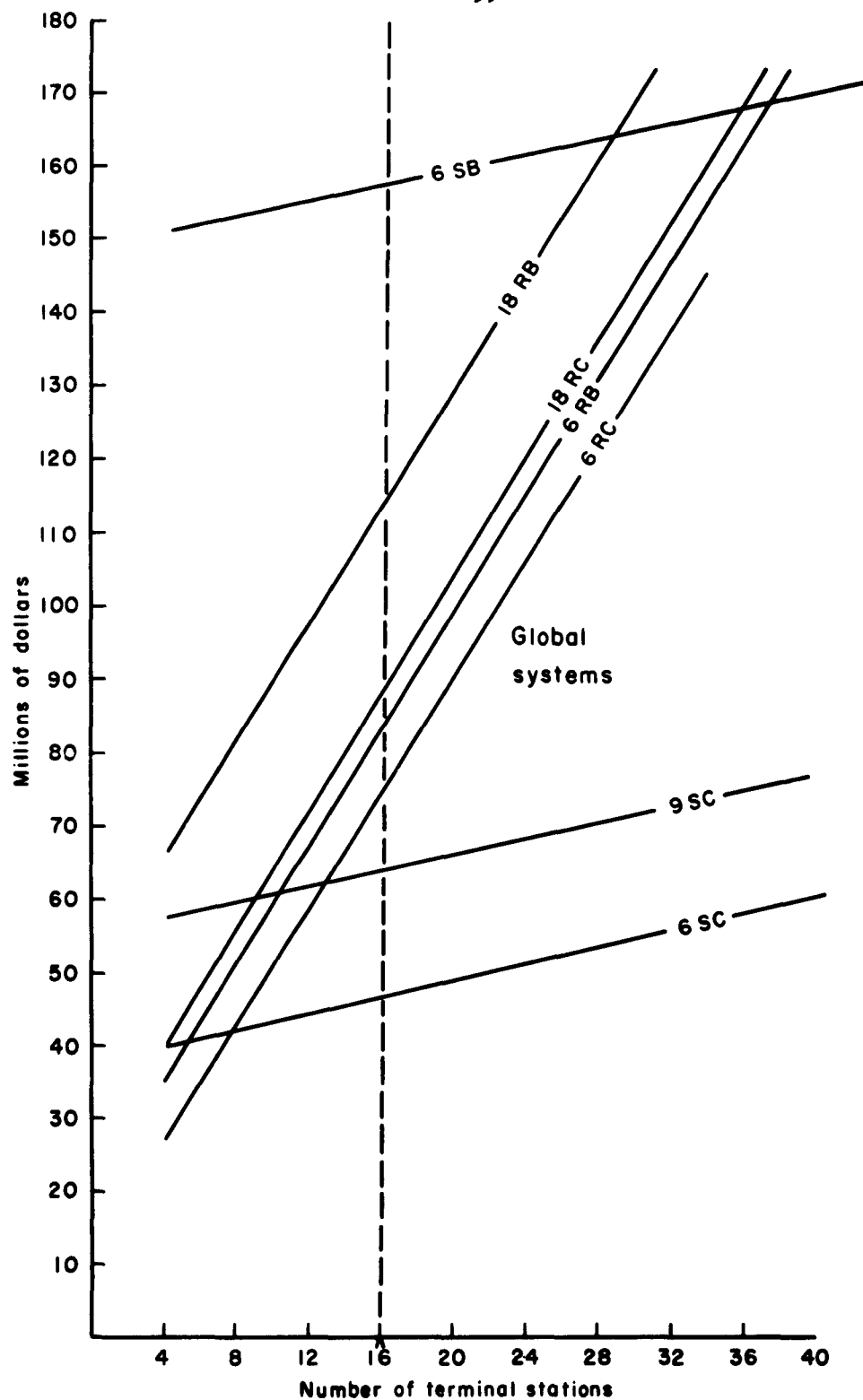


Fig. 6 — Estimated level annual costs for early global systems, by number of terminals (includes satellites, terminal stations, and Data and Management Center)

should be remembered that the choices just described are critically dependent on the assumptions in Table 8. But, leaving aside the particular cost estimates, we think that the problem of satellite system choice should be thought of as a sequence of decisions of this kind.

An important point to keep in mind in such a sequence of decisions is that the lifetime of a ground station is a long one in relation to the successive advances in satellite technology that we foresee. A given network of terminals will serve a succession of different orbiting systems.¹ When a terminal station network is already in being, the choice of future orbiting systems can be made as if the existing stations represented "sunk" costs. The relevant cost data would therefore be of the kind represented in Fig. 4.

¹Terminal stations designed for use with random satellites can also be used with stationary satellites.

IV. DEMAND AND REVENUES

WHAT IS THE NORMAL RATE OF GROWTH OF TELECOMMUNICATIONS DEMAND?

Long-distance telephone revenues within the United States have been increasing since the end of World War II at a rate of about 9 per cent per year. This is not a high rate of increase, in comparison with the increase of the output of comparable services. For example, the output of the electricity and gas industries has also increased at a rate of 9 per cent per year in the post-War years.

It is less easy to give a meaningful estimate of the "normal" rate of increase of the use of overseas telecommunication facilities. Increases in the volume of overseas business over a very long period, from 1930 on, have been significantly effected by the reduction in overseas telephone rates. Real rates for calls to London--dollar rates corrected for the over-all increase in the price level--are now only 13 per cent of the rates in 1930; that is, the real rates have fallen by 87 per cent.

More recently, since 1955, the overseas telecommunication industry has been profoundly affected by the introduction of the submarine telephone cable. Deepwater telephone cables were introduced as early as 1921 on short routes, such as Florida to Cuba, but the real era of overseas cable service may be dated from September 25, 1956, when the first transatlantic cable, between the United States and Britain, was placed in operation. Since that time, cable construction has advanced rapidly. It now appears that by 1965, the overseas telecommunications of the United States will be carried almost entirely by telephone cable, although only ten years before, in 1955, they were carried almost entirely by high frequency radio (and telegraph cable). Telephone cable systems provide a much higher quality of service than do high frequency radio systems. The substitution of cable-quality service for high-frequency radio service has on the average resulted in doubling of telephone revenue minutes.

There is, therefore, no easy way to assess the "normal" or ordinary growth of overseas telecommunications.

It has been estimated that from 1970 to 1980 the number of circuits required for telecommunication facilities would triple, which works out to a rate of increase of 11.5 per cent per year.¹ We understand that between 1970 and 1980, the Ad Hoc Committee's estimates were based on estimates of normal growth, assuming no marked change either in prices, in the adequacy of internal communications in foreign countries, in military demand, or in quality of service.

As the Ad Hoc Committee's estimate suggests, there is some reason for believing that communications between the United States and other countries will increase more rapidly than communications within the United States. The wealth of the world outside the United States has been increasing more rapidly than the wealth of the United States itself, partly because of ephemeral factors but partly for reasons that seem likely to be of importance in the future. The telephone statistics themselves furnish evidence of the growth of the world outside the United States relative to the growth within the United States. On January 1, 1951, 57 per cent of the world's telephones were in the United States; on January 1, 1961, ten years later, only 52 per cent of the world's telephones were in the United States. Therefore, if 9 per cent is a reasonable estimate of the annual growth of internal long-distance revenues, a somewhat higher rate (say 11.5 per cent) should characterize the annual growth rate of overseas revenues.

So much for the past. What of the future? There are signs of leveling off of the rates of increase in the use of some specific types of telecommunication service (see Appendix E). Eventually, we would expect the rate of increase of international communications to level off. But we believe that during the time period of interest

¹"Report of the AD HOC Carrier Committee," Federal Communications Commission, Docket No. 14024, October 12, 1961.

in this study, the best estimate of "normal" growth rate is very nearly the growth rate of the past. For the reasons stated above, estimates of normal rates of increase in the future are of course subject to much uncertainty. As was noted in an earlier study,¹ the factors that influence the demand for overseas communications include: the amount of international trade and travel; the level of incomes throughout the world; the cost of devices used jointly with long-distance transmission equipment, such as computers, facsimile apparatus, and closed-circuit television; and the size and number of overseas military installations. Prediction about any of these factors is hazardous. While, therefore, our best estimate of the normal rate of growth of overseas telecommunication volume is 11.5 per cent per year, it is an estimate in which we have limited confidence: we would not be astonished if the growth rate were to be as high as, say, 15 per cent, or as low as, say, 8 per cent in the next ten or fifteen years.

WHAT WILL BE THE DEMAND FOR OVERSEAS TELECOMMUNICATION SERVICES, 1962-1970?

We asked above about the "normal" rate of increase in telecommunications demand. Here we discuss specifically the outlook for the next few years, which are likely to be characterized by abnormally large rates of increase in the use of overseas communication services.

The amount of overseas telephone message traffic is likely to continue to increase from now until the end of 1965 at a high rate, say, at about 22 per cent per year. This has been their average annual rate of increase since the advent of the submarine cable.

Our main reason for this optimistic forecast is that the era of cable building is by no means over. The value of cable systems to be installed in the three years, 1963, 1964, and 1965, will be about

¹William Meckling and Siegfried Reiger, Communications Satellites: An Introductory Survey of Technology and Economic Promise, The RAND Corporation, RM-2709-NASA, September 15, 1960, pp. 29-30.

double the value of systems installed in the period 1956-1962. Cable-quality service will become available on routes where now only high frequency radio service is offered, and on such routes we may expect the number of revenue minutes to double. In addition, existing cables on some routes, especially the routes to Hawaii and Europe, are badly overloaded; some demand is not now being satisfied but will be satisfied when more facilities are available.

Our discussion to this point has centered on telephone calls (telephone messages). The second major category of users of international telecommunication facilities consists of organizations which lease channels from international telephone carriers. Government agencies and international telegraph carriers are of prime interest here.

Almost all of the overseas military traffic that is handled by commercial telephone systems is carried over private channels leased by the telephone companies to the Defense Department, and therefore does not figure in the revenues from telephone calls.

As we argue in Appendix A the military demand for commercial overseas facilities is likely to comprise a very sizeable share of the total demand by 1965. Although the military has a vast communications system, its international network is in the main a high frequency radio network. Two things have happened. First, the military is shifting from use of its own system to use of the commercially-owned cables. Second, just as in the case of the civilians, the military is at the same time greatly increasing its use of overseas communications because of the advantages that cable-quality circuits afford.

The telegraph carriers are in much the same position as the Defense Department. They also lease channels in the telephone company cables and they have been rapidly increasing the number of such leases. The reason is in part the familiar one of the substitution of telephone cable service for high frequency radio service. In part, it is also a matter of substituting service over telephone

cables for service over telegraph cables: the former is cheaper.

The year 1965 is a turning point. By the end of 1965, cable systems radiating out from the United States will have reached all points of significant traffic volume. The era of transition to cable-quality service, with all that entails for the ordinary civilian user, for the Department of Defense, and for the telegraph companies, will be over.

What will the over-all demand and supply position be in 1965? On the supply side, we have shown in a separate study¹ that the capacity of commercial submarine telephone cables will nearly triple between the end of 1962 and the end of 1965. The combined capacity of all types of overseas telecommunication facilities will probably double. Nevertheless, the Ad Hoc Carrier Committee concluded that "...communications requirements to and from the United States until 1965...can be largely accommodated in present and planned submarine cables and conventional radio systems. New facilities will be needed to meet estimated requirements in 1965 and thereafter."²

It is not altogether clear whether the Ad Hoc Committee intended to imply that new facilities would be needed everywhere, or on, say, the important North Atlantic route only. The problem on the North Atlantic route, in summary, is that the circuits are already greatly overloaded and that the only firmly-planned, new transatlantic cable may be used to an appreciable extent to satisfy Department of Defense requirements. Elsewhere, the problem of additional capacity appears to be less pressing. For example, to Hawaii, the number of submarine telephone cable voice channels terminating in the United States and Canada will be 256 or more by 1965, as compared with the present 48. To South America there will be 160 telephone cable voice channels while now there are none.

¹R. T. Nichols, Submarine Telephone Cables and International Telecommunications, The RAND Corporation, RM-3472-RC, February 1963.

²"Report of the AD HOC Carrier Committee," op. cit., p. 15.

In turning to the period 1965-1970, the first thing to note is that the Ad Hoc Committee continues to predict a very sizeable increase in demand. The Committee's 1970 requirements seem to be about three or four times as great as our estimates of 1965 capacity. We understand that the Committee based its 1970 requirements on: (a) the "normal" growth of traffic, (b) the assumption of a rate decrease between 1965 and 1970, and (c) the assumption that by 1970 the domestic telephone systems of foreign countries would be brought up to standard. With a normal growth rate of 11.5 per cent per year, the first factor would account for a 70 per cent increase in requirements. The effect of the second factor (on circuit needs) depends on the extent of the price reduction and on the elasticity of demand.

The assumption of a price reduction is reasonable. The British price for calls to this country ever since 1945 has been 3 pounds sterling, or \$8.40 at the present rate of exchange. By comparison, the American rate for calls to Britain, and elsewhere, is \$12.00. On November 1, 1961, the Canadians reduced their prices for calls to the United Kingdom from \$12.00 to \$9.00. An American price reduction probably waits only on the provision of facilities adequate to supply the demand; at the moment, demand at the existing price seems to be very much in excess of supply.

WHAT REVENUES COULD A COMMUNICATIONS SATELLITE SYSTEM EARN?

To arrive at an estimate of the potential market for a communications satellite system is hazardous. Some of the difficulties have already been suggested, such as type of use (message traffic and leased channels), changes in rate, etc. Another major uncertainty is that the new capability that a communications satellite system will provide (real-time wide-band capability over transoceanic distances) may bring new types of transoceanic services into use (television, closed-circuit television conferences, etc.). In what follows we attempt to arrive at a revenue estimate that is based on conventional services and does not include these novel types of transoceanic services.

The total revenues of the United States international telephone and telegraph carriers in 1961 were on the order of \$140,000,000. The telephone companies accounted for about \$50,000,000 of the total and the telegraph companies about \$90,000,000.

This total is not very meaningful as an estimate of the revenue that might be obtained by a carrier's carrier--a corporation engaged solely in the business of providing overseas facilities. The greater portion of the services provided by the telegraph companies and a significant share of the services provided by the telephone companies are not directly related to long-distance circuitry or overseas communications as such. A complicating factor is that the portion of total revenue applicable to overseas facilities is clearly dependent on the type of service rendered (that is, telephone message, telegraph, or leased channel).

For the purpose of estimating the revenues attributable to the demand for the services of overseas facilities, it is appropriate to focus on the year 1965. First, by 1965 the telephone cable systems will have been extended to include all points of high or potentially high traffic volume; and second, by 1965 most of the nonvoice (record or telegraph) as well as voice communications will be carried overseas in the main by telephone cable.

Available data on revenues in recent years apply to revenues collected by international carriers in the United States, and sometimes to the total revenues collected by all carriers providing services to and from the United States. For our purposes we will assume that the pertinent revenues in connection with a communications satellite system for traffic originating or terminating in the United States are the total revenues.

On this basis our studies lead to the following results:

1. The revenues from channels in the telephone cables leased to the Federal Government and to the international telegraph carriers will probably be on the order of \$40,000,000 by 1965. This revenue comes from traffic originating and terminating in the United States.

This calculation rests on two assumptions, first, that the Department of Defense will, in fact, take up the number of channels that it now foresees as its requirements (see Appendix A), and, second, that the rate for leased channels will be about half the 1961 rate (about \$120,000 for a transatlantic channel). In defense of this second assumption, it should be noted that existing rates are not closely related to costs of additional capacity, mainly because on American-owned routes the actual existing capacity is far less than that required to sustain demand at the going rates. The Canadians have already cut leased channel rates, in some instances by 30 per cent.

Revenues from leased telephone channels are quite directly related to circuit requirements. A dollar's income from leased telephone channels is a dollar that might accrue to a carriers' carrier. For example, on the Alaskan cable system, 95 per cent of the leased telephone channel revenue is allocated to the services of the cable system itself, and only 5 per cent to the provision of other services.

By 1965, there will almost surely be a substantial number of telephone voice channels leased to individuals. Until 1962, such leases were of negligible importance, accounting for only 1 per cent of the total revenues from leased voice channels. However, by May 1962, lease of channels to private individuals and to private corporations accounted for 6.5 per cent of the total revenue from leased channels (the government share fell from 99 per cent to 93.5 per cent).¹ We understand that the telephone company expects to lease channels to private entities as rapidly as facility expansion permits.

We have not attempted to estimate the revenues from channels leased to private entities. It is more convenient to start with

¹Committee on Foreign Relations, U. S. Senate, 87th Congress, Second Session, Communications Satellite Act of 1962, U. S. Government Printing Office, Washington, D. C., 1962, p. 444.

the message-service revenues of 1961, and on the basis of the 22 per cent per year increase that we foresee through 1965, estimate the message-service revenues of that year. The result will be an overestimate of actual message-service revenues in that year, because in fact by 1965 some of the revenues that would otherwise be message-service revenues will be private-line revenues. But this difference is of small consequence for present purposes.

2. We estimate that the total overseas 1965 telephone message revenue will be of the order of \$180,000,000, with a volume of calls somewhat less than 7,000,000. Again, these numbers refer to telephone messages originating and terminating in the United States. Of this revenue we allocate \$120,000,000 to the overseas facilities proper.

There is no really satisfactory method for distinguishing the revenues attributable to the provision of overseas facilities from the revenues attributable to the provision of local or domestic facilities. However, for present purposes, it suffices to estimate the costs of providing the local or domestic services, which are about \$8 per message, or a total of \$60,000,000, and to allocate the revenues over and above these costs, that is, \$120,000,000, to the services of the overseas facilities. In defense of our estimate of \$8 per call for local service in 1965 we note that on routes where overseas calls are becoming routine, with direct operator dialing, prices for a station call of average length (7-1/2 minutes), night and Sunday, are as low as \$10.50. All calls to Europe are still person-to-person. However, this year, direct operator dialing of calls to many European countries will be introduced; eventually, although perhaps not by 1965, they may be handled as casually as long-distance calls now are within the United States.

3. Thus, the portion of the total revenue in 1965 due to overseas traffic originating and terminating in the United States and applicable to overseas facilities is estimated at \$160,000,000.
4. From 1965 to 1975 we look forward to a normal growth rate of 11.5 per cent per year, as discussed earlier.

5. Finally, we add 30 per cent to allow for traffic which neither originates nor terminates in the United States.

In 1960, such traffic was about 30 per cent of total commercial traffic; for the 1965-1975 time period, one might estimate a smaller proportion, say 25 per cent, because of the very heavy contribution of the U. S. Department of Defense to traffic originating or terminating in the United States. On the other hand, as pointed out earlier, the number of telephones abroad has increased more rapidly than in the United States.

6. We assume that the revenue of interest to a communications satellite system is the portion that represents an increase over the revenue in 1965.

Because it costs very little to repair, maintain, and operate submarine telephone cable systems, and because they are designed to operate free of serious trouble for a period of 20 years or so, it is plausible to assume that the volume of traffic that exists in 1965 will continue to be carried over conventional systems, whether or not communication satellite systems are available as of that date. The revenues that the 1965 volume of traffic will afford in the years after 1965 will be less, perhaps considerably less, than the revenues derived from this volume of traffic in 1965. The reason is that in all likelihood the capacity of overseas telecommunication facilities will be greatly expanded, at relatively low cost, with a resulting reduced revenue per unit of capacity. Apart from the cost-reducing innovations promised by communications satellite systems, the submarine telephone cables that could easily be available in, say, 1968, will cost only 1/10 of the cost of the cables available in 1961. Hence, the additional revenue in, say, 1970, attributable to the provision of new facilities since 1965, would be somewhat larger (perhaps much larger) than the difference between the 1970 revenues and the 1965 revenues. However, we have purposely erred on the low side.

The results are summarized as estimated revenues in Table 12.

Table 12

REVENUE ESTIMATE, 1965, 1970, 1975
(millions of dollars)

	1965	1970	1975
Revenue from traffic originating and terminating in the United States	160	270	480
Worldwide	210	350	620
Increase over 1965		140	410

Note:

These revenues are those that would be collected by all international carriers, whether using satellites or other means of communication.

As we have noted earlier we would not be astonished to experience a growth rate of 8 per cent or 15 per cent in the 1965-1975 time period, although we believe the 11.5 per cent growth rate is a reasonable estimate. The dependence of post-1965 revenues on the growth rate is shown in Fig. 7. The increase in revenue over the 1965 figure may be regarded as the potential market for a communication satellite system.

We wish to mention a few other significant topics. It is of relevance to assess the distribution of 1965 revenues to and from the United States by route.

To Europe	41.7
To Hawaii and the Pacific	32.7
To the Caribbean, Central and South America	23.0
Miscellaneous	<u>2.6</u>
Total	100.0

It should be noted that our estimates of revenues 1965 to 1975 exclude revenues on circuits to Alaska, the Bahamas, and Cuba. Alaska is now served by microwave, as is the continental United States. The Bahamas and Cuba are served by tropospheric scatter propagation systems, which at small cost may be expanded to the equivalent of several hundred voice channels, and which can carry television programs. The routes to both these places seem therefore to be more akin to domestic routes than to the usual overseas routes.

To turn specifically to the prospects for revenues for a communications satellite system, much depends on the alternatives available to the carriers. A third-generation cable system is already very much within the state of the arts, and if we have calculated correctly, such a system should be able to carry a 3-minute station-to-station message from the cable terminal station on this side of the Atlantic to the cable terminal station in, say, Britain, at a cost of 75 cents.

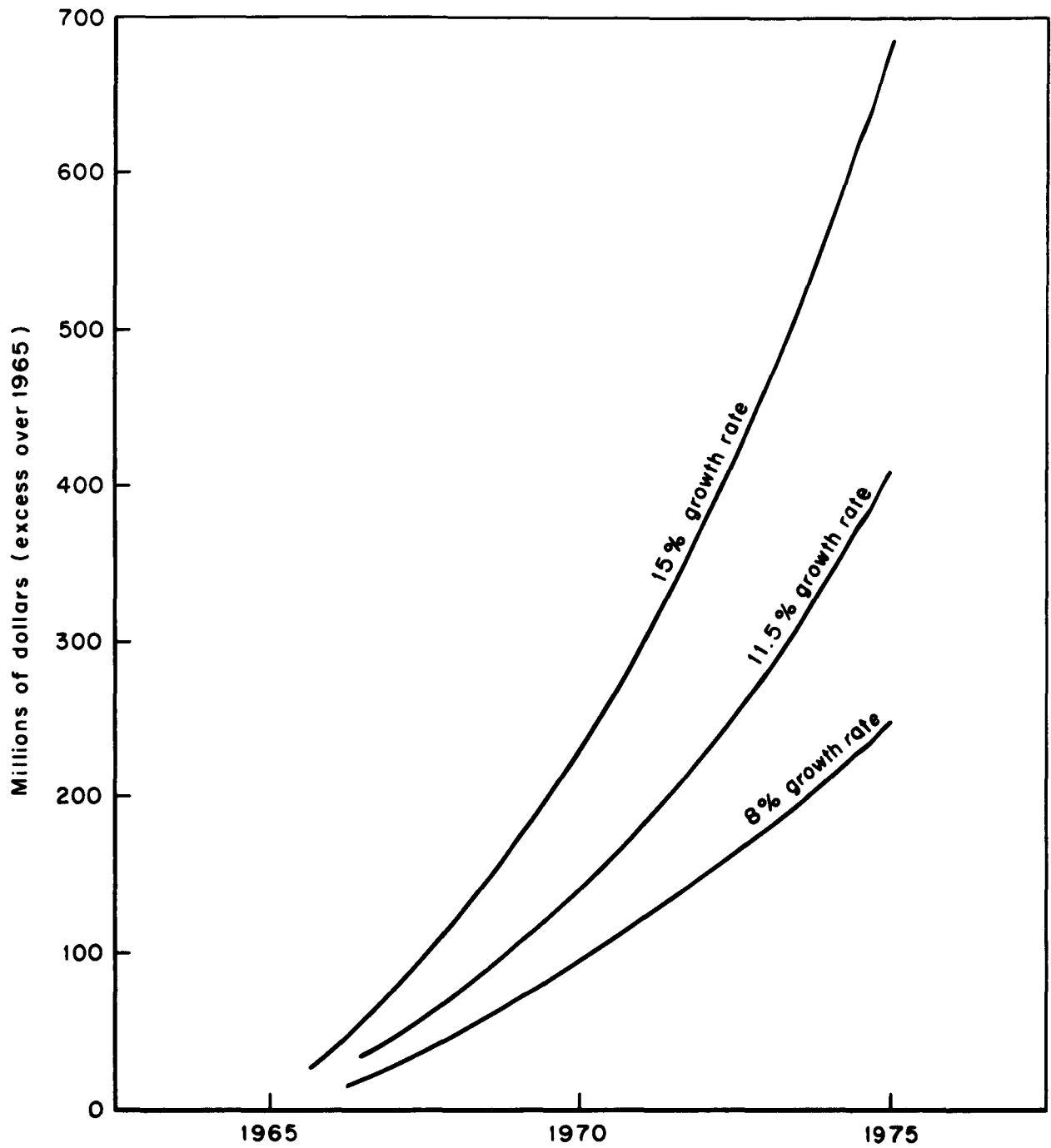


Fig.7 — Increase over 1965 of worldwide annual overseas telecommunication revenues, 1965 — 1975

We have not considered for the time period of this study the use of communications satellite systems for high density overland routes, such as between the East and West Coast in the United States. Such use might bring in some extra revenues, because peak loads over such routes occur at different times than over transoceanic routes (for example, over the Atlantic). This subject deserves further study.

Finally, an unknown factor of importance is the volume of demand by the military. We have estimated that Department of Defense requirements would account for at least 20 per cent of the 1965 revenues attributable to the provision of overseas services, and (implicitly) the same proportion in later years. In 1959, the then chairman of the Federal Communications Commission, John C. Doerfer, remarked that,

...a large proportion of the leased-channel revenues comes from U. S. Government customers, particularly the Defense Establishment. Such Government leases are subject to cancellation on 30 days' notice. Changes in the international situation, or in congressional appropriations, can drastically reduce the requirements for such leased facilities and the revenues resulting from such services. Similarly, if the defense agencies were to supply their own facilities the revenue of the carriers could be diminished drastically.¹

Mr. Doerfer was speaking specifically of the international telegraph carriers, but his remarks are equally applicable to any international carrier.

Throughout this discussion, we have limited ourselves to more or less conventional demands placed on telephone and telegraph systems. One need not be an enthusiast to recognize that new uses for new products are often discovered only after the new product has been produced. The history of invention is replete with examples of

¹Committee on Interstate and Foreign Commerce, U. S. Senate, 86th Congress, First Session, Merger of International Telegraph Carriers, U. S. Government Printing Office, Washington, D. C., 1959, p. 27.

ideas and products for which no earthly use could be discovered before the product was actually put in operating condition. Sometimes an idea works in a field quite distinct from that for which it was intended. It is possible that in the specific case of the communications satellite systems there may be some misguided enthusiasm.¹ On the other hand, although we cannot now identify the reason or the source, we may expect with some confidence that the future will reveal one or more major new uses for services such as those a communications satellite system could provide. Certainly the submarine telephone cable systems created some part of their own demand; no less should be expected from communications satellites.

¹See the discussion of this in L. L. Johnson, The Commercial Uses of Satellite Systems, The RAND Corporation, P-2601, June 1962.

V. SYSTEM COST VERSUS SYSTEM REVENUE

Having discussed systems cost in Section III and estimated revenues in Section IV, we can now turn to the question: "When can a communications satellite system pay for itself?"

If we knew at what time a system would reach the technological levels (A, B, C) postulated in Table 8, we could answer this question within the uncertainties of our cost and revenue estimates. But we have no way of knowing exactly when year-C reliabilities will be reached with either of the two types of system (random or stationary) discussed earlier. Only actual experience with satellites in orbit can provide answers here. For this reason we shall consider the question from the other point of view, that is, "In a given year, what performance must a system have so that its costs do not exceed its revenues in that year?"

We will (somewhat arbitrarily) choose the year 1970 as the year of comparison, simply because it is likely that at that time a satellite system will be in operation. Furthermore we will concentrate our attention on the Atlantic area, the region where a satellite system is expected to become operational first.

For 1970 the total worldwide revenue applicable to new overseas communications facilities (the excess over 1965 revenue) was estimated at \$140 million, of which about \$70 million could come from the Atlantic area. We will assume that the ground stations (of the 7-station regional network postulated earlier) are so located that most of the traffic that is the source of this revenue can be handled, provided the system has sufficient channel capacity.

Inspection of Figs. 5 and 6 (pages 54 and 55) shows that several possible system configurations have level annual costs of about \$70 million or less. Taking into account the most significant factors only, one reaches these conclusions:

(1) A regional random system having in-service times of 95 per cent or more must reach development level B, that is, a satellite

lifetime of three years, before its annual costs fall below the \$70 million postulated for Atlantic area revenues in 1970.

(2) A regional stationary system will meet this condition by 1970 if the lifetime of the satellites reaches about one year by then.

(3) For the costs of global systems to fall below the \$140 million estimated for worldwide revenues, both the random and stationary satellites must reach development levels between B and C: in the random system, because of the relatively high costs of ground stations; and in the stationary system, because of the cost of placing additional satellites in orbit so as to extend from regional to global coverage.

(4) Once stationary satellites reach development level C (that is, three years lifetime in orbit) the stationary system should be quite profitable.

In relating the three development levels to the revenues of the year 1970, it is essential to note that we assume no substantial additions to the cable network after 1965. Any such additions would subtract revenues from a satellite system.

Finally, it is clear that any satellite system that becomes operational by about 1965 could earn some revenue immediately, and, on the North Atlantic route, probably substantial revenues.

Appendix A

MILITARY USE OF COMMUNICATION FACILITIES

LOCAL AND OVERSEAS SERVICE

Among the various entities furnishing communication services, the United States Department of Defense ranks second only to AT&T. The undepreciated value of the investment by the military in its communications plant, from the end of World War II until early 1959, was \$1,019,000,000 [Merger, p. 177]¹. In contrast, the gross cost of the communication plant of all of our telegraph carriers, including those furnishing domestic service as well as those furnishing international service, was \$538,000,000 on December 31, 1959 [FCC CCS, 1959, p. 3].

The military communications complex serves many areas that are not reached by commercial communications facilities. A good example is the Arctic area, where we have both important bases and early warning systems such as the DEW line and BMEWS.

The military agencies have also pioneered in the development of service in sparsely populated areas. An example is the Alaska Communications System, formerly operated by the Signal Corps, but now operated by the Air Force. The Alaska Communications System provides service to civilians as well as to the military.

In addition to the plant owned and operated by the military, there are communications systems owned by commercial companies but operated by the military. One example is the cable from Seattle to Ketchikan, Alaska, installed and owned by AT&T, but installed with the intent of leasing the entire cable system to the Alaska Communications System. Another example is the microwave system up the Alcan Highway, constructed and owned by Canadian companies, but leased, in large part, to the U.S. Air Force [Merger, pp. 180-181].

¹Sources cited here by short title in brackets [] are given in full at the end of this Appendix.

Finally, the Department of Defense makes substantial use of commercial communications facilities both owned and operated by commercial companies. The military has instigated the development of many commercial systems. We have elsewhere noted the influence of military demand on the timing of the AT&T submarine cables [RM-3472-RC, pp. 8-10]. Military demands have also affected the development of systems within the United States, and within and among various foreign nations. The Defense Department has to some extent subsidized the development of commercially owned facilities within Europe and the Middle East [Merger, p. 184], and probably elsewhere as well.

Secretary McNamara testified in 1962 that the Defense Department bill for the use of commercial communications facilities is \$180,000,000 or more [Comsat, p. 304]. This figure is all-inclusive, including not only the bill for service between the United States and foreign points, but also the bill for service within the United States and for service between points abroad.

In summary, for service everywhere in the world, including local service as well as long-distance service, the Defense Department now pays \$180,000,000 a year to commercial companies and, in addition, it makes use of its own plant with a value on the order of \$1,000,000,000.

OVERSEAS SERVICE

Our explicit information on the use of overseas telecommunication facilities by the Defense Department is rather meager, and perhaps in consequence it also appears to be self-contradictory. However, because of the importance of the subject, we will set forth our "best estimate" of the truth of the matter.

By 1965, we believe that the bulk of military overseas traffic will be carried over commercial channels. This was not the case a few years ago. In April 1959, Colonel W. W. Bailey, then the Chief of the Communications Systems Division, United States Air Force,

testified that in "...the Department of Defense, in the transocean communications business today, about 79 percent of what we have is military-owned and operated. About 21 percent of the total is leased today" [Merger, p. 175].

The advent of the overseas submarine telephone cable system is the factor mainly responsible for the increased use of commercial facilities by the Defense Department. The first such system was put into service September 25, 1956. Since that time the overseas private line revenues (excluding the revenues from channels leased to the telegraph carriers) of AT&T have increased rapidly:

1956	\$ 188,000
1957	717,000
1958	1,358,000
1959	3,120,000
1960	4,237,000
1961	6,231,000

These data include the revenues from private lines leased to individuals, but in 1961 individual leases accounted for only one per cent of the total. The remaining private-line leases, 99 per cent of the whole in 1961, were leases to the Federal Government. We believe that the leases to the Federal Government were almost entirely leases to the Defense Department (and to NASA).

The distribution (approximate for 1962) of the private lines leased by AT&T to the Federal Government is as follows:

	<u>1961 average</u>	<u>December 1, 1962</u>
To Europe	20.5	28.5
TAT-1	10.5	15.5
TAT-2	10	10
Cantat	0	3
To Hawaii (cable)	11	11
To Puerto Rico	2	3
Cable	1	2
HF Radio	1	1

[Tabulation continued on p. 78]

	<u>1961 average</u>	<u>December 1, 1962</u>
To Bermuda	<u>6</u>	<u>14</u>
Cable	<u>0</u>	<u>13</u>
HF Radio	6	1
To the Bahamas (OH Radio)	<u>1</u>	<u>1</u>
Grand total	40.5	57.5

As of December 1, 1962, of the 57.5 channels leased to the Federal Government, 54.5 were cable channels, 2 were high frequency radio channels, and 1 was a tropospheric scatter channel. The explanation of the small number of lines leased in the cable to Puerto Rico is that the Air Force has its own cable there, as part of the facilities of the Atlantic Missile Range. An extension of the Air Force cable system in the Caribbean is to be completed early this year [Tel Rpts, 3/5/62, p. 38].

A question that has aroused much attention is that of the proportion of commercial overseas facilities that are used by the Department of Defense. Secretary McNamara, testifying in 1962, said, "If I recall the figures correctly, we utilize about 25 percent of the total intercontinental commercial communications capacity and, hence, the overhead costs, a large percentage of which we would otherwise have to absorb ourselves were we to be operating an exclusively military system, are shared with the commercial customers who form 75 percent of the total traffic" [Comsat, p. 305]. This proportion is somewhat higher than we have been able to find. It is conceivable that the Secretary was referring to the cable capacity on the North Atlantic route; as of December 1, 1962, AT&T had available for its use 112 voice channels in the cables on this route, of which 28.5, or 25 per cent, were leased by the Federal Government.

Summing over all routes, it appears to us that the Federal government's use of overseas commercial communication facilities was on the order of 15 per cent in 1962. In this count, we exclude traffic and facilities to Alaska, Cuba, and the Bahamas, but include

traffic and facilities to points like Puerto Rico and Hawaii. On the routes included, we count not only the voice channels on the telephone cable facilities but also the equivalent voice channels on the telephone and telegraph companies' high frequency radio facilities and the telegraph cables. The count of channels used by the Federal Government includes channels leased from the telegraph companies as well as the telephone companies, and, in addition, the equivalent number of channels used by the Federal Government for ordinary telephone message or telegraph message purposes.

By 1965, we envisage a greatly expanded use by the Defense Department of commercial overseas facilities. The number of private lines leased by the Department in telephone cables at that time may be of the following order:

To Europe	64
From Hawaii westward	64
To Hawaii	96
To the Canal Zone, etc.	20
To Bermuda	20
To Caribbean points and Venezuela	20

In part, these estimates rest on the Department of Defense requirement for capacity in units of 48 kilocycles, equivalent to 16 (3-kc) voice channels; the requirement was first set forth, to our knowledge, in 1959 [Merger, p. 290], and it was re-iterated in the Department of Defense 1962 policy statement "Industry-Department of Defense Cooperation in Satellite-Based Telecommunications" [Comsat, p. 291]. The question then is the number of such units required by route. We have elsewhere argued that as many as 64 channels are required to Europe and westward from Hawaii [RM-3472-RC, p. 10]. To Hawaii proper, we imagine that an additional 32 channels will be needed to serve traffic terminating there. For the Canal Zone, we assume that the Department will require its basic unit, or 16 voice channels; the Canal Zone cable will serve other points, to which we assume a requirement of 4 voice channels. The estimate for Bermuda allows for the leasing of an additional 6 lines by 1965. Finally, the estimate for Caribbean points is mainly a guess, supported somewhat by the

AT&T statement of a military requirement for 12 voice channels in a Puerto Rico-Antigua cable to be built by AT&T [AT&T applications to the FCC for the Puerto Rico-Antigua cable, October 24, 1960, revised December 9, 1960].

In summary, by 1965, the requirements of the Department of Defense on overseas point-to-point facilities will be supplied mainly by commercially owned submarine telephone cable systems. This generalization does not apply to systems serving special purposes, such as command and control and support of the Atlantic Missile Range. In 1965, about 30 per cent of the voice channels in submarine cables available to AT&T will be used by Defense (and NASA). This proportion is not "normal"; by 1970, the proportion may be 20 per cent, which is more typical.

THE DEFENSE DEPARTMENT EXPENDITURES FOR OVERSEAS SERVICES

Of the total of \$180,000,000 given by Secretary McNamara as the expenditure by the Defense Department for the use of commercial communication facilities, \$19,000,000 was spent for "intercontinental charges for commercial purposes" [Comsat, p. 295; see also pp. 300, 304, and 307].

This amount appears to be rather high in contrast with the payment of only \$6,000,000 or so to AT&T for leased lines in 1961. The explanation is that the Defense expenditure includes not only payments to AT&T for leased lines but also payments to the telephone companies at the other or foreign end of the lines leased from AT&T; it also includes payments to domestic and foreign telegraph companies for leased telegraph channels; it includes payments for foreign telephone and telegraph companies for such intercontinental services as they render our Department of Defense (for example, London to the Middle East); and, finally, because Defense expenditures for overseas commercial facilities are rising, the rate of expenditure the Secretary had in mind when he was testifying (August 1962) probably exceeded the expenditures in 1961.

For the Federal Government as a whole in 1961 (or in the first quarter of 1962), the payments for overseas services to commercial companies owned by United States interests were as follows (quarterly data converted to annual rates):

To Western Union, RCA Communications,
and American Cable & Radio Corporation

For leased telegraph channels	\$ 3,600,000
For message service and other	<u>1,200,000</u>
Total	\$ 4,800,000

To AT&T

For leased channels	\$ 6,170,000
For message service and other	<u>1,580,000</u>
Total	\$ 7,750,000

Grand total	\$12,550,000
-------------	--------------

[Source: Comsat, p. 444, except AT&T message revenues; AT&T message revenues supplied by private communication from AT&T.]

Of this total, we believe that about \$9,000,000 would represent the Defense Department bill alone. Mainly because in 1961 AT&T happened to own in whole or almost in whole, some circuits it leased to the Defense Department, the share of foreign-owned telephone and telegraph companies in the Defense Department bill is not equal to the domestic share; it is on the order of \$7,000,000. We have accounted, more or less, for \$16,000,000 of the \$19,000,000 mentioned by Secretary McNamara. The remaining \$3,000,000 may represent payments to foreign telephone and telegraph companies for intercontinental services rendered abroad, or in part it may reflect the difference between the annual rate of expenditure in mid-1962 and the year's bill for 1961.

REFERENCES CITED IN APPENDIX A

- Comsat: Committee on Foreign Relations, United States Senate, 87th Congress, Second Session, Communications Satellite Act of 1962, U.S. Government Printing Office, Washington, D.C., 1962.
- FCC CCS (with year): An annual publication of the Federal Communications Commission, U.S. Government Printing Office, Washington, D.C. Through 1956, the publication was called Statistics of the Communications Industry in the United States; starting with the 1957 yearbook, the name was changed to Statistics of Communications Common Carriers. The publication is usually referred to as "FCC Common Carrier Statistics."
- Merger: Committee on Interstate and Foreign Commerce, United States Senate, 86th Congress, First Session, Merger of International Telegraph Carriers, U.S. Government Printing Office, Washington, D.C., 1959.
- RM-3472-RC R. T. Nichols, Submarine Telephone Cables and International Telecommunications, The RAND Corporation, RM-3472-RC, February 1963.
- Tel Rpts: Telecommunications Reports, Washington, D.C., weekly.

Appendix B

WORLD OVERSEAS TELEPHONE TRAFFIC IN 1960

The data in this section are taken from a special study prepared by AT&T, "Estimated Overseas Telephone Message Traffic, 1960," October 1961 (mimeographed). In this study, traffic is identified by originating and terminating points, while in other reports traffic is identified by relay points, which may or may not be identical with country of origin or destination.

Europe. Excluding traffic to and from North America, there were 377,000 messages originating or terminating in Europe, with distribution by area of destination or origin as follows:

South America	34,000
Africa	170,000
Middle East and South Asia	110,000
North Asia (Japan, etc.)	16,000
Oceania (Australia, New Zealand)	47,000
Alaska and Hawaii	<u>1,200</u>
	377,000

Because of rounding errors, the details may not exactly sum to the totals.

This count of European overseas traffic omits traffic between France and North Africa, which may run as high as a million or more messages a year. It includes traffic of the Communist nations, which have about 6.5 per cent of the total number of telephones in Europe.

South America. Excluding traffic to and from North America, there were 36,000 messages originating or terminating in South America, of which 34,000 messages originated or terminated in Europe.

Africa. Excluding traffic to and from North America and traffic between France and North Africa, there were 198,000 messages originating or terminating in Africa, distributed by area of origin or destination as follows:

Europe	170,000
South America	300
Middle East and South Asia	9,500
North Asia	12,000
Oceania	6,500
Alaska and Hawaii	<u>negligible</u>
	198,000

Middle East and South Asia. This area includes Turkey, Israel, India, Malaya, Indonesia, and many other countries. Excluding North American traffic, there were 173,000 messages originating or terminating in the Middle East and South Asia, distributed by area of origin or destination as follows:

Europe	110,000
South America	400
Africa	9,500
North Asia	49,000
Oceania, Alaska, and Hawaii	<u>4,700</u>
	173,000

In addition, there were 42,000 overseas messages originating and terminating within the area.

North Asia. Excluding North American traffic, there were 89,000 messages originating or terminating in North Asia, distributed as follows:

Europe	16,000
South America	800
Africa	12,000
Middle East and South Asia	49,000
Oceania	8,300
Alaska and Hawaii	<u>3,600</u>
	89,000

In addition, there were 108,000 overseas messages originating and terminating within the area. Of these intra-area messages, 80,000 messages were exchanged between Japan and the remainder of the area, and 28,000 messages within the North Asian area excluding Japan.

Of the 89,000 messages exchanged between this area and other areas, 41,000 originated or terminated in Japan, and 48,000 originated or terminated in the remainder of the area--China, Philippines, Hong Kong, Korea, etc.

Oceania. In terms of number of calls, this area may be practically defined to comprise Australia and New Zealand. There were 35,000 messages between Australia and New Zealand. Excluding this intra-area traffic and North American traffic, there were 70,000 messages originating or terminating in Oceania, distributed as follows:

Europe	47,000
South America	1,200
Africa	6,500
Middle East and South Asia	4,700
North Asia	8,300
Alaska and Hawaii	<u>2,800</u>
	70,000

Alaska and Hawaii. Excluding North American and intra-area traffic, there were only 8,000 messages between Alaska and Hawaii and the rest of the world.

Recapitulation. Excluding traffic to and from North America, there were 662,000 overseas telephone messages originating and terminating in the remainder of the world, distributed as follows:

Europe	to South America	34,000
	to Africa	170,000
	to Middle East and South Asia	110,000
	to North Asia	16,000
	to Oceania, Alaska, and Hawaii	48,200
Africa	to South America	300
	to Middle East and South Asia	9,500
	to North Asia	12,000
	to Oceania, Alaska, and Hawaii	6,500
Middle East and South Asia		
	to South America	400
	to North Asia	49,000
	to Oceania, Alaska, and Hawaii	4,700
	to intra-area points	42,000
North Asia	to South America	800
	to Oceania	8,300
	to Alaska and Hawaii	3,600
	to intra-area points	108,000
Oceania	to South America	1,200
	to Alaska and Hawaii	2,800
	to intra-area points	35,000
Hawaii	to Alaska	<u>1,120</u>
		662,000

The relative importance of each area and subarea, in terms of overseas telephone traffic, can most readily be shown by counting each message twice, once at the point of origin and once at the point of destination:

Europe		377,000
United Kingdom	183,000	
Continental Europe	194,000	
South America		36,000
Africa		198,000
Union of South Africa	73,000	
Rest of Africa	125,000	
Middle East and South Asia		257,000
Middle East (Turkey, Israel, etc.)	53,000	
South Asia (Iran to Indonesia)	204,000	
North Asia		305,000
Japan	121,000	
China, Hong Kong, Philippines, etc.	184,000	
Oceania		141,000
Australia	91,000	
New Zealand, etc.	50,000	
Alaska and Hawaii		10,000
Alaska	2,000	
Hawaii	8,000	
		1,324,000

The main conclusions that may be drawn from these tabulations are:

- (1) South America has very little traffic with the world outside of North America.

(2) The United Kingdom alone has almost half the traffic of all Europe to points outside of North America.

(3) The British Commonwealth is a very important factor in traffic other than North American traffic. This conclusion emerges much more strongly when allowance is made, as it is not made above, for circuit length and hence total revenues.

(4) Traffic to and from the Asian countries is far from negligible, especially in comparison with the traffic to and from South America.

(5) Japanese traffic does not dominate the traffic from other nearby Asiatic countries. It appears that on a revenue basis Japanese traffic might be equal to, but is probably less than, traffic to and from China, Hong Kong, Korea, the Philippines, etc.

North American and World Traffic. The number of overseas telephone messages originating or terminating in North America in 1960 was 2,530,000. Hence, of the world total number of messages of 3,192,000, North America accounted for 80 per cent. The continental United States alone accounted for 70 per cent; in other words, 70 per cent of the world's overseas telephone traffic originated or terminated in the continental United States.

The count of North American traffic just given omits traffic among the various North American countries. In particular, it omits traffic, often classified as overseas traffic, between the continental United States (and Canada and Mexico) and Central America, Bermuda, Bahamas, Cuba, Puerto Rico, Jamaica, and other West Indian islands;

as well as traffic that originated and terminated in the West Indies and Central America.

There are one or two reasons that suggest that traffic to the West Indies from the remainder of North America should be omitted from the count of world traffic--in particular, if the aim is to assess the standing of the United States. These reasons are: first, traffic from France to North Africa, and, in addition, traffic from the United Kingdom to Norway, Sweden, Denmark, Iceland, Germany, and other continental points--all carried by submarine telephone cable--is omitted; second, much of the traffic to the West Indies is very short haul, shorter than the haul from Marseilles to Algiers: half the traffic with the West Indies originates or terminates in Cuba and the Bahamas, scarcely a stone's throw away by cable or tropospheric scatter from Florida.

We revert, then, to the world overseas telephone message count of 3,192,000. Counting each message twice, the total is 6,384,000, with distribution as follows:

United States (continental)	2,281,000	(35.7%)
Rest of North America	249,000	(3.9%)
Europe	1,517,000	(23.8%)
South America	288,000	(4.5%)
Africa	207,000	(3.2%)
Middle East and South Asia	287,000	(4.5%)
North Asia	446,000	(7.0%)
Oceania	181,000	(2.8%)
Alaska and Hawaii	<u>927,000</u>	<u>(14.5%)</u>
	6,384,000	(100.0%)

This tabulation may be read in either one of two ways. First, if we are interested in the proportion of world traffic that originates or terminates in any one area, we double the percentages shown; for the

United States, the result is 71.4 per cent. Second, if we are interested in the participation in world telephone revenues by the carriers of any one area, we simply read off the percentages as shown (on the assumption that the revenues on traffic to and from each area are divided half-and-half with foreign carriers); for United States carriers, the result is 35.7 per cent.

Appendix C

OVERSEAS TELEPHONE TRAFFIC TO AND FROM THE UNITED STATES IN 1961

Areas	Number of messages	Revenues of all carriers (and per cent of total revenue)
<u>Total all areas</u>	4,317,162	\$87,950,900 (100.0%)
<u>Europe (and nearby)</u>	1,225,406	39,120,000 (44.5%)
Great Britain	398,737	
Germany	279,190	
France	173,688	
Italy	85,146	
Switzerland	72,364	
Netherlands	43,210	
Sweden	29,828	
Belgium	27,404	
Denmark	20,282	
Spain	19,792	
Norway	16,288	
Austria	14,302	
Greece	13,648	
Israel	10,820	
Portugal	4,288	
Poland	3,177	
Turkey	3,138	
U.A.R. (Egyptian Sector)	2,951	
Finland	2,807	
Russia	2,762	
Saudi Arabia	1,584	

Note: Each point of communication may be either (1) the foreign country or overseas point of destination or origin of the call (2) an intermediate country or overseas point through which the call is relayed onward. Therefore, the number of calls reported herein with respect to a particular place is not necessarily the number of calls originating or terminating with that place. The absence of certain foreign countries in the above listing indicates that no direct cable or radio telephone service was provided therewith in 1961. Any calls that may have been handled with such countries during 1961 are included in the traffic of the intermediate country through which indirect service was rendered.

The revenues shown in this Appendix are the total revenues received by all communication companies, not just the half of the revenues that are retained by United States concerns. The message count includes both incoming and outgoing messages. This material was prepared especially for RAND by AT&T and that company's cooperation is gratefully acknowledged.

Areas	Number of messages	Revenues of all carriers (and per cent of total revenue)
<u>Caribbean Sea</u>	292,620	\$4,040,000 (4.6%)
Bahamas	175,215	
Jamaica	50,018	
Dominican Republic	30,971	
Trinidad	11,702	
Barbados	8,330	
Haiti	7,464	
Curacao	4,754	
Aruba	3,639	
Martinique	527	
<u>Cuba</u>	688,192	6,210,000 (7.1%)
<u>Puerto Rico & Virgin Islands</u>	493,161	7,860,000 (8.9%)
<u>South America</u>	191,402	4,830,000 (5.5%)
Venezuela	44,071	
Argentina	39,687	
Brazil	32,398	
Colombia	30,830	
Peru	18,081	
Chile	11,522	
Ecuador	7,220	
Uruguay	5,999	
Surinam	1,594	
<u>Central America</u>	104,778	1,690,000 (1.9%)
Panama	37,768	
Guatemala	18,360	
Costa Rica	14,701	
Nicaragua	13,270	
Honduras	10,815	
El Salvador	8,468	
British Honduras	1,396	
<u>Northeast Asia</u>	136,404	4,110,000 (4.7%)
Japan	79,002	
Korea	16,281	
Hong Kong	13,535	
Guam	11,743	
Okinawa	10,930	
Formosa	4,898	
China	15	

Areas	Number of messages	Revenues of all carriers (and per cent of total revenue)
<u>Southeast Asia</u>	23,559	\$ 600,000 (0.7%)
Philippines	18,845	
Viet Nam	1,827	
Indonesia	1,444	
Malaya	1,443	
<u>South Pacific</u>	27,367	740,000 (0.8%)
Australia	22,195	
New Zealand	4,384	
Tahiti	788	
<u>Hawaii</u>	568,121	9,960,000 (11.3%)
<u>Alaska</u>	450,610	7,740,000 (8.8%)
<u>Miscellaneous</u>	68,933	1,050,000 (1.2%)
Bermuda	61,958	
Union of South Africa	3,636	
Iceland	2,252	
Ascension	1,087	
<u>Overseas to Overseas</u>	46,609	

Appendix D

NUMBER OF TELEPHONES IN SERVICE BY CONTINENTAL AREAS,
JANUARY 1, 1961

	Number	Per cent of world total
North America	79,830,600	56.3
Middle America	1,075,900	0.8
South America	3,337,600	2.3
Europe	43,172,700	30.5
Africa	2,005,300	1.4
Asia	9,053,400	6.4
Oceania	3,224,500	2.3
World	141,700,000	100.0
United States	74,342,000	52.4

Source:

"The World's Telephones, 1961," American Telephone
and Telegraph Company, New York [1962].

Appendix E

INTERNATIONAL TELEX AND DATA SERVICE

Record and data transmission services currently being offered on intercontinental links include, in addition to message telegraph and facsimile transmission, message teletypewriter exchange service (telex), message datatelex (the counterpart of telex in the data transmission field), and private line telegraph service. These last three are interrelated. A very large consumer will rent a telegraph circuit rather than pay message rates for telex service.

The revenue of the U.S. international telegraph carriers from telex service has been increasing at a yearly average rate of about 40 per cent (1956 to 1961). Datatelex service was inaugurated only in September 1962. Revenue from telegraph circuits leased to consumers by the telegraph carriers has increased at a rate of about 10 per cent a year since 1956. In 1961, telex revenues were \$9,700,000 and leased telegraph circuit revenues were \$8,600,000.

A growth rate of 40 per cent is an impressive rate. There is every reason to believe, however, that the rate of increase during the period 1956 to 1961 will not be sustained in the future. The high rates of growth of recent years reflects the fact that a latent demand for such a service has been developing over a long period of time and has suddenly been accommodated. The international experience with telex gives some idea of this phenomenon. International telex traffic involving the United Kingdom grew at a rate of 55 per cent per year during the period 1952-1955; the rate of increase fell to

about 12 per cent by 1960. For Germany, telex traffic increased at 42 per cent per year during the period 1952-1955; the rate of increase fell to 16 per cent in 1960 and 11 per cent in 1961. In Japan, which received telex service only in 1956, traffic doubled from 1957 to 1958, but increased by only 42 per cent from 1960 to 1961. In the United States, the increase in telex service revenue from 1960 to 1961 was only 32 per cent--perhaps an indication of the slackening of the rate of increase to come.

The overseas circuits required to handle the 1961 volume of telex business were trifling in comparison with the circuits required for message telephone service. Circuit requirements for message telephone service were greater than requirements for telex service by at least 20 to 1.

There has been much speculation as to the extent of the future market for "broadband" or "rapid" data transmission. Several points should be mentioned here. First, both broadband and rapid are relative terms. Commonly, a broadband data circuit utilizes the bandwidth of one voice channel. In terms of speed of transmission, the standard rate on telegraph circuits is 60 words per minute; datatelex service, using one voice channel, is offered commonly at the equivalent rate of 1500 words per minute. Second, we cannot foresee a commercial demand during the next decade for real time intercontinental data transmission at speeds that would require the bandwidth of a large number of voice channels. A very large number of channels are required only for linking computers for simultaneous solution of problems. On the other hand, computer systems can be

programmed and data supplied over the bandwidth of a single voice channel.

The demands of the Defense Department are another story. For several years, the Defense Department has shown an interest in very broadband and very rapid channels of a bandwidth equivalent to that of 16 ordinary telephone voice channels. These channels are intended to transmit data at a rate of 40.8 kilobits per second, which works out to about 90,000 words a minute. The very broadband channels are also to be used for voice transmission.

It is interesting to see what circuit requirements of the future might be, if demand for telex and datatelex, whether expressed as demand for message service or as demand for private line service, were to continue to increase at a rate of 40 per cent per year. In 19 years, by 1980, the demand would have increased 580-fold. If, however, the growth rate were to be more modest, only 20 per cent per year, by 1980 the demand would have increased only 32-fold. Circuit requirements for telex, etc. are now somewhat less than 5 per cent of circuit requirements for telephone message service; if each increases at a rate of 20 per cent per year, the ratio of circuit requirements still remains 1 to 20. However, if telex, etc. demand were to increase at the rate of 40 per cent, and telephone message service at the rate of only 20 per cent, the 1980 circuit requirements for telex, etc. would be almost as great (90 per cent) as the circuit requirements for telephone messages. An important qualification is that these calculations are based on the assumption of no

change in the circuit requirements per telex message relative to the circuit requirements per telephone message.

Two or three points are worthy of mention:

(1) Except for service to faraway points of small traffic density, all services offered by our international telegraph carriers, including message telegraph, facsimile transmission, telex, and data-telex, will in the near-term future be carried in telephone company cables. The telephone company will lease voice channels to the telegraph companies. The telegraph companies in turn will use these voice channels for message service (telegram, telex, or datatelex), or they will rent telegraph circuits within the voice channel to individual customers. Hence, a double leasing may be involved, one lease from the telephone company to the telegraph company, and a second lease from the telegraph company to the customer.

(2) The distinction between voice and nonvoice or record service will be increasingly obliterated in the future. Voice channels may now be rented for alternative voice and record service, at the pleasure of the customer. The very broadband service that the Defense Department is contemplating will be used for both voice and record service.

(3) Technological innovation is likely to have a much more profound effect on the circuit requirements for telex and datatelex than on the circuit requirements for telephone service. Early this year, Western Union filed an application with the FCC that suggested that the company contemplated very soon the obtaining of 44 telegraph

channels from one telephone voice channel rather than the customary
22. Other improvements, not too far off, are likely to increase
several-fold the quantity of information that can be transmitted per
unit of frequency bandwidth.