MEMORANDUM
RM-3766-PR
AUGUST 1964

ON DISTRIBUTED COMMUNICATIONS:
X. COST ESTIMATE

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PREPARED FOR:
UNITED STATES AIR FORCE PROJECT RAND

The RAND Corporation
SANTA MONICA • CALIFORNIA

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PREFACE

This Memorandum is one in a series of eleven RAND Memoranda detailing the Distributed Adaptive Message Block Network, a proposed digital data communication system based on a distributed network concept, as presented in Vol. I in the series.* Various other items in the series deal with specific features of the concept, results of experimental modelings, engineering design considerations, and background and future implications.

The series, entitled On Distributed Communications, is a part of The RAND Corporation's continuing program of research under U.S. Air Force Project RAND, and is related to research in the field of command and control, and in governmental and military planning and policy making.

The present Memorandum, the tenth in the series, presents the equipment cost estimates for a proposed system based on an arbitrary network configuration consisting of 400 Switching Nodes servicing 100,000 simultaneous users via 200 principal Multiplexing Stations. Although not specifically discussed in detail in this Memorandum, the network can be expanded to handle more than one million users.

The Memorandum is of primary interest to those concerned with the feasibility and implementation of the network under consideration. Many of the assumptions upon which the estimates are based should be of interest to communications planners and designers in general. The

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*A list of all items in the series is found on p. 19.

cost estimate reflects the advantages of using redundancy with low-reliability components. These advantages are especially apparent when considered in connection with the stringent survivability requirements imposed on any future communications system. As is stated in Vol. XI, the concept is especially sensitive to poor system design. A brute-force, massive-organization approach could easily result in an expensive, fractional-GNP-priced kluge.

SUMMARY

An estimate of the expected costs of the proposed Distributed Adaptive Message Block Network is given.

While the network can be expanded to accommodate over 1,000,000 simultaneous users, the base used in these cost estimates assumed a partial network of 400 Switching Nodes, providing a "high-speed," cryptographically-secure, error-free, highly reliable, survivable service to 100,000 simultaneous users tied into 200 major Multiplexing Stations in the continental United States.

The important message of this series of Memoranda is the specific distributed concept--its merits, feasibility, flexibility, and survivability. Incidental to this message is the absolute, or even relative cost.

As it is anticipated that construction of such a network will not be started until all components of the final system have been built and thoroughly tested, a development program, starting with a general, broad study and leading to a final implementation scheme, is described.

The estimated cost for the system, if built and operated as described, assuming a usable life of ten years, is about $60,000,000 per year, based on amortizing a capital investment of $235,000,000. It seems only fair, however, to state that these estimates are based on a level of austerity and a mode of operation uncommon and unique among communication systems.

FOREWORD

Since it was necessary to "cost" a system not completely defined, using equipment never built, the author must absolve all concerned (and possibly even himself) for the errors and inconsistencies that inevitably occur in compiling cost for an untried system, especially one that uses unorthodox construction techniques to fulfill an unknown, but rapidly growing, demand for a new service. This inconvenience is part of the price we pay for new systems concepts.

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I. COST ESTIMATE

EXAMINED NETWORK CONFIGURATION

Table I lists the parameters on which the definition of the specified communications network is based for costing purposes. The definition of a redundancy level of 4' is shown in Fig. 1.

COST SUMMARY

Table II presents an approximate estimate of the cost anticipated for the proposed system using the limiting assumption defined and enumerated in Table I. Table II is divided into two major sections. The first, "Total Initial System Investment," includes the three sequential phases of Research and Development, Engineering and Installation, and Purchase of Major System Elements. The development and hardware purchased in these phases are capitalized and form a fixed investment of about $235 million.

The second section of Table II includes those annual cost factors involved in amortizing the initial investment on a ten-year basis, as is commonly done in the communications business; also included are operating personnel costs and a profit factor.

It should be understood that the cost estimate is based on a number of assumptions about system design, implementation, and operation; these assumptions represent a significant departure from today's commonly accepted practices. It is for this reason that the cost estimate is as low as it is.

To obtain a feeling for the size of the undertaking being considered, we might compare the $60 million annual cost to the $1 billion the Department of Defense currently spends each year for communications of all forms. This outlay has been growing 15 per cent annually.

It is to be noted that if the distributed network could reduce the present expenditure by 6 per cent or more, it would thereby pay for itself--not to mention the key goal of increased survivability which it offers.

Table I

NETWORK COSTING PARAMETERS
(Size and Configuration of Network
Serving 102,400 Subscribers)

Number of Switching Nodes	400	Assuming a 20 x 20 array (see ODC-I)*
Number of Multiplexing Stations	200	Assuming one Multiplexing Station per two Switching Nodes (see ODC-VIII)
Ratio of subscribers connected to a Multiplexing Station compared to allowable number of links	½	Arbitrary assumption
Uniform redundancy level	4'	See ODC-I
Maximum number of subscribers per Multiplexing Station	1,024	See ODC-VIII
Continental U.S. — Width in miles	3,000	Rough estimate
Continental U.S. — Length in miles	2,000	Rough estimate
Number of parallel paths in north-south cross-section	20	See ODC-I
Number of parallel paths in east-west cross-section	20	See ODC-I
Total subscribers assumed for preliminary costing examination.	102,400	(½)(200)(1,024)

*ODC is an abbreviation of the series title, <u>On Distributed Communications</u>; the numeral following refers to the particular volume within the series. A list of all items is found on p. 19.

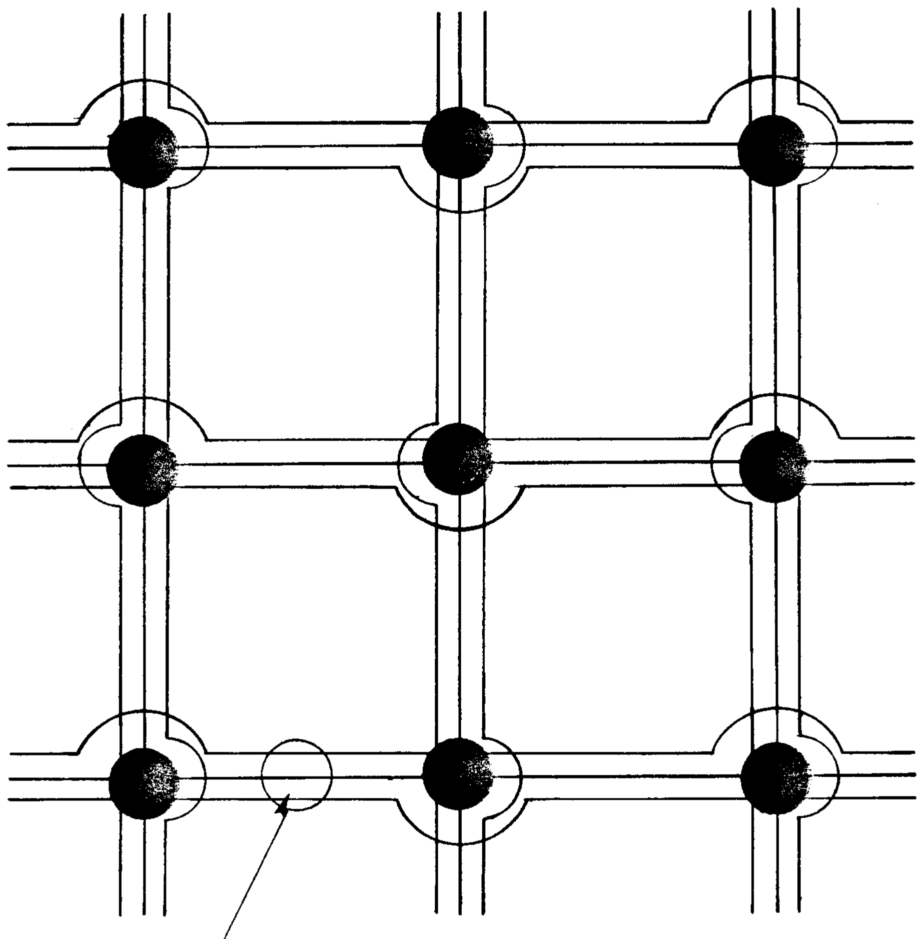

Fig. 1--Definition of Redundancy Level 4'

Table II

COST SUMMARY

Item	Item Cost	Total
Research and Development		
Study (Table III)	$ 5,000,000	
Design (Table IV)	6,600,000	
Test Unit Construction (Table V)	4,100,000	
Development (Table VI)	6,000,000	
Final Test (Table VII)	2,000,000	
		$ 23,700,000
Engineering and Installation (Table VIII)	22,760,000	
		22,760,000
Purchase of Major System Elements (Table IX)	188,000,000	
		188,000,000
Total Initial System Investment		234,460,000
Annual Costs (Table XI)		
Annual Maintenance Cost (Table X)	18,969,240	
Profit, Technical Direction, Management Fees	3,620,730	
Contingencies	1,810,365	
Capital Recovery Factor ($234,460,000, 10 years, 8% interest)	$ 35,000,000	
		59,400,335
Basic Annual System Cost (10 years basis)		$ 59,400,335

II. COST BREAKDOWN

RESEARCH AND DEVELOPMENT

Research and development items are individually detailed below (Tables III-VII). It is proposed that construction be delayed until after a thorough engineering test evaluation has been made. Mass production techniques are envisioned for actual major equipment construction costs--but these costs will accrue only after successful completion of the earlier stages of development.

Study

The following set of studies (Table III), listed in ODC-XI, are intended to provide a firm technical foundation before proceeding with the system development.

While a total figure is shown for each study, it is anticipated that the money for each item will be divided into a few relatively long-term studies by companies already expert in the particular fields.

More-successful studies in these fields are generally found in those situations where the company performing the research study is sufficiently interested to also underwrite a portion of the costs.

Table III

STUDY COSTS

Item	Approximate Price	Total
Investigate feasibility of new analog-to-digital voice modulation schemes, such as High Information Delta Modulation, for use within this system.	$ 250,000	
Investigate new problems that may be encountered in a bit-transportation communications system.	250,000	
Perform traffic analysis and recommend a detailed system growth plan.	1,000,000	
Perform cost comparison studies.	500,000	
Study the precise degree of secrecy required in future systems.	500,000	
Simulate the entire system operation in depth with emphasis on reliability.	2,000,000	
Amplify the detailed description of the mechanisms used for automating precedence.	500,000	
		$5,000,000

Design Costs

Table IV

DESIGN COSTS

Item	Approximate Price	Total
Design of a low-cost digital telephone with push-button signaling.	$ 200,000	
Design of the Switching Node in full detail.	1,500,000	
Design of the Multiplexing Station in full detail.	3,000,000	
Design of the mini-cost microwave.	200,000	
Design of low-cost high-data-rate plowed cable line.	200,000	
Design low-cost graphic and text input/output devices suitable for user-to-user service in this system.	1,500,000	
		$6,600,000

Test Unit Construction and Test

Table V

TEST UNIT CONSTRUCTION AND TEST

Item	Approximate Price	Total
Build and test mini-cost microwave.	$ 250,000	
Build and test low-cost plowed cable line.	200,000	
Build and test critical assemblies in Switching Node.	500,000	
Build and test critical assemblies in Multiplexing Station.	750,000	
Build and test low-cost text handling devices.	2,000,000	
Build and test TTY and HIDM modems.	400,000	
		$4,100,000

Development

Table VI

DEVELOPMENT

Item	Approximate Price	Total
Build and test three Switching Nodes.	$2,000,000	
Build and test three Multiplexing Stations.	4,000,000	
		$6,000,000

Final Test

Table VII

FINAL TEST

Item	Approximate Price	Total
Evaluate performance of test units before proceeding.	$2,000,000	
		$2,000,000

Engineering and Installation

Table VIII

ENGINEERING AND INSTALLATION

Item	Quantity	Approximate Price	Total
Test Equipment (per repair vehicle)	480	$ 20,000	$ 9,600,000
Systems Engineering	5%	188,000,000	9,400,000
Propagation Studies Site Selection Site Preparation Building Layout Shipping Cabling Diagrams Fencing Roadways Fuel Storage	Included within price of subsystems		
Installation and test	2% of major items	188,000,000	3,760,000
			$22,760,000

SWITCHING NODE AND MULTIPLEXING STATION

The pricing for the Switching Node and the Multiplexing Station is based on the assumption that the preliminary logical design of the equipment in ODC-VII and ODC-VIII is representative of system complexity.

Several people familiar with computer manufacture and pricing were asked their opinion as to the expected price for units of the described level of complexity and construction. No specific acknowledgment of individuals is included because of a common reluctance to be quoted on an estimate based upon so many unknowns. Among the ground rules given was the assumption of use of known and understood 1962-63 technology and the use of low-cost components. (One more-recent estimate based upon silicon, high-reliability, 1964-era microminiaturized equipment indicated prices on the same order of magnitude as the 1962-63 lower-reliability, germanium transistor assumption.)

Item Costs: Multiplexing Station ~ \$300,000
Switching Node ~ \$150,000.

TERMINAL DEVICES

The cost estimate for the analog-to-digital telephone units was reviewed by members of a company involved in the manufacture of digital communications equipment, familiar with the complexity of equipment required. The consensus was that size and cost goals could probably be met using about 1965 technology.

Item Cost: Terminal Device ~ \$200.

TRANSMISSION LINKS

Total Mileage

(20 N-S paths)(2000 mi)
+ (20 E-W paths)(3000 mi)
= 100,000 airline mi
+ 20% for connection to Multiplexing Stations and indirect routing.
= 120,000 airline mi.

While the amount of transmission path-length required is computed on the basis of airline miles, unit costs for transmission by mini-cost microwave include the "round-about" factor caused by real-world topographical constraints.

Detailed pricing of the mini-cost microwave is described in ODC-VI.

Although several different types of links have been under consideration, the assumed cost was primarily based upon the acceptable development of a mass-produced, simplified "mini-cost" microwave digital relay equipment, inasmuch as this appears to be the cheapest way of buying new high-data-rate routes (with the possible exception of TV links).*

Originally it was thought that pulse-regenerative line would turn out to be the least expensive way of building new high-data-rate links. It was surprising to discover how much cheaper mini-cost microwave could be. The pulse-regenerative line required the operation of each piece of terminal equipment at a synchronous rate matching the regenerative repeaters used. This 1.54-megabit/sec data rate poses an awkward constraint, since the devices feeding the

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*Baran, Paul, Coverage Estimate of FM, TV and Power Facilities Useful in a Broadband Distributed Network (UFOUO), The RAND Corporation, RM-3008-PR, March 1962.

network operate at data rates in the 75 x 2^n bits/sec series (where n is an integer). Much of the equipment in both the Multiplexing Station and the Switching Node has been included in order to provide buffering between different data rates to match the narrow timing constraints of the link data rate.

The mini-cost microwave imposes no such constraints upon terminal timing, thereby facilitating an equipment simplification and providing for a cost savings by being able to design the links to fit the terminals--not the other way around. Further savings may possibly result from combining the Multiplexing Stations and Switching Nodes and increasing to 400 the number of major input points into the network. This arrangement would allow construction of 400 such stations at a lower unit cost than envisioned for the present Multiplexing Station, and would eliminate the need for the separate Switching Nodes. Even if the cost of the combined node was similar to the cost of the present Multiplexing Station, the overall costs would be identical.*

The maintenance cost for the mini-cost microwave has not yet been accurately determined. Almost all the cost of repairs resides in the travel time spent reaching microwave repeater sites. Since these repairs can be done on a delayed basis, and since no special skills are required in effecting repairs, we could let the repairmen who service the Switching Nodes and the Multiplexing Stations (who also spend much of their time traveling) also service the microwave repeaters. These repeaters will generally be situated alongside the roads between the Multiplexing Stations and Switching Nodes.

Alternatively, we could contract the servicing of the

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*400 Switching Nodes @ $150,000 plus 200 Multiplexing Stations @ $300,000 equals $120,000,000; 400 Composite Stations @ $300,000 equals $120,000,000.

microwave repeaters to independent television servicemen who specialize in antenna work. Independent operators should be able to perform first-echelon repairs at a labor charge of less than about $30 per repair call. As a worst-case estimate we can assume that each repeater has a 100-day mean-time-to-fail rate. As there are about 6000 repeaters in 120,000 miles of link, we would experience a maximum average of 60 failures per day. This would result in a cost of about $1800 for contract labor per day, or $657,000 per year if the entire system were serviced by contractors. Second-echelon repairs would be done by the repairmen at the Multiplexing Stations.

To the labor costs, we must also add the costs of repair parts. There are very few components which can fail, so a budget of $200 per mini-cost microwave repeater per year is felt to cover replacement parts (not including amortization).

This concept of building a reliable network out of unreliable low-cost elements is, admittedly, a highly unorthodox approach. Construction techniques are proposed that are not common practice. It is only the particular redundant network configuration, using all-digital modulation and switching, that allows the consideration of the low-cost, lower-reliability techniques proposed.

Item Costs

A conservative overall cost of $400 per airline mile, including the factor of round-about construction necessary because of topographic limitations, is used for mini-cost microwave. The cost basis for this and other links may be found in ODC-VI.

PURCHASING MAJOR SYSTEM ITEMS

Table IX

PURCHASING MAJOR SYSTEM ITEMS

Item	Quantity	Approximate Unit Price	Total
Switching Nodes	400	$150,000	$ 60,000,000
Multiplexing Station	200	300,000	60,000,000
End Terminal Devices	100,000	200	20,000,000
Links (airline mi)	120,000	400	48,000,000
			$188,000,000

ANNUAL MAINTENANCE COSTS

Table X

ANNUAL MAINTENANCE COSTS

Item	Quantity	Approximate Price	Subtotal	Total
Operating Personnel Five operators per each of 200 Multiplexing Stations (for 1-man 24-hr-per-day coverage)	1,000	$7,500	$7,500,000	
Repairmen One repairman per each two of 400 Switching Nodes	200	10,000	2,000,000	
One repairman per each of 200 Multiplexing Stations	200	10,000	2,000,000	
Contract 1st-level repair of microwave repeaters	6000 x 3.65	30	657,000	
Administrators, 1 per 5 workers	200 40 40	12,000 15,000 15,000	2,400,000 600,000 600,000	
				$15,757,000
Power Mini-cost microwave (assume 20% use of L-P fuel for max. cost estimate)	6000	0.2 x 175.2	210,240	
Switching Nodes	400 x 5 kw	2,000 x $7.7*	15,400	
Multiplexing Stations	200 x 10 kw	2,000 x $7.7	15,400	
				241,040
Rental of Sites Link repeater site--(use existing governmental rights-of-way)	400 x 15	-0-	-0-	
Switching Node	400	600**	240,000	
Multiplexing Station	200	1,200**	240,000	
				480,000
Personnel Vehicles One per repairman	400	1,440***	576,000	
One per repair administrator	80	1,440***	115,200	
				691,200
Test Equipment (consumed) Spares used and supplies Link repeaters (400 x 15)	6,000	200	1,200,000	
Switching Nodes	400	1,000	400,000	
Multiplexing Stations	200	1,000	200,000	
				1,800,000
Total				$18,969,240

*Assuming a price of $7.7 per kilowatt-year.

**These will generally be situated on sites already owned by the government. These costs are the pro-rata payment in return for additional costs that accrue to the present site agency. This cost is to compensate landlord agency.

***Assuming 18,000 mi/yr @ $0.08 per mi.

ANNUAL COST COMPUTATION

Table XI

ANNUAL COST COMPUTATION

	Factor	Approximate Investment Cost	Approximate Annual Cost
Capital Recovery Factor	0.149*	$234,460,000	$35,000,000**
Maintenance Costs			18,969,240
Profit, Technical Direction, Management Fees			3,620,730
Contingency			1,810,365
Basic Annual System Cost			$59,400,335

*R. D. Chipp and T. Cosgrove, "Economic Analysis of Communications Systems," IRE Transactions on Communications Systems, Vol. CS-10, No. 4, December 1962, pp. 416-421.

**Basis: 10-year usable system life; 8% interest rate for capital investment.

ON DISTRIBUTED COMMUNICATIONS:

List of Publications in the Series

I. Introduction to Distributed Communications Networks, Paul Baran, RM-3420-PR.

Introduces the system concept and outlines the requirements for and design considerations of the distributed digital data communications network. Considers especially the use of redundancy as a means of withstanding heavy enemy attacks. A general understanding of the proposal may be obtained by reading this volume and Vol. XI.

II. Digital Simulation of Hot-Potato Routing in a Broadband Distributed Communications Network, Sharla P. Boehm and Paul Baran, RM-3103-PR.

Describes a computer simulation of the message routing scheme proposed. The basic routing doctrine permitted a network to suffer a large number of breaks, then reconstitute itself by rapidly relearning to make best use of the surviving links.

III. Determination of Path-Lengths in a Distributed Network, J. W. Smith, RM-3578-PR.

Continues model simulation reported in Vol. II. The program was rewritten in a more powerful computer language allowing examination of larger networks. Modification of the routing doctrine by intermittently reducing the input data rate of local traffic reduced to a low level the number of message blocks taking excessively long paths. The level was so low that a deterministic equation was required in lieu of Monte Carlo to examine the now rare event of a long message block path. The results of both the simulation and the equation agreed in the area of overlapping validity.

IV. Priority, Precedence, and Overload, Paul Baran. RM-3638-PR.

The creation of dynamic or flexible priority and precedence structures within a communication system handling a mixture of traffic with different data rate, urgency, and importance levels is discussed. The goal chosen is optimum utilization of the communications resource within a seriously degraded and overloaded network.

V. History, Alternative Approaches, and Comparisons, Paul Baran, RM-3097-PR.

A background paper acknowledging the efforts of people in many fields working toward the development of large communications systems where system reliability and survivability are mandatory. A consideration of terminology is designed to acquaint the reader with the diverse, sometimes conflicting, definitions used. The evolution of the distributed network is traced, and a number of earlier hardware proposals are outlined.

VI. Mini-Cost Microwave, Paul Baran, RM-3762-PR.

The technical feasibility of constructing an extremely low-cost, all-digital, X- or K_u-band microwave relay system, operating at a multi-megabit per second data rate, is examined. The use of newly developed varactor multipliers permits the design of a miniature, all-solid-state microwave repeater powered by a thermoelectric converter burning L-P fuel.

VII. Tentative Engineering Specifications and Preliminary Design for a High-Data-Rate Distributed Network Switching Node, Paul Baran, RM-3763-PR.

High-speed, or "hot-potato," store-and-forward message block relaying forms the heart of the proposed information transmission system. The Switching Nodes are the units in which the complex processing takes place. The node is described in sufficient engineering detail to estimate the components required. Timing calculations, together with a projected implementation scheme, provide a strong foundation for the belief that the construction and use of the node is practical.

VIII. The Multiplexing Station, Paul Baran, RM-3764-PR.

A description of the Multiplexing Stations which connect subscribers to the Switching Nodes. The presentation is in engineering detail, demonstrating how the network will simultaneously process traffic from up to 1024 separate users sending a mixture of start-stop teletypewriter, digital voice, and other synchronous signals at various rates.

IX. Security, Secrecy, and Tamper-Free Considerations, Paul Baran, RM-3765-PR.

Considers the security aspects of a system of the type proposed, in which secrecy is of paramount importance. Describes the safeguards to be built into the network, and evaluates the premise that the existence of "spies" within the supposedly secure system must be anticipated. Security provisions are based on the belief that protection is best obtained by raising the "price" of espied information to a level which becomes excessive. The treatment of the subject is itself unclassified.

X. Cost Estimate, Paul Baran, RM-3766-PR.

A detailed cost estimate for the entire proposed system, based on an arbitrary network configuration of 400 Switching Nodes, servicing 100,000 simultaneous users via 200 Multiplexing Stations. Assuming a usable life of ten years, all costs, including operating costs, are estimated at about $60,000,000 per year.

XI. Summary Overview, Paul Baran, RM-3767-PR.

Summarizes the system proposal, highlighting the more important features. Considers the particular advantages of the distributed network, and comments on disadvantages. An outline is given of the manner in which future research aimed at an actual implementation of the network might be conducted. Together with the introductory volume, it provides a general description of the entire system concept.