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CHOOSING NEW TELECOMMUNICATIONS TECHNOLOGIES: TRADEOFFS BETWEEN CONFLICTING GOALS

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CHOOSING NEW TELECOMMUNICATIONS TECHNOLOGIES: TRADEOFFS BETWEEN
CONFLICTING GOALS^{*}

Patricia M. Dinneen

May 1981

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INTRODUCTION



Depending on how strongly a firm, sector, regulatory agency, or nation values certain objectives, its choice of new telecommunications technologies may differ accordingly. If we can understand how trade-offs are made between conflicting goals, by different groups, then we may begin to understand, predict, and perhaps some day control the rate and nature of technological change and the resulting mix of telecommunications technologies.

In this paper, we consider six primary telecommunications goals: (1) economic efficiency, (2) security and privacy, (3) reliability and quality of service, (4) industrial stability, (5) international comity, and (6) technological innovation. The relative weighting of these goals will depend on:



- o who you are and what you expect to gain or lose from a new technology (e.g., whether you are a producer, consumer, owner of the new or old technology, regulator, government or communications-intensive firm, etc.)
- o the size of your budget (e.g., relative difficulty and cost of raising capital, cost of technology relative to your total budget, etc.)
- o the scope of your telecommunication demands (e.g., very short distances, dense urban or diffuse rural, intra- or inter-firm, remote areas or global coverage, etc.)
- o the magnitude of your telecommunications demand (e.g., the number of people and routes you wish to connect, how frequently, how rapidly, at what rate of growth over time, peaked versus levelized demand, etc.)
- o the length of your planning horizon (e.g., near term (1-5 years) or intermediate (6-15 years) or long term (16 or more years))

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- o your expectations about further technological change, costs and the level of competition, and
- o your existing political and social infrastructure and values.

Given a set of weights for telecommunications goals, new technologies can be evaluated on the basis of how well they satisfy the more important goals. If a new technology can satisfy highly-valued goals relatively better (e.g., more effectively, at less cost, more rapidly) than an existing technology, we might expect the new technology soon to replace the existing one. However, if a new technology either fails to satisfy highly-valued goals or generates conflicts between them, tradeoffs must be made--which may limit the rate and scope of technological change. Furthermore, if a new technology satisfies the highly-valued goals of one group, but generates conflicts with those of another group, compromises may be required which will affect the relative level and mix of technology utilization.

A GENERAL FRAMEWORK FOR ANALYSIS

Table 1 represents, conceptually, a ranking of existing and new technologies, according to their ability to satisfy telecommunications goals. Goals (G_i) are listed across the columns of the matrix, and ranked in importance according to their relative weights (g_i). Technologies (T_j) are listed down the rows. Entries (t_{ji}) indicate the relative ability of technology, j , to satisfy goal, i . Reading across the rows allows us to compare how well a given technology can satisfy different goals. Reading down columns allows us to compare the relative ability of different technologies to satisfy each goal.

Table 1 merely suggests a framework for evaluating technologies; it does not explain the process by which tradeoffs between goals influence the choice of new technologies. However, we may use the general framework to understand and test how the process works in specific cases. To illustrate, we present, in this paper, the results of a case study involving two technologies--both of which can provide international telecommunications. Even though the new technology (communications satellites), at the time of its development, promised major

←----- GOALS -----→

↑ TECHNOLOGIES ↓		G_1	G_2	G_3	o o o	G_N
		g_1	g_2	g_3		g_N
	T_1	t_{11}	t_{12}	t_{13}	o o o	T_{1N}
	T_2	t_{21}	t_{22}	t_{23}	o o o	t_{2N}
	T_3	t_{31}	t_{32}	t_{33}	o o o	t_{3N}
	o o o	o o o	o o o	o o o	o o o	o o o
T_M	t_{M1}	t_{M2}	t_{M3}	o o o	T_{MN}	

TABLE 1: Relative Ranking of Telecommunications Technologies by Their Ability to Satisfy Telecommunications Goals

where: G_i = Telecommunications goals, $i = 1, 2, \dots, N$

g_i = Relative weights of goals, $\sum_i^N g_i = 1$

T_j = Telecommunications technologies, new and existing,
 $j = 1, 2, \dots, M$

t_{ji} = Relative ability of technology j to satisfy goal i

potential advantages over the existing technology (undersea cables), tradeoffs between conflicting objectives prevented the full and rapid commercial exploitation of the new technology. Instead, both cables and satellites were utilized at an approximately proportional rate. And, the mechanism for limiting the relative utilization level and rate of the new technology was and continues to be U.S. regulatory policy. We shall argue below that, in the case of U.S. international telecommunications, tradeoffs between goals are reflected in regulatory policies that lead to distortions in the efficient relative prices of cables and satellites. The regulatory-induced distortions in relative prices determine the utilization and investment level and mix of the new, relative to the existing, technology.

CHOOSING NEW TELECOMMUNICATIONS SATELLITES: THE CASE OF COMMUNICATIONS SATELLITES

The first commercial communications satellite, "Early Bird," was successfully launched in 1965. Compared with the primary existing technology, undersea cables, satellites promised major potential advantages for overseas communications, in terms of reduced costs, increased capacity, increased flexibility in routing, positioning and broadcasting ability. However, despite these potential advantages, satellites did not completely and rapidly replace cables. To understand why not, we must first ask if the two technologies are perfect substitutes. And, if not, what are their relative advantages and disadvantages in satisfying the six telecommunications goals enumerated above (e.g., economic efficiency, security and privacy, reliability, etc.).

The New Versus the Existing Technology: Relative Abilities to Satisfy Goals

Either satellites or cables are technically capable of transmitting signals overseas.¹ However, the extent to which they are

¹There are basically two ways of transmitting signals overseas: signals can either be carried in enclosed conduits (via undersea cables) or radiated through the atmosphere (via telecommunications satellites).

considered substitutes or complements depends on: (1) which telecommunications goals you value most highly and (2) the particular conditions, services and/or users involved. For each goal, we shall indicate the relative advantages of using satellites or cables exclusively, or using both.

1. Economic Efficiency. To satisfy the goal of economic efficiency requires choosing the least cost level and mix of technologies. Although both technologies have demonstrated economies of scale and decreasing costs over time, satellite costs have fallen more rapidly and, since 1968, have been consistently lower than cable costs. Table 2 compares average investment costs per circuit, average operating costs per circuit and both, in constant 1970 dollars, for cables and satellites--including space segment costs only² and space and ground³ segment costs combined.

There are several reasons why satellite costs are lower. First, unlike cable costs, which are an increasing function of distance, satellite costs are distance-insensitive--since it ties up the same amount of satellite equipment to transmit over short or long distances.⁴ Furthermore, unlike cables, which are inherently point-to-point links, satellites are capable of broadcasting to and from multiple users simultaneously.⁵ By connecting large numbers of users, over vast distances, simultaneously, satellites provide more efficient use of resources, at less cost. Furthermore, because of their much greater bandwidths and circuit capacities (to be discussed later), satellites can provide multiple voice, record and broadband services (such as television) simultaneously, at lower and lower unit costs, as

²Space segment costs consist of launch vehicle, spacecraft, development costs, capitalized incentives and department expenses.

³Ground segment costs consist of ground control equipment, multiplex and frequency- and capacity-related equipment.

⁴For distances exceeding approximately 700-1000 miles, satellite costs are less than cable costs. But for very short distances, cable costs may be less.

⁵Broadcasting ability requires multiple ground stations. But, to the extent that ground stations can be optimally located, broadcasting costs can be minimized.

TABLE 2
COMPARATIVE COSTS PER HALF-CIRCUIT-YEAR, OVER TIME,
CABLES VERSUS SATELLITES,
(in 1970 \$000)

Name of Cable	CABLES			SATELLITES									
	Average Investment Cost per half circ.-yr.	Average O&M Cost per half circ.-yr.	Aver Inv't & O&M Costs per half circ.-yr.	SPACE SEGMENT			GROUND SEGMENT			COMBINED			
				Name of Satellite	Aver Inv't Cost per half circ.-yr.	Aver O&M Cost per half circ.-yr.	Aver Inv't & O&M Costs per half circ.-yr.	Aver Inv't Cost per half circ.-yr.	Aver O&M Cost per half circ.-yr.	Aver Inv't & O&M Costs per half circ.-yr.			
1956	TAT-1	15.6	1.05	16.65									
1957													
1958													
1959	TAT-2	12.8	1.40	14.20									
1960													
1961													
1962													
1963	TAT-3	8.9	.35	9.25									
1964													
1965	TAT-4	8.7	.48	9.18	IS-I	17.63	4.56	22.19	8.3	1.40	25.93	23.59	49.52
1966					IS-II	9.49	3.33	12.82	6.2	1.32	15.69	14.14	29.83
1967													
1968					IS-III	1.43	.93	2.36	.60	.14	2.03	2.50	4.53
1969													
1970	TAT-5	1.95	.14	2.09	IS-IV	.73	.25	.98	.08	.05	.81	1.03	1.84
1971													
1972													
1973													
1974													
1975					IS-IV	.42	.13	.55	.05	.03	.47	.58	1.05
1976	TAT-6	.60	.04	.64									
1977													
1978													
1979					IS-V	.28	.08	.36	.05	.02	.33	.38	.71
1980													
1981	TAT-7	.59	.02	.61									

SOURCES:

- "The World's Submarine Cable Systems," Office of Telecommunications, U.S. Department of Commerce, OT Contractor Report 75-2, 1975.
- FCC Docket 18875, "Future Licensing of Facilities," *Proposed Long Range Plan*, submitted by the USISCs, April 29, 1977.
- FCC Docket 18875, "Future Licensing of Facilities," *Submission and Analysis of Alternative Facilities Plans by Communications Satellite Corporation*, submitted by Comsat, April 26, 1977.
- Comsat internal document on costs and capacities, January 11, 1977.

demand increases. Cables, on the other hand, are bandwidth-limited (to be discussed later) and may only provide wideband services at the expense of other services, if demand is very large.

Although satellites, exclusively, can satisfy the economic efficiency goal, nonetheless, in the future, as technology advances or as frequency spectrum becomes an increasingly scarce resource,⁶ cables may increase in relative efficiency.

2. Security and Privacy. To satisfy the goal of security and privacy requires protecting telecommunications from unwarranted monitoring or jamming. Cables have a relative advantage because to intercept and interfere with cable transmissions requires direct physical contact--which can be detected and therefore, presumably, removed or avoided. Satellites, on the other hand, can be monitored or jammed, without physical connection, from remote hidden receivers or transmitters--which are difficult to detect and, therefore, to remove.⁷ There are, however, technical means for minimizing the vulnerability of monitoring or jamming satellites, such as encryption devices, frequency hopping and narrow beam configurations. But each of these technical modifications adds costs and complexity. Thus, for groups valuing security and privacy highly, such as the Defense community, banks, multinational firms, and diplomatic services, satellites are not considered perfect substitutes for cables, and cables are the preferred technology--for sensitive communications.

⁶The degree to which frequency spectrum may be considered a "scarce" resource depends on the current technology available for exploiting it and the administrative/political method for allocating it. For further discussion, see Charles Jackson, "Technology for Spectrum Markets." Ph. D. dissertation, M.I.T., 1977.

⁷For a detailed discussion of covert observation and interception, see Richard L. Garwin, "Some Aspects of Technology and Privacy," a reprint, originally published as "Intelligence and Technology," a staff report of the Senate Select Committee on Intelligence, Vol. IV, April 23, 1976, pp. 109-119. For more details about alleged unlawful interception by gangsters and industrial spies, as well as by foreign nations, see New York Times, September 3, 1977, p. 14; New York Times, August 29, 1977; New York Times, July 30, 1977, p. 8; Washington Star, April 3, 1977, p. A-5; Atlanta Journal and Constitution, April 3, 1977, p. A-1; Christian Science Monitor, August 10, 1977, p. 1.

3. Reliability and Quality of Service. High quality, continuous service, even in the event of unexpected increases in demand or outages, is a highly valued goal for persons or groups which depend upon instantaneous, two-way responses and for whom access time is restricted, for example, by differences in international time zones. What is important is not only the availability of a circuit (e.g., no "busy signals"), but the continued availability of the circuit (e.g., no interruptions or disconnections) and the quality of the circuit (e.g., no "delay" or "echo" or electrical interference-- that might render the signal incomprehensible.)

Regarding reliability, both satellites and cables provide consistently high service continuity, but satellites are slightly more reliable and are often used to restore cable outages. For example, in a study of satellite and cable reliabilities, over a six-year period 1970-1975, satellites averaged 99.9% availability while cables averaged 98.6%.⁸ One of the reasons for the lower continuity level is that, once cables are damaged or cut, it frequently takes a long period of time to repair them (often up to several days or weeks), especially if they are cut at great depths or if adverse sea conditions prevail to complicate and hamper repair efforts. During the period 1970-1975, facility outage duration per circuit for cable systems exceeded that for satellites by about 27 times (4.91 *days* outage/circuit/year for cable systems compared with 4.28 *hours* outage/circuit/year for satellite systems).⁹ Furthermore, 75 percent of all cable system facility outages were restored by satellites. On the other hand, the average circuit interruptions for satellite systems were about 16 times as frequent as for cables (about 12 interruptions per circuit per year for satellites and only .77 for cables).¹⁰ However,

⁸ George S. Li, "Submarine Cable and Communications Satellite Systems Reliabilities," Office of Telecommunications OT Contractor Report 77-5, Dept. of Commerce, April 1977, p. 3, and Tables 11, 12 and 16.

⁹ Ibid.

¹⁰ Ibid.

in the future, reliabilities of both can be expected to improve due to more protective sheaths and greater depths for cable construction and technological improvements for satellites.

Although the differences in reliabilities are relatively small, there are more significant differences in the quality of service. These quality differences arise from a basic technical asymmetry in the way circuits are produced by the two technologies. Since cables carry signals through enclosed conduits, they are physically limited from using higher and higher frequencies (i.e., wider and wider bandwidths) by the nature (e.g., conductivity) of the materials through which the signals travel and by the power requirements for transmitting signals and amplifying them along the way.¹¹ Unlike cables, however, satellites radiate signals through the atmosphere and are able to transmit at very high (microwave) frequencies (i.e., very wide bandwidths) with limited power sources in the satellite and on the ground for signal amplification.¹² The greater bandwidth capacity allows satellites to provide multiple broadband services (such as TV) simultaneously; whereas, cables can only provide multiple TV channels by preempting alternative voice and record channels. In fact early generation cables were so bandwidth-limited that they were incapable of producing even one TV channel. Thus, substituting satellites for cables allows greater capacity. However, in the future, if undersea cables can be constructed of optical fibers, then signals can be transmitted at light wave frequencies--even higher than currently-used satellite microwave frequencies. Thus, the relative quality differences may change over time.

¹¹"Repeaters" (i.e., amplifying devices) are spaced at regular, frequent intervals along the cable to protect signals from being attenuated or dispersed. Each repeater requires its own limited amount of power.

¹²Satellites, however, are technically limited from indefinitely expanding capacity or exploiting ever higher and higher frequencies by the problems of electronic and atmospheric signal interference.

Another quality difference concerns two-way voice and two-way, high-speed data communications. The difference arises from time delays between a signal and response when transmitting via high-altitude satellites in tandem (i.e., two-hop routing). For one-hop routings, it takes about 0.3 second for signals, travelling at the speed of light, to be transmitted from origination points on earth, up to a geo-stationary satellite at altitude 22,300 miles, and then down to destination points on earth. And similarly, it takes about 0.3 second for the response to be returned. Experiments of customer reactions to this slight time delay indicate that for slow or normal rates of conversation, the delay is barely perceptible, or at least, most customers tested were willing to adapt to it. However, if people have a very rapid rate of speech or are prone to interrupt frequently, then even a 0.3 second delay will be perceptible and perhaps bothersome, but probably not intolerable. However, with two-hop routings, it takes about 0.6 second for signals to travel one-way and in this case, the delay is perceptible, even for slow or normal rates of speech. In experiments of consumer reactions to simulated two-hop delays, the majority of consumers considered the delay "intolerable."¹³

Furthermore, if, in addition to delay problems, there are also echo problems,¹⁴ service quality may be seriously degraded. Nevertheless, with currently available technical devices for echo suppression and with moderate rates of speech and frequency of interruption, the quality differences between satellite and cable circuits can be greatly minimized.

¹³"Satellite User Reaction Tests" (Chronological Summary), reprinted in AT&T's Submission to FCC Docket 18875 (August 1977), Attachment 3.

¹⁴The "echo" phenomenon, often mistakenly confused with satellite delay, can occur in either satellite or cable circuits when signals transmitted to the far end of the circuit rebound through the circuit carrying the caller's response. The resulting audio effect resembles echoes in a cave or tunnel and can distort service to such an extent as to render conversations unintelligible for many people.

Another service, for which delays from two-hop satellite routings may constitute a quality difference from cables, is that of two-way, high speed data communications: (1) between people and computers, and (2) between two high speed computers. Although the delay problem could be serious in some applications (e.g., radar computer tracking for strategic military purposes), in other applications (e.g., university and industrial packet-switched networks), the delay problem may be tolerable. In fact, the U.S. Department of Defense Advanced Research Projects Agency Network--the ARPANET--uses satellites for extending the continental U.S. computer network to Hawaii and to a few nodes in Europe.¹⁵

Because of the relative advantages of cables (e.g., no delay for high-speed data communications) and the relative advantages of satellites (e.g., greater bandwidth capacity, slightly higher reliability), those groups valuing the quality goal highly might consider the two technologies to be complements, and favor continued use of both.

4. Industrial Stability. Those who value industrial stability tend to favor the continued commercial viability of both satellites and cables. To the extent that it is considered socially or politically desirable to prevent monopolistic domination by either technology, groups valuing industrial stability wish to prevent destructive competition and predatory pricing. But they may also wish to prevent efficient marginal-cost pricing, if it jeopardizes the commercial survivability of either technology or if it restricts or eliminates service to customers along unprofitable routes, for unprofitable routes, for unprofitable uses.

In the early years of commercial satellite development (mid-1960s), there was concern that if satellites were owned by the common carriers--which already owned cables--then satellite communications would never be developed. On the other hand, there was con-

¹⁵ Leonard Kleinrock, Queuing Systems, Vol. II: Computer Applications (New York: John Wiley & Sons, 1976), pp. 304-305.

cern that if satellites were owned by an independent entity, then the rate-of-return regulated cable-owning common carriers (with a rate base preference for cables) would not lease circuits and the satellite-owning entity would fail to be commercially viable. Since satellites were already recognized to be a potentially very important and efficient means of communication and an important way of allowing the public to share in the social benefits of the U.S. Space Program, the U.S. regulatory agency intervened in the telecommunications market to encourage the satellite communications industry. However, in view of the uncertainty about how reliable and effective satellite communications would be, regulators also intervened to preserve the commercial viability of the cable industry. We will discuss particular regulatory policies in more detail, ahead.

More recently, concerns have arisen about protecting the industrial stability of the U.S. cable industry. For example, one of the arguments presented by AT&T to the FCC, in defense of building a new trans-Atlantic cable (TAT-7), is that failure to authorize the cable "could well lead to the demise of the U.S. submarine cable industry, with various resulting adverse effects on technological developments, on the U.S. defense posture and on the U.S. economy."¹⁶ AT&T argues that, in addition to the large number of jobs involved ("over 2000 men and women are actively engaged in the many varied elements of the submarine cable industry"),¹⁷ discontinuation of U.S. cable manufacturing and consequent reduction in research and development would adversely impact national defense communications programs--which have evolved and benefited from cable technology developed commercially.¹⁸

¹⁶FCC Docket 18875, "Future Licensing of Facilities," Petition for Reconsideration and Request for Oral Presentation. Submitted by AT&T, February 2, 1978, pp. 21-22.

¹⁷FCC Docket 18875, "Future Licensing of Facilities," Comments in Response to Notice of Proposed Rulemaking. Submitted by AT&T, August 31, 1977, paragraphs 35-43.

¹⁸Ibid., pp. 35-36.

Thus, those who value industrial stability highly tend to consider cables and satellites as complementary elements of the total communications system, and favor continued use of both.

5. International Comity. Complying with preferences of foreign telecommunications partners is an important goal which tends to limit the degree of U.S. control over technology choices. Generally, those who highly value international comity, favor continue use of both cables and satellites, primarily for three reasons: 1) contractual arrangements for cables, 2) cooperative ownership arrangements for satellites, and 3) the internationally accepted accounting convention for defining international half-circuits.

The U.S. regulatory agency, the Federal Communications Commission (FCC), has limited influence over the international entities responsible for making investment decisions in cables or satellites. Under the ownership structure for cables, the U.S. International Service Carriers (USISCs) own cables jointly with their foreign counterparts (typically on a 50/50 percent basis). But, in the case of satellites, Comsat's ownership share in the International Telecommunications Satellite Consortium (INTELSAT) is proportional to usage and has been declining in recent years, from 44% in 1965 to 27% in 1977.¹⁹ Thus, with regard to long-range planning, the FCC has only a limited degree of power to influence global investment decisions. For cables, the USISCs perform all the preliminary stages of negotiating a tentative agreement with their foreign counterparts and then, at the final stage, just before the contract is signed and the construction bids announced, the FCC is consulted for its approval. Of course, the FCC is fully empowered to deny the U.S. request at this point, but foreign entities, already having gained domestic approval, can be expected to exert a tremendous amount of political

¹⁹ COMSAT Annual Reports, 1970-1978.

pressure for the proposal to be approved.²⁰ For satellites, the FCC appears to have even less influence, because long-range planning decisions for the global satellite system are determined by the votes of all members of INTELSAT and the U.S. share (represented by Comsat) has been declining in recent years. Even though Comsat consults with the FCC when a new satellite investment is being considered, ultimately, if all the other members of INTELSAT decide to proceed, the FCC has little direct power to halt them. Nonetheless, the FCC does play an active role in the long-range global planning process through its direct participation at INTELSAT meetings and its direct regulatory control of Comsat.

In addition to being influenced by contractual ties to respect the investment preferences of foreign entities, the U.S. producers are also influenced by the peculiar way in which "international half-circuits" are defined for accounting and revenue-sharing purposes. To illustrate, we depict in Figure 1 the method of defining "international half-circuits" for two-way communications. For satellites, the half-circuit consists of the transmit path up to the satellite (Path BD) and one-half of the receive path (Path DB) carrying the return messages back from the satellite. For cables, the half-circuits extend to mid-ocean (Path CG) and back (Path GC). Defining utilization units in this way tends to "lock in" the U.S. and foreign correspondents to using the same mode of communication (or, at least, the same proportion of each mode). Consider, for example, if the United States were to decide, independently, to send all two-way messages 75 percent by satellite and 25 percent by cable, but all foreign correspondents (e.g., members in INTELSAT and joint owners of cables) decided to return messages 75 percent by cable and 25 percent by satellite. Under existing ownership arrangements, the

²⁰For example, in August 1977, when the FCC announced its intention to deny approval for a proposed trans-Atlantic cable, TAT-7, European telecommunications entities raised a strong cry of protest, expressed in letters to the Chairman of the FCC. I was shown copies of these letters during interviews with staff from AT&T in April 1978.

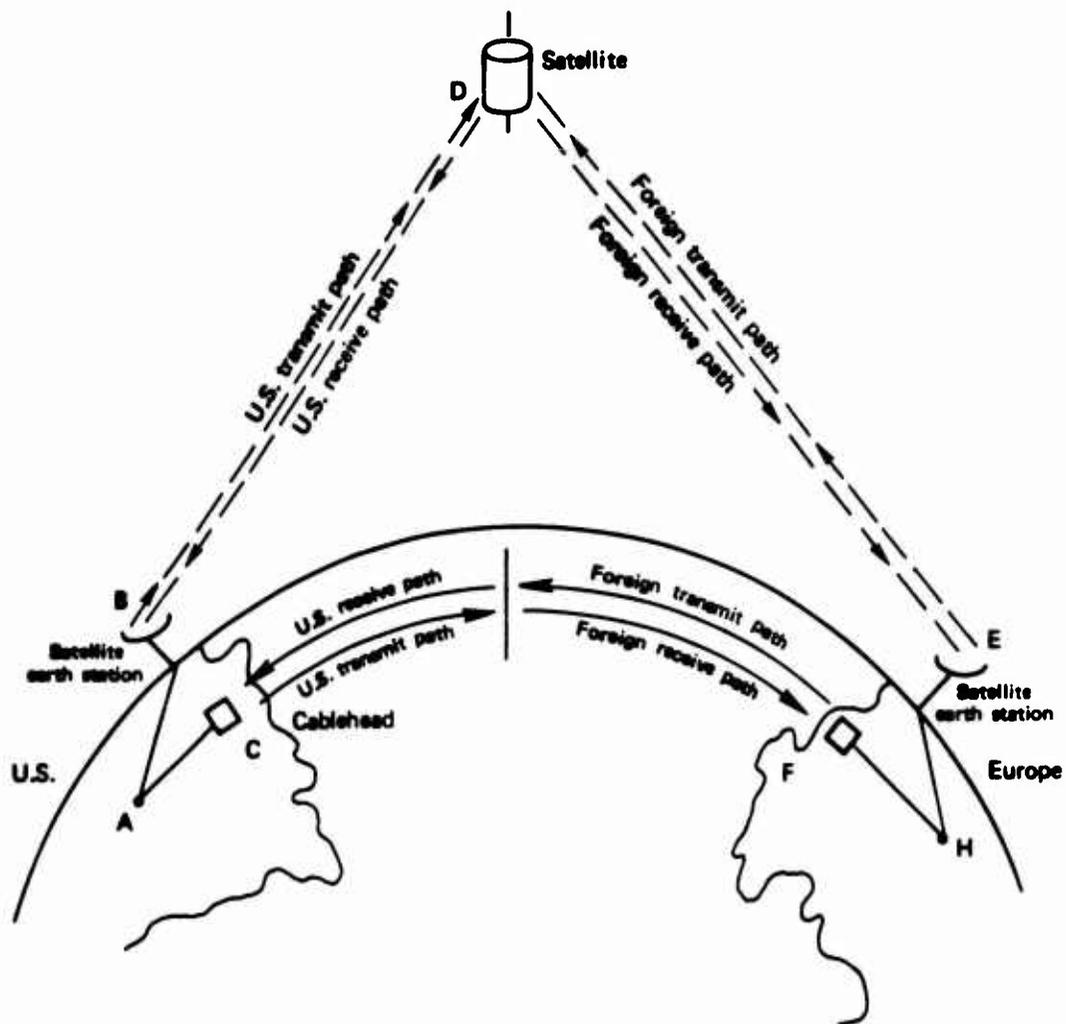


Fig. 1 — Definition of International Half-circuits

United States would be liable for 75 percent of total INTELSAT satellite costs (i.e., proportional to usage) and 50 percent of cable costs (fixed by contract--regardless of usage), but foreign countries would only be liable for 25 percent of satellite costs (proportional to their limited usage) and 50 percent of cable costs. Therefore, the asymmetries in ownership, cost- and revenue-sharing between cables and satellites, may result in an inequitable distribution of costs and revenues under the current accounting definition, unless all countries agree to use the same mix of satellites and cables. Alternatively, if utilization units were defined as one complete transmit or receive path (such as Path BDE for satellites or Path DGF for cables), then each country would be free to choose its own utilization mix.

Thus, for those who highly value international comity, the extent to which satellites can be considered substitutes for cables depends on international agreements and preferences.

6. Technological Innovation. The extent to which the continued use of both technologies provides competitive incentives for each to develop further and faster is an open question. However, on the basis of historic evidence as well as predictions for the future, both technologies have demonstrated rapid technological change, resulting in major increases in capacity and decreases in unit costs, over time. Cable technology has progressed through four generations of improvements during the 25 years since the first trans-Atlantic coaxial cable was laid (TAT-1, 1956), resulting in over an 83-fold increase in capacity (from 196 to 8000 half-circuits) and a 27-fold decrease in unit investment costs (from \$16,650 to \$610 per half-circuit in 1970 dollars). Also, satellite technology has progressed through five generations of improvements during the 16 years since the first commercial communications satellite began operation ("Early Bird," INTELSAT I, 1965), resulting in over a 52-fold increase in capacity (from 480 to 24,800 half-circuits) and over a 62-fold decrease in unit costs (from \$22,190 to \$360 per half-circuit). Furthermore, future predictions indicate that both technologies will continue to experience technological improvements.

For example, if optical fiber technology can be successfully developed for use in undersea cables, then the bandwidth capacity of cables will be enormously increased and costs per circuit reduced, owing to reductions in bulk, size, number of repeaters, and cost of the transmitting medium: sand, compared with copper. Similarly, advances in space technology are expected to reduce launch costs (e.g., by exploiting the reusable space shuttle) and increase capacity through exploitation of higher frequencies and more intensive utilization of currently available frequencies (e.g., by dual polarization, spot-beam configurations, etc.). Also, inter-satellite communications may increase capacity, flexibility and reliability. Finally, future generation satellites may be used to establish direct broadcasting links to individual homes.

Those who highly value technological innovation tend to favor continued research and development of both technologies, primarily for two reasons: (1) predictions that both technologies are likely to continue to achieve significant technological improvements in the future and (2) uncertainty as to whether or not the comparative advantages of one will significantly outweigh those of the other, at various future points in time, for various routes and purposes.

Summarizing, we indicate in Table 3, the relative advantages of satellites, cables or both for satisfying the six telecommunications goals. Table 3 uses the framework of Table 1 but does not rank the goals nor the relative abilities of the technologies to satisfy them. We consider various rankings below.

Choice of Technologies Based on Efficiency Goal

Suppose that economic efficiency were our most important goal. From Table 3 (indicating qualitative advantages of satellites) and Table 2 (indicating lower costs of satellites), we might expect, a priori, to choose satellites.

To test this a priori expectation, we consider a specific route (U.S. to Europe) and time period (1970-1985). Using an efficient cost allocation pricing scheme based on long-run marginal cost

TABLE 3: SATELLITES, CABLES OR BOTH: RELATIVE ABILITIES TO SATISFY GOALS

Goals Technologies	Economic Efficiency	Security and Privacy	Reliability and Quality of Service	Industrial Stability	Interna- tional Comity	Techno- logical Innovation
Satellites	(+) Consistently lower costs per circuit (+) Distance insensitive costs (+) Broadcasting ability (+) Greater capacity	(-) More vulnerable to unwarranted monitoring & jamming (+) Encryption devices & technical modifications can increase security	(+) Slightly more reliable (+) capable of providing multiple voice, data & TV services simultaneously (-) 2-hop delay problems for 2-way messages	(+) Continued utilization supports satellite industry stability	(+) Cooperation with other members of INTELSAT on satellite investment & use	(+) Opportunities for future technological changes (e.g. space shuttle launches and repairs, higher frequencies, etc.)
Cables	(+) Efficient use of spectrum (-) Currently more costly per circuit	(+) Less vulnerable to unwarranted monitoring & jamming	(+) no delay (-) bandwidth-limited	(+) Continued utilization supports cable industry stability	(+) Cooperation with foreign partners in contractual arrangements	(+) Opportunities for future technological changes (e.g., fiber optics)
Both	(+) Efficiency requires choosing the least cost combination for particular routes, services, time periods (-) satellites preferred	(+) Diversity of mode increases likelihood of security & privacy (-) cables preferred	(+) Diversity of mode improves overall quality and reliability of the total network	(+) Industrial stability achieved through continued commercial viability of both	(+) Foreign telecommunications entities tend to prefer both (+) Definition of international half-circuits favors both--in same ratio	(+) Continued use of both may stimulate continued R&D for both

(+) indicates relative advantage in satisfying goal
 (-) indicates relative disadvantage in satisfying goal

pricing²¹ and an efficient investment strategy based on minimizing the total discounted stream of costs, we generate three "efficient" plans²²--for three levels of ex ante (1970) expected demand.²³ Our objective is to minimize costs subject to a quantity constraint--to ensure adequate²⁴ levels of reliability. Each plan therefore includes spare satellites, for restoration purposes, in addition to excess capacity resulting from building large, indivisible facilities ahead of demand. The results are presented in the first three rows of Table 4, and are consistent with our a priori expectation that satellites, exclusively, would be chosen.

Actual Choice of Technologies Based on Tradeoffs Between Goals

By comparison, if we examine the actual plans approved by the U.S. regulatory agency²⁵ for the same route and time period, we find that they differ: both cables and satellites are included. In Table 4, we compare the differences between efficient and actual plans, with regard to mix, level of capacity and cost (in constant 1970

²¹Devising an efficient marginal cost pricing scheme is highly complicated due to joint and decreasing costs. See detailed discussion of second best long-run marginal cost pricing schemes in "Departures from Efficiency in Regulated Industries: The Case of International Telecommunications" by P. M. Dinneen, unpublished Ph. D. Dissertation, M.I.T., 1980.

²²A detailed discussion of the method, assumptions, constraints, and data sources used in this analysis are contained in my Ph. D. Dissertation, cited in the previous footnote.

²³In view of the ex ante uncertainties about demand, we consider three alternative sets of predicted demand, each based on peak load requirements. One set was developed at the beginning of the planning period by the USISCs, in consultation with Comsat, and with the approval of the FCC. The second and third set represent an updating of demand predictions made at the midpoint of the planning period, by the USISCs (in consultation with Comsat) and by the FCC.

²⁴We assume adequate levels of reliability as defined, ex ante, in 1970 by the FCC.

²⁵Two alternative versions of planned future facilities, 1979-1985, are used. Plan A4M is the plan originally approved by the FCC on August 1, 1977, and Plan A1 is the plan subsequently approved--which includes the construction of a new cable in 1981.

Table 4
SUMMARY COMPARISON OF EX ANTE EFFICIENT VERSUS ACTUAL PLANS

PLANS	MIX		LEVEL (In Half-Circuits of Capacity)				COST (Real Present Discounted Values in 1970 \$000)			
	Number of Satellite Facilities	Number of Cable Facilities	Total New Capacity Added	Average Excess Capacity, including Spares, as a Percentage of Excess Demand Relative to:			Satellite Facilities	Cable Facilities	TOTAL	
				Plan 1	Plan 2	Plan 3				
1	11	0	56,411	83%	-	-	\$157,876	0	\$157,876	EX ANTE EFFICIENT PLANS
2	9	0	36,695	-	99%	-	\$143,429	0	\$143,429	
3	10	0	61,495	-	-	91%	\$164,666	0	\$164,666	
A6M	11	2	89,927	162.5%	224%	152%	\$172,874	\$136,858	\$309,732	ACTUAL PLANS
A1	11	3	97,927	172%	241%	160%	\$172,874	\$166,296	\$339,170	

dollars). We examine the differences for evidence of tradeoffs between economic efficiency and other goals.

With regard to the mix, there is a striking difference between the 100 percent satellite mix of all three ex ante efficient plans and the more balanced mix of satellites and cables in the actual plans. For example, the balance of new cable to satellite capacity, year by year, over the entire period 1970-1985, is, on the average, 35 percent. Furthermore, the number of facilities, year by year, including cables built prior to 1970, with remaining useful lifetimes is roughly equivalent. Therefore, the mix in the actual plans is in sharp contrast to the proposed efficient mix of zero additional cable capacity or facilities.

With regard to the level, the average total new capacity added in the actual plans (93,927 half-circuits) is almost twice that of the average added in the ex ante efficient plans (51,534 half-circuits). Furthermore, the average percentage of redundant capacity for the actual plans--under all of the different demand predictions (185 percent)--is more than twice that of the ex ante efficient plans (91 percent). And, in terms of new facilities added, the actual plans provide for 11 new satellites and 2-3 new cables whereas the efficient plans provide for only 64 percent of the total number of new facilities and only 50 percent of the total amount of additional capacity.

Even though we cannot observe the actual ranking of goals, we may infer, from the discrepancies between the actual and efficient choices of technologies, that economic efficiency is not exclusively the most important goal. To determine the relative importance of other goals, we examine regulatory policies.

Tradeoffs Between Goals as Reflected in Regulatory Policies

Tradeoffs between goals are reflected in regulatory policies and implemented through specific regulatory policy tools--that determine the actual mix of technologies. Therefore, to explain the differences between the actual and efficient technology choices, in the case discussed above (U.S.-Europe, 1970-1985), we examine specific regulatory policies.

In formulating regulatory policies, the Federal Communications Commission (FCC) must take into account and coordinate the concerns of other groups. In the first place, the FCC is obligated by law (i.e., the Communications Act of 1934) "to make available, so far as possible, to all the people in the United States, a rapid, efficient, nationwide and worldwide wire and radio communication service...." In addition to this legislative mandate, FCC policy is also influenced by the telecommunications needs and concerns of other government agencies. For instance, the Department of Defense imposes certain national security requirements--which are generally expressed in terms of capacity levels and specific mix of satellites and cables. Also, the FCC must satisfy certain political requirements and report annually on its policies, activities, and decisions to the President and the Congress. Before making major decisions concerning rate changes or new investments, the FCC must circulate its plans to other government agencies and to the public, for comments and possible revisions. Finally, as discussed above, the FCC must take into account the preferences of foreign partners.

To reflect tradeoffs between its own and others' goals, the FCC uses the following five regulatory policies, in combination:

1. Separated Ownership of Technologies
Satellites are owned exclusively by Comsat and cables, exclusively by the USISCs.
2. Authorized Users Restriction
Comsat is not permitted to sell directly to the public, but may only lease half-circuits, wholesale, to authorized users, namely, the USISCs.
3. Fixed Proportional Fill Rule
To ensure high standards of reliability, the regulatory agency requires diversity of mode, to protect against the failure or saturation of either mode. According to this policy of diversity, additional satellite and cable circuits must be utilized (or activated for utilization) in a specified proportion--which may vary over routes and

over time, but which, historically, for U.S. traffic, in the period 1970-1978, has been very close to 1:1.²⁶ This policy guarantees a market for satellite circuits but also imposes an arbitrary upper limit on their increased utilization.

4. Redundancy in Satellite Capacity

To ensure high standards of reliability in the event of unforeseen increases in demand or unexpected outages, the regulatory agency requires redundancy, typically in the form of excess satellite capacity aboard operational satellites as well as entire satellite "spares" in orbit and on the ground.

5. Rate-of-return Regulation

Both Comsat and the USISCs are allowed to earn no more than a specified proportion of the value of the capital they invest in providing services. In practice, regulators generally aim to set the allowed rate slightly above the cost of capital so that producers will neither be driven out of business nor earn excess profits. In effect, rate-of-return regulation implies average-cost pricing because it allows producers to set prices high enough so that total revenue covers total operating costs plus a return on capital invested in the provision of services.

In Table 5, we indicate (by a checkmark) which specific goals each policy is intended to promote. Reading across the rows, we see that the proportional fill policy is intended to satisfy more of the goals (all except economic efficiency) than any other policy.

²⁶Strictly defined, the fixed proportional fill rule requires that circuits be used in such amounts that all satellite and cable capacity reach saturation at the same point in time (with the exception of spare satellite capacity designated for restorative purposes). However, in practice, the FCC has shifted from a policy of Proportional Fill (involving a 5:1 ratio of satellite cable circuits in 1970) to a policy of "Reasonable Parity"--consisting primarily of a 1:1 ratio after 1970, for U.S.-Europe traffic.

Goals

	Economic Efficiency	Security and Privacy	Reliability and Quality	Industrial Stability	International Comity	Technological Innovation
Separated Ownership				X		
Authorized Users				X		
Proportional Fill		X	X	X	X	X
Redundancy			X			
Price Regulation				X		

Table 5: Regulatory Policies That Are Intended to Support Certain Goals

By ensuring utilization of both cables and satellites (in an arbitrarily determined fixed ratio) this policy is intended to capture the technical and qualitative benefits of using both, as summarized previously in Table 3. For example, diversity of mode promotes security, privacy, reliability and quality. By guaranteeing each producer a continuing share of the market, this policy also supports the goal of industrial stability. And since European partners prefer both technologies (not necessarily in the same fixed ratio), this policy contributes to international comity. Finally, the goal of technological innovation may be promoted if the continued use of both stimulates further research and development of both. However, because the proportional fill ratio is arbitrarily determined and fixed, and therefore unlikely to represent the least cost mix of technologies over different routes and time periods, the economic efficiency goal is not likely to be satisfied.

The proportional fill policy supports almost all of the goals; the other four policies help contribute to two goals in particular. First, the goal of industrial stability is supported by all but one policy (i.e., redundancy). By requiring separate ownership, restricted leasing by Comsat to authorized users only, fixed proportional use of cables and satellites by the authorized users, and composite average-cost pricing, the FCC guarantees a market for both technologies and discourages price competition between them. Second, the goal of reliability is supported by redundancy (in satellite capacity) as well as diversity (via proportional fill).

Regulatory Mechanism for Determining Choice of Technologies

Capacity levels and mix of technologies are determined by regulatory pricing and investment behavior. As we shall argue below, regulatory policies--which reflect tradeoffs between goals--cause the relative prices of cables and satellites to depart from their efficient prices--which causes departures from efficient investment behavior. The actual choice of technologies--based on regulated prices and investment--can therefore be expected to differ from the

efficient choice, as we discovered in the case of U.S.-Europe communications, 1970-1985. (Recall Table 4.)

To understand how the regulatory mechanism works, we examine how specific regulatory policies, described above, affect the pricing and investment behavior of Comsat and the USISCs.

Under rate-of-return regulation, both Comsat and the USISCs are allowed to earn a "reasonable" return on their rate base. Thus, as their rate base increases, so also does the absolute level of their returns. But, under the separated ownership policy, Comsat may not own cables (i.e., may not include them in their rate base) and the USISCs may not own satellites, only lease them (i.e., satellites may not be included in their rate base; lease rates are expensed dollar for dollar). Therefore, to increase its own rate base and returns, each separate owner has an incentive to invest in more of its own technology--even if the relative cost of the other is less. The incentive to increase investment (i.e., the rate base) is further strengthened by the policies of redundancy (in satellite capacity) and reliability--which encourage building more and larger capacity ahead of demand. And the policy of proportional fill fosters increases in one technology to match increases in the other, even if this leads to excess capacity.

Because of these regulatory-induced incentives for excess capacity, prices become inflated above their efficient levels. In particular, satellite prices become especially inflated relative to cable prices, for the following reasons. Under regulatory pricing policy, Comsat is allowed to set prices to recover costs--averaged over all routes and services, including spare capacity--which is provided for under the policy of redundancy. Since prices are based on costs-per-circuit-in-use, therefore, the greater the excess capacity, the fewer units over which to spread costs, and thus, the higher the regulated prices. Similarly, the less the utilization of satellite capacity, the higher the prices. Because the policy of proportional fill restricts Comsat's relative share of the market and the authorized users policy restricts Comsat's direct access to the market, satellite

prices are further inflated above their efficient level. As a result, regulated satellite prices exceed the efficient level of cable prices, so the USISCs favor reduced utilization of satellites²⁷ and greater investment in cables--which creates more excess satellite capacity and leads to even higher prices.

To illustrate by how much regulated satellite prices may differ from theirs and cables' efficient prices, we return to the example of U.S.-Europe communications, 1970-1985. In Table 6, we compare hypothetical long-run marginal cost prices for cables and satellites with actual Comsat lease charges. The discrepancy is enormous: Comsat prices are, on the average, 22 times greater than efficient cable prices and 28 times greater than efficient satellite prices. These regulatory-distorted relative prices provide further incentives to the USISCs to invest in cables and to restrict utilization of satellites. But, by doing so, more excess capacity is generated in both.

Thus, in view of regulatory-induced distortions in the relative prices of satellites and cables--which affect the profitability perceptions and investment behavior of Comsat and the USISCs, and in view of the regulatory policies requiring diversity and redundancy (regardless of relative least-cost considerations), we can explain why the actual choice of technologies for U.S.-Europe telecommunications, 1970-1985, departs from our efficient choice.

²⁷ Of course, under the proportional fill policy, the USISCs are restricted from reducing satellite utilization below a specified fixed ratio.

TABLE 6: EFFICIENT VERSUS REGULATED PRICES

Year	Satellite Facility	Cable Facility	Actual Comsat lease charge	Hypothetical cable long-run marginal-cost price per most advanced available new facility, assuming 100% utilization	Hypothetical Satellite long-run marginal-cost price per most advanced available new facility, assuming 100% utilization
1970	IS-III	TAT-5	\$45,600	1684	2728
1971	IS-IV	TAT-5	34,200	1751	1048
1972	IS-IV	TAT-5	34,200	1788	1087
1973	IS-IV	TAT-5	34,200	1970	1196
1976	IS-IVA	TAT-6	34,200	1123	970
1977	IS-IVA	TAT-6	34,200	1203	1051
1978	IS-IVA	TAT-6	18,900	1262	1090

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

On the basis of this case study analysis, we conclude that trade-offs between conflicting goals are reflected in U.S. regulatory policies--which affect pricing and investment behavior--which in turn determines the level and mix of new and existing technologies. Further research is required, however, to understand how the trade-off process affects the choice of technologies in other countries with other goals and rankings. Further research is also required to understand and predict how the technology mix will be determined, in the future, as U.S. goals and rankings change. And, to test the applicability of the general framework suggested in Table 1, additional case study analysis would be useful. Common metrics need to be developed for evaluating the relative abilities of different technologies to satisfy goals. And a better method for inferring the ranking of goals from the observed choice of technologies should be devised.