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COMMUNICATIONS SATELLITES: SUPPLEMENTAL INFORMATION ON THE COST ESTIMATES GIVEN IN RESEARCH MEMORANDUM RM-2709-NASA

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I. INTRODUCTION

This memorandum was prepared at the request of the Chief of the Communications Satellite Program of the National Aeronautics and Space Administration, to provide the detailed background for an earlier analysis of the economic costs of communications satellites. This is therefore in the nature of a supplement to Communications Satellites: An Introductory Survey of Technology and Economic Promise, referred to hereafter as RM-2709.

In Section II of RM-2709, the economic potential of communications satellites is assessed in terms of cost comparisons with other forms of telecommunications and in terms of demand prospects. A communications satellite system would very greatly increase the number of long-distance channels available, and the cost per channel is therefore tied critically to the question of future demand for additional channels. It is shown that, at something like full utilization, a satellite system should provide cheaper transoceanic communications than present methods. RM-2709 also considers future demands, and concludes that the day will come when communications satellite receipts are sufficient to cover all costs.

In RM-2709, cost comparisons are made between low-altitude active and 24-hour satellite system, on the one hand, and conventional telecommunications systems, on the other. The basis of comparison is cost per voice channel per year. The present memorandum explains the derivation of the satellite and other telecommunications system costs used in these comparisons.

II. COSTS PER VOICE CHANNEL FOR COMMUNICATIONS SATELLITES

PRINCIPAL COST EQUATION USED

Equation (1), given below, was used to compute the costs per voice channel for communications satellites as reported in RM-2709.

$$V_c = \frac{D_c + T_c + O_c K + \frac{N_o}{P}\left(S_c + \frac{L_c}{N_s}\right)\left(1 + \frac{K}{M}\right)}{CK} \qquad (1)$$

where:

V_c = Cost per voice channel per year

D_c = Development cost

T_c = Total system investment in terminals

O_c = Annual terminal operating cost

N_o = Maximum number of satellites in orbit

P = Probability of successful launch

S_c = Cost of a satellite

L_c = Launch cost per launch

N_s = Number of satellites launched with a single launch vehicle

M = Mean time to failure in orbit

C = Capacity of the system in voice channels

K = Discount factor -- present value of $1 per year for 15 years at 8% interest

The numerator of (1) is simply the total 15-year costs of the communications satellite systems. Fifteen years was chosen because that was the estimated life of ground equipment.

INVESTMENT COST VERSUS OPERATING COSTS

"Total cost" as used here means present total costs. Computing total costs calls for aggregating investment and operating costs, the latter including satellite replacement. Adding operating costs directly to investment, however, is like adding apples to oranges. Operating costs take the form of a future stream of expenditures. To make them commensurate with initial investment, such streams must be discounted. They are like an annuity, and it is the present value of the annuity that must be added to investment to arrive at total costs. This is neither a financial trick nor trivial. It is simply a recognition of the fact that a dollar's worth of resources invested today will produce more than a dollar's worth of resources five years hence.

To indicate why it is important, the following example is repeated from RM-2709.

Suppose:

1. System A requires $100 of initial investment and no operating cost. The life of the system is 10 years.

2. System B requires no initial investment but operating costs of $10 per year over a period of 10 years.

Allocating the cost of System B in conformity with straight line depreciation practice, the two systems would appear to cost the same amount, namely, $10 per year. But clearly, System B is preferable to System A, for, if the former is chosen, the $100 which must be invested in System A could be invested elsewhere at a positive interest rate. Suppose that the $100 could be invested at 10% per year. At that interest rate $100 will purchase a 10-year annuity of $16.27 per year.

That is, with \$100 one could purchase 10 annual payments of \$16.27 beginning one year hence. The "correct" level annual cost of System A, therefore, is \$16.27, and on an annual basis the cost of System A is 16.27 - 10.00 = \$6.27 greater than that of System B.

This example is very similar to the actual circumstances for communications satellites and submarine cables. Initial investment is a much larger proportion of total costs for telephone submarine cables than for communications satellites. Or, to put it the other way around, submarine cables have relatively low operating costs while communications satellite systems have relatively high operating costs (especially when satellite replacement is taken into account). Thus, comparisons that do not discount operating costs are biased against communications satellites. The interest rate used in discounting costs for RM-2709 was 8%. Although a higher rate of interest might have been used, 8% was adopted as "conservative"; higher rates would favor communications satellites relative to cables.

The four terms in the numerator of (1) are:

(1) D_c = Development cost

(2) T_c = Total system investment in terminals

(3) O_cK = Present value of operating cost of the terminals for 15 years

(4) $$\frac{N_o}{P}\left(S_c + \frac{L_c}{N_s}\right)\left(1 + \frac{K}{M}\right) = \frac{N_o}{P}\left(S_c + \frac{L_c}{N_s}\right) + \frac{N_o}{P}\frac{K}{M}\left(S_c + \frac{L_c}{N_s}\right)$$

= total system cost of satellites and launchings for 15 years. In the expanded form of 4, the first term covers initial satellite and launch costs, and the second term all subsequent costs for satellites and launching.

The parameter K (the present value of $1 per year for 15 years at 8% interest) appears in the numerator twice -- once in computing the present value of operating costs, and once in computing the present value of satellite and launch costs subsequent to the first operational launchings.

The product CK, (or CK')* which is the denominator of equation (1), converts total costs to cost per channel per year. The first factor, C, is the estimated total number of terminal-to-terminal voice channels in the system; the second factor, K, is the discount factor that has been described above. The use of K (in this case 8.56) or K' (in this case 3.76), rather than the system life (in this case 15), deserves some explanation. (In what follows, we will use K to mean K or K', as appropriate.)

Though it is not obvious intuitively, cost per channel per year is a function of the time profile of service rendered. Consider two systems, A and B, both of which have a total cost of $40 and a life of two years. Suppose that with system A, one channel is provided in year 1 and three channels in year 2; while with system B, two channels are provided in year 1 and two in year 2 (See Table I).

Table I

ANNUAL OUTPUT AND TOTAL OUTPUT
(in channels per year)

Year \ System	A	B
1	1	2
2	3	2
Total	4	4

*K'=3.76 is substituted for K in the denominator of equation (1) for systems with capacity not fully utilized at the beginning, assuming linear increase of utilization to full capacity at the end of system lifetime.

What is the cost per channel per year for systems A and B? If we simply use lifetime and total output, the answer is the same for both systems, namely, $\frac{\$40}{4}$ = \$10 per channel per year. But system B would be clearly preferable to system A, because with system B the investment is recovered more rapidly. The way to take differences in the pattern of output into account is to discount the future streams of output of both systems, so that we can speak in terms of present-day values.

This is what we have done in introducing K into the denominator of equation (1). By using K rather than system lifetime, we discount future "deliveries" to take account of differences in the patterns of output. CK is a weighted lifetime system output where the weighting converts output in future years to equivalence with output in the base year.

In comparing the costs of the competing systems considered in RM-2709 -- for example, submarine cables vs. 24-hour satellites -- the use of K had no effect on the relative costs of the systems, where full utilization was assumed. The absolute magnitudes of the cost estimates were, of course, higher where K was used rather than system lifetime; but since the costs for all systems were divided by the same constant, the relative costs, and therefore the cost comparisons, were unaffected.

Relative costs of competing systems were affected, however, where utilization differed from system to system. In RM-2709, we assumed that new submarine cable links (providing only moderate increases over existing capacity) would be fully utilized from the beginning of service, but that a communications satellite system (providing extremely large additions to existing capacity) would not be fully utilized at the beginning. As a first approximation, we have assumed that, for a large-capacity satellite system, 1/15 of capacity is revenue-producing in the first year, and that this increases linearly to 15/15 (full utilization) in the last year.*

There are two points to be considered here. First, the satellite system's unused capacity in the earlier years cannot be counted as service rendered and paid for. For that reason alone, cost per channel per year will be higher than it would be if the total capacity of the system were fully utilized throughout its lifetime. Second, the use of K increases the cost per channel per year even more than would be the case if 15 years was used in the denominator of equation (1). The effect of using K in equation (1) is readily seen from Table II, where cost indexes for four different cases are presented. For convenience in comparison, the cost of the fully utilized system with the output stream undiscounted is set at 100. Comparison between the two figures in the left-hand column isolates the impact of unused capacity in the earlier years -- the effect is to increase costs by 87 percent. The effect of discounting alone is revealed by comparing the figures in the first row -- costs are increased by 75 percent. The combined effect of discounting and taking unused capacity into account is revealed by comparing the figures underlined -- the cost estimates are multiplied by four. For the reasons explained earlier, we always discounted output in preparing the cost estimates given in RM-2709. On this basis, the effect on cost of unused capacity in the earlier years is revealed by the figures in the right-hand column of Table II -- 400 against 175.

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*RM-2709, p. 28.

TABLE II

SYSTEM COST AS RELATED TO SYSTEM UTILIZATION

(Cost units per channel per year)

Utilization Profile \ Index of Cost	Output stream not discounted	Output stream discounted
System capacity fully utilized throughout 15-year lifetime	100	(Computed with K in denominator) 175
System utilization linearly increasing over 15 years from 1/15 to 15/15 of capacity	187	(Computed with K' in denominator) 400

Table III gives the values used in RM-2709 for the variables of equation (1). Where two or more figures appear, costs were calculated for each value of the parameter.

COSTS FOR CONSTRUCTION AND OPERATION

The details of costs for the construction and operation of ground terminals are shown in Table IV and Table V. For both the low-altitude system and the 24-hour system of RM-2709 there were three different sizes of ground terminals. A Type I station in the low-altitude system is one that communicates with one other station, a Type II station communicates with two others, and a Type III station communicates with three others. For the 24-hour system, New York and London were the large stations. With the low-altitude system, spare antennas, receivers, and transmitters are provided at all ground terminals. Spare receivers and transmitters are provided at the 24-hour stations.

The physical parameters used to estimate the number of voice channels provided by each of the two satellite systems are shown in Table VI.

Table III

VALUES FOR VARIABLES IN EQUATION (1)

(dollars in millions)

	Low-Altitude Satellite	24-Hour Satellite
D_c	\$ 50.0	\$ 150.0 [a/]
T_c	\$112.0	\$ 22.0
O_c	\$ 19.0	\$ 12.0
N_o	120	2 [b/]
P	1/2, 2/3, 3/4, 9/10	1/2, 2/3, 3/4, 9/10
S_c	\$ .1	\$ 1.0
L_c	\$ 5.0, \$10.0	\$ 6.0, \$12.0
N_s	40	1
M	1, 2, 3, 5 years	.5, 1, 2 years
C	7,800	4,800
K	\$ 8.56	\$ 8.56
K'	\$ 3.76 [c/]	\$ 3.76 [c/]

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a/ 1/3 assigned to single Atlantic Satellite.

b/ One spare.

c/ K' is substituted for K in equation (1) (in the denominator only) to compute costs for systems with initially unused capacity, utilization rising linearly from 1/15 to 15/15 over 15 years.

Table IV

GROUND TERMINAL COSTS -- LOW-ALTITUDE SYSTEMS

(dollars in millions)

		Station Type					
		#1		#2		#3	
Initial Investment	Unit Cost	No. of Units	Cost	No. of Units	Cost	No. of Units	Cost
Receiver Antenna (84' parabola or 50' horn)	.75	(3)	2.3	(4)	3.0	(5)	3.6
Receiver - Low Noise Parametric	.07	(3)	.2	(4)	.3	(5)	.4
Transmitter Antenna - 28'	.10	(3)	.3	(4)	.4	(5)	.5
Transmitter - 2-5 KW	.15	(3)	.5	(4)	.6	(5)	.8
Acquisition Function - Including Control	--		1.2		1.5		1.8
Microwave Function - TD-2 Terminal	.70	(1)	.7	(1)	.7	(1)	.7
Power and Distribution	--		.3		.3		.4
Facilities and Site	--		.5		.5		.5
Installation and Checkout	--		.5		.6		.6
Spares - Equipment	--		.3		.4		.5
			6.8		8.3		9.8
Annual Operating Costs							
Facilities Maintenance			.1		.2		.2
Equipment Maintenance and Parts			.4		.5		.5
Pay and Allowances			.5		.7		.9
Services and Miscellaneous			.1		.1		.1
			1.1		1.5		1.7

Table V

GROUND TERMINAL COSTS -- 24-HOUR SYSTEM

(dollars in millions)

		New York		London		Others	
Initial Investment	Unit Cost	No. of Units	Cost	No. of Units	Cost	No. of Units	Cost
60' Receiving Antenna	.350	1	.35	1	.35	1	.35
28' Transmitting Antenna	.100	1	.10	1	.10	1	.10
Parametric Low-Noise Receiver	.070	6	.42	5	.35	2	.14
2-5 KW Transmitters	.150	6	.90	5	.75	2	.30
Facilities			1.50		1.20		.30
Power and Distribution			1.00		.80		.20
Installation and Checkout			.50		.40		.10
Spares			1.00		.80		.20
			5.77		3.75		1.69
Annual Operating							
Facilities Maintenance			.25		.25		.05
Equipment Maintenance			1.50		1.50		.30
Pay and Allowances			.90		.75		.30
Services and Miscellaneous			.50		.50		.10
			3.15		3.00		.75

Table VI

BASIS FOR ESTIMATING CAPACITY OF SATELLITE SYSTEMS

The calculation in RM-2709 of the number of channels is based on the following parameters:

A. Low Altitude System

Orbital altitude	n m	3000
Maximum slant range	n m	5000
Effective radiated power of satellite	watts	1
Radio frequency	mc	2000
Ground antenna diameter	ft	84
Antenna efficiency	%	55
Received power level	dbw	- 128
Ground receiver noise temperature	^oK	30
Noise power per cps	dbw	- 214
System margin	db	6
Bandwidth in which 12 db SN ratio is achieved	mc	6
Baseband	mc	3
Equivalent number of voice channels		600
Radio frequency spectrum required for 40 db output SN ratio (frequency modulation with feedback)	mc	100

B. 24-hour System

Orbital altitude	n m	19,300
Maximum slant range	n m	22,000
Satellite antenna gain	db	16
Power output of each repeater	watts	1
Ground antenna diameter	ft	60
Antenna efficiency	%	55
Received power level	dbw	- 128
Ground receiver noise temperature	^oK	30

(continued)

Table VI (continued)

Noise power per cps	dbw	- 214
System margin	db	6
Bandwidth in which 12 db SN ratio is achieved	mc	6
Baseband	mc	3
Equivalent number of voice channels per repeater		600
Radio frequency spectrum required per repeater for 40 db output SN ratio (frequency modulation with feedback)	mc	100

Note: If frequency modulation with feedback should fall short of the performance which is assumed here, the number of voice channels may be somewhat lower. But since identical assumptions were made for both systems, the relative costs per channel of the two systems would remain unchanged. Also, in both systems a margin of 6 db was allowed as a conservative safety factor.

III. COSTS PER VOICE CHANNEL FOR CONVENTIONAL TELECOMMUNICATIONS SYSTEMS

Basically, the same equation was used to compute cost per channel per year for submarine cables and the TD-2 microwave system as was used for the satellite systems. Operating costs over the life of the system were discounted, added to investment, and the sum converted to cost per channel per year using the appropriate divisor.

TD-2 MICROWAVE SYSTEM COSTS

TD-2 system investment costs were set at $18,800 per mile -- the nation-wide average. Annual operating costs were 10% of initial investment. Usable capacity for the TD-2 was taken as 4,800 circuits. Equipment life was 15 years.*

The equation used to compute cost per channel mile per year for the TD-2 was:

$$(2) \qquad V_{cm} = \frac{O_c K + I}{CK}$$

where:

V_{cm} = Cost per voice channel mile per year

O_c = Annual operating cost per channel mile

I = Investment cost per channel mile

C = Capacity

K = Present value of $1 per year for 15 years at 8% interest

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*All of these parameters were supplied by the Long Lines Department of American Telephone and Telegraph Company.

SUBMARINE TELEPHONE CABLE COSTS

The submarine cable costs in RM-2709 were for the duplex type cable which American Telephone and Telegraph Company plans to lay in 1962 or 1963. The costs also assume the use of TASI (Time Assignment Speech Interpolation) with the cable.

Cable investment costs were estimated at $10,000 per mile exclusive of terminals and TASI. TASI costs for such a cable were $9,000,000 and terminal costs $2,000,000. Operating costs were $300,000 per year. With TASI it is estimated the new cables will provide 176 (4 KC) voice channels. Cable system life was taken as 20 years.* Since the 20-year cable life was 5 years longer than the life estimated for both microwave equipment and the ground equipment associated with the satellite systems, a salvage value had to be assigned to the cables. The salvage value of the cable at the end of 15 years was estimated to be one-fourth of the original investment.

The equation for calculating cost per voice channel mile per year for cables was:

$$(3)\quad V_{cm} = \frac{O_c K + \left(T_c - S_t K''\right) + \left(A_c - S_a K''\right)}{NCK} + \frac{I - S_i K''}{CK}$$

where:

V_{cm} = Cost per voice channel mile per year

O_c = Annual operating cost

T_c = Terminal investment cost

S_t = Salvage value of terminals

A_c = TASI investment cost

S_a = Salvage value of TASI

*As for the TD-2, all parameters were provided by the Long Lines Department of American Telephone and Telegraph Company

I = Investment cost per mile for cable

S_i = Salvage value per mile of cable

K" = Present value of $1 fifteen years hence at 8% interest

C = Capacity of a cable in voice channels

N = Length of the given link in miles

K = Present value of $1 per year for 15 years at 8% interest