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9. ABSTRACT

The development and implementation of a telecommunications network in a lesser developed country requires a substantial amount of speculation since growth patterns cannot be predicted with high accuracy. In Indonesia, these uncertainties coupled with difficult geography lead us to suggest serious consideration of the use of a satellite communications system designed in a manner to minimize growth problems and to provide a maximum of flexibility in serving a wide range of earth stations.

Such a system could be initiated with the lease of an INTELSAT IV spot beam transponder, assuming no legal or political obstacles to such a lease. The spot beam is to be preferred over the global beam because of its greater initial circuit capacity and because a later switch to a domestic satellite could be made without changing earth station parameters or performance (only the antenna needs repositioning).

The INTELSAT global beam transponder could be considered for initial use if there were no concern with the implementation of small "telephone booth" stations for isolated industry use. The low power of the global beam makes these small stations unduly expensive. The satellite system, started with INTELSAT IV, can at a later date make use of a second INTELSAT IV transponder for TV distribution. As a system use increases, or as more users request service, the shift to a dedicated satellite can be made without transients. The high capital investment in a domestic satellite does not have to be carried during the initial phases of the system implementation when traffic will be light.

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Telecommunications Development in Indonesia

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I. Introduction

In a previous report the authors examined the technical and economic factors influencing the choice of an educationally oriented broadcast system for India and Brazil. Our sponsors requested that we consider the broadcast and telecommunications problems in a country with significantly different geometry from that of India or Brazil. It was requested further that we give greater emphasis to the telecommunications aspects of the situation.

Since Indonesia does have an unusual geographic situation, is currently involved in a significant expansion of its communications system, and is competing plans for further expansion, it seemed an appropriate choice. It was decided therefore to analyze, insofar as possible, the choices available to Indonesia in communications development. Our concern in this report will be with the transmission network and the communications requirements of the educational system.

Our analysis of public service broadcast in India and Brazil was conducted at a time when established plans for a satellite based educational broadcast system were under active consideration in both countries. It was natural that our effort should center on the technical and economic considerations relating to those plans. The telecommunications aspects of our analysis was minimal. In Indonesia there is no plan for expansion of either radio or television networks. Emphasis there is on the expansion of telecommunications services and it would appear that any educational services will come as an add on to that expansion. This in fact may be the final situation in India and Brazil but the apparent emphasis during our work was on education. In any event our emphasis in each case has focussed on what we believe to be the important current issue and this has resulted in some lack of parallelism between the studies.

Differences in the population distribution, geography, and the present state of radio/television and telecommunication services have influenced our approach in studying different countries.

II. Indonesia Statistical Summary[1,2,3,4]

Indonesia covers a huge area – from east to west it stretches 3200 miles from easterninost W. Irian (New Guinea) to the city of Medan on the western tip of Sumatra. From northern Kalimantan (Borneo) to Southern Java is 1200 miles (see Fig. 1).

Total population is about 120 million, area is about 2,030,000 sq. km. or about 800,000 sq. miles. These aggregated figures are misleading for 76,000,000 persons live on Java which constitutes only 6.6% (53,000 sq. miles) of the total land area. Java population density is 1500 per square mile. (In the U.S.A., Illinois, Florida and New York have about the same area as Java and population densities of 196, 123, and 375. The actual population distribution for Indonesia, India and Brazil is shown in Fig. 1A. India has a more uniform population than either Indonesia or Brazil. Indonesia and Brazil both have high concentrations of population but of the two, Indonesia would have the highest marginal costs for providing public service (of any kind) for the sparsely settled areas because of the ocean barrier. Brazil and Indonesia are similar in that they both have a densely populated thin strip of population along one side of their territory – Java/Bali in Indonesia and the coastline in Brazil – and they both have generally hostile geography throughout the rest of the area.

In the 1970 census, 40,000,000 Indonesians declared they were economically active. 60% of that number were involved in agriculture, hunting, forestry or fishing. Six of the forty million are classified as urban dwellers.

The unit of currency is the Rupiah; the exchange rate is 414 Rupiah to the dollar.

GNP in 1970 was $7.6 billion or about $63 per capita.

Manila
Quezon City
PHILIPPINES
Hong Kong
Hanoi
Vientiane
Saigon
Phnom Penh
CAMBODIA
Moulmein
Andaman Islands
Banda Aceh
Medan
Padang
Kep Mentawai
Palembang
Jakarta
Bandjarmasin
Makassar
Surabaja
Jogjakarta
Balikpapan
Tarakan
Manado
Ternate
Ambon
Kupang
Darwin
Townsville
Port Moresby
Rabaul
Manila
Davao
Iloilo
Cebu
Tawau
Sandakan
Kuching
Singapore
Penang
Bangkok
Vientiane
Hue
Tuyen Quang
Lang Thep
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Canton
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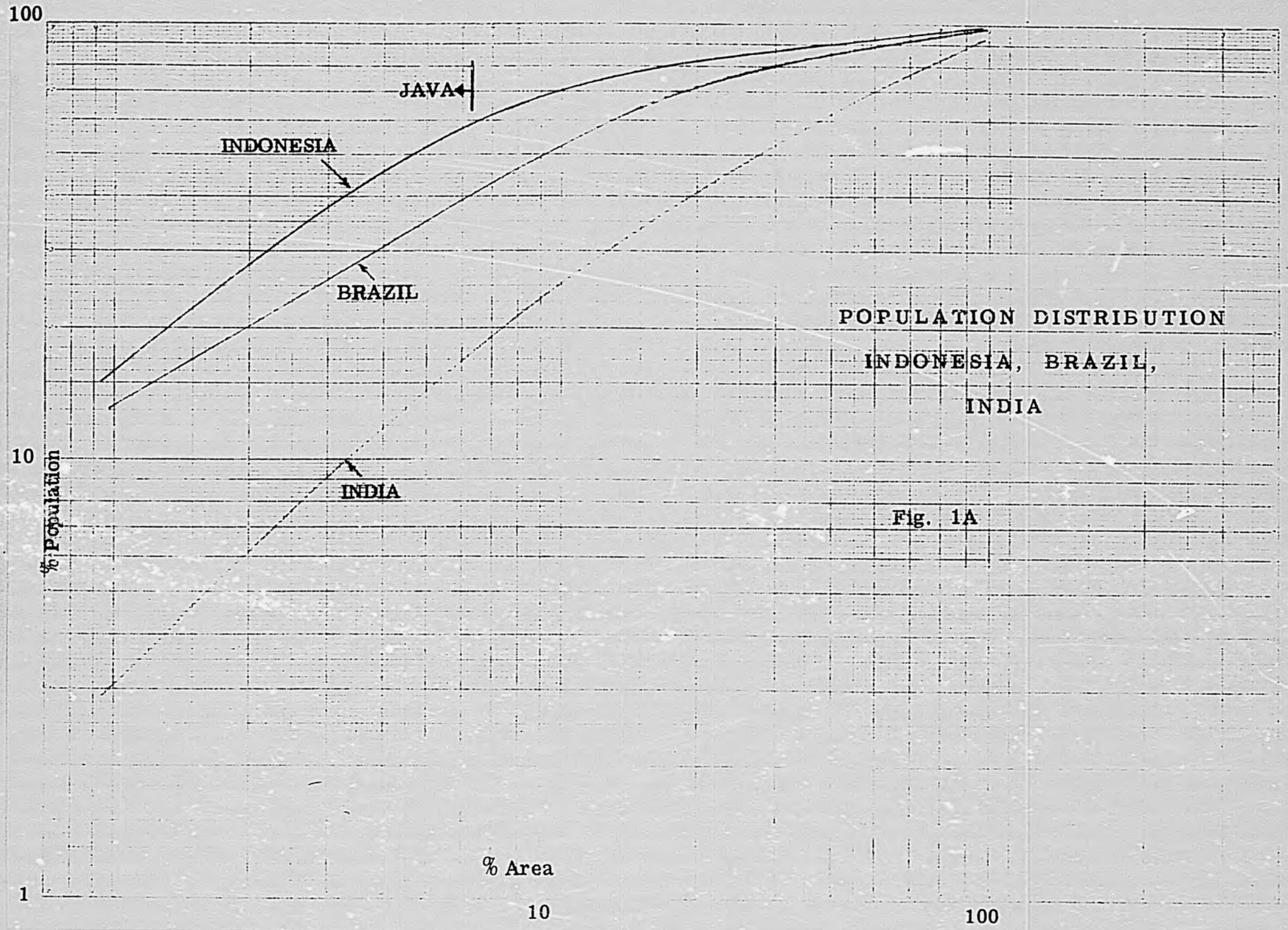
Haikou
Hanoi
Bangkok
Phnom Penh
Saigon
Medan
Padang



POPULATION DISTRIBUTION

INDONESIA, BRAZIL,

INDIA

Fig. 1A

III. Telecommunications and Broadcast – Current Situation and Future Prospects

A. Telecommunications

1. General

The Indonesian telephone, Telex, and Telegraph system is owned and operated by Perusahaan Umum Telekomunikasi (PERUMTEL). PERUMTEL is a government owned corporation which is obliged to operate at a profit.

PERUMTEL facilities are generally inadequate and/or outdated in spite of the substantial upgrading effort which has taken place in the first five year plan known as Repelita I (1969-1973). In 1972, a little more than a year before the end of the first plan, Indonesia had one of the lowest per capita telephone densities in the world. There were about 125,000 line units* in service outside of Jakarta and about 37,000 in the city itself. The official waiting list for telephone installation in Jakarta stood at 9,550 but it is believed that the unsatisfied demand exceeds that figure by a substantial amount since the knowledge that the probability of action is low discourages applicants. Cost of installation, officially set at 130,000 rupiah ($300) in Jakarta, may also be a deterrent. Telephone service in Jakarta is bad and may be near the point of instability – where the amount of time spend in dialing escalates rapidly because of the failure to obtain a connection.

Table I, a tabulation of telephone density and demographic data in several developing countries, is included for perspective. A graph of telephone density, Fig. 1B, as a function of per capita income shows the rapid increase in telephone density with income in the countries listed in Table I.

Table II is a breakdown of telephone density within Indonesia. Projected growth in telephone use in Indonesia is shown in Figs 2, 3, and 4.†

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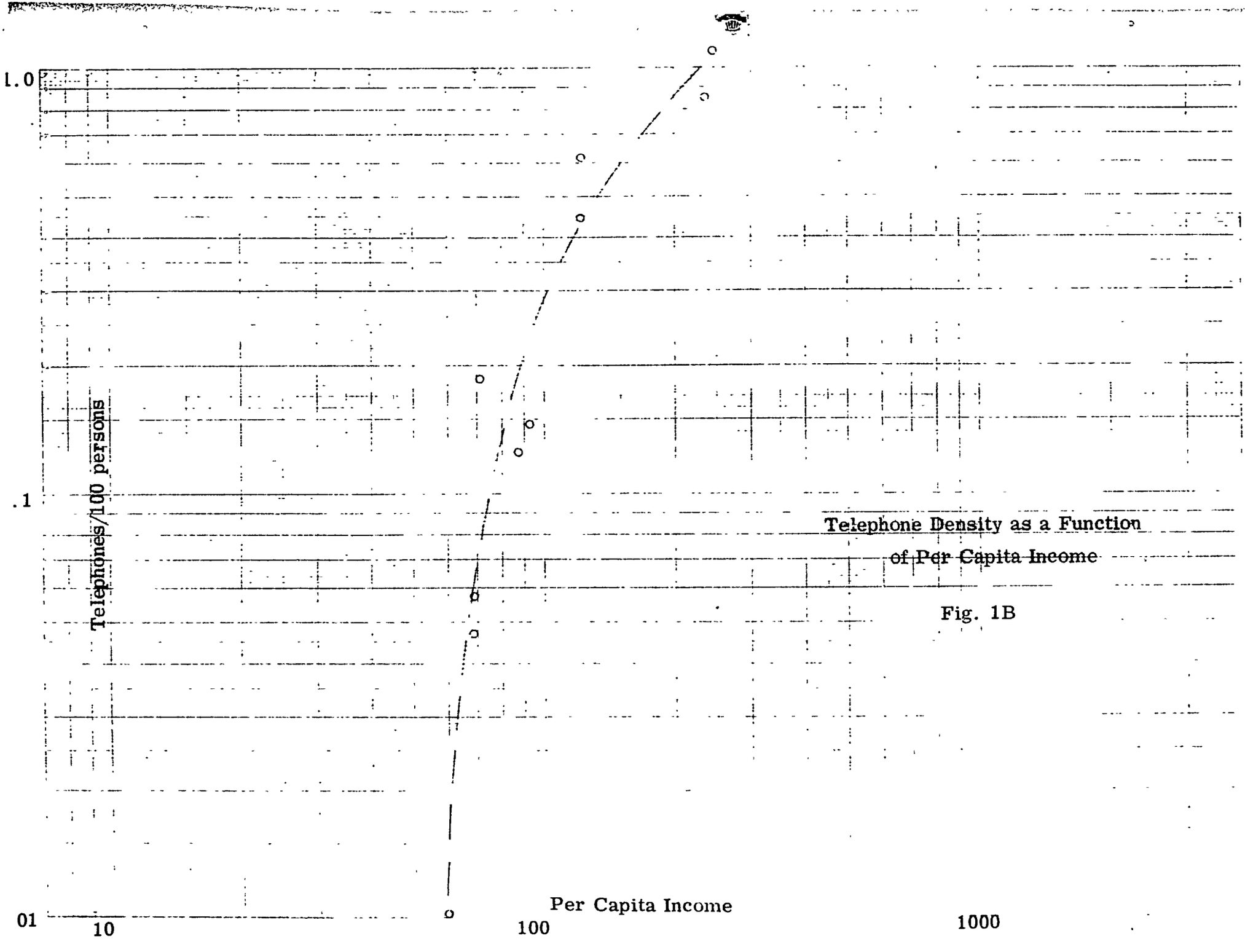
*A line unit is a service line available for telephone connection in a neigborhood.

† From "Proposal for Telecommunications Development in the Second Five Year Plan," Vol. I.

	Population (mill.)	Area (mill. sq. mi.)	Per Cap. Income($)	% of Pop. in School	Telephones per 100	Ratio of per cap. Income to Telephones/100	Inhabitants per physician
Afghanistan	17	.249	70	2.66	.059	1186	21,000
Algeria	14	.919	250	10	1.11	225	11,400
Ceylon	12.6	.025	124	20.5	.457	271	7,840
Chad	3.7	.495	60	3.7	.01	6000	72,400
India	554	1.26	73	11.0	.19	384	4,860
Indonesia	119	.575	95	14.3	.152	625	23,000
Iran	28.4	.636	243	11.5	.88	276	3,670
Nepal	11.2	.054	70	4.6	.048	1458	72,000
Pakistan	137	.365	89	7.1	.129	690	6,600
United States	204	3.617	3680	23.5	56.4	65	670

Table I. Statistical Data for Several LDC's and the U. S.



Telephone Density as a Function of Per Capita Income

Fig. 1B

TABLE II

†Telephones in Indonesia - 1971

Area	Population (Millions)	Number of Telephones	*Telephones per 100 persons
Jakarta Raya	4.58	58,588	1.28
Java and Madura	47.15	67,584	.143
Central Java	21.87	21,800	.099
D. I. Jogjakarta	2.49	2,932	.118
North Sumatra	8.6	22,886	.266
Mid "	5.3	7,256	.137
South "	6.7	9,781	.146
Kalimantan	5.11	6,556	.128
Sulawesi	8.53	11,492	.135
Maluku	1.08	1,565	.145
W. Irian	.92	3,066	.333
Nusatenggara	4.49	5,221	.116
Bali	2.1	6,000	.285

† Source – Statistical Pocketbook of Indonesia, 1970 and 1971

* Number of lines will be less than number of telephones by a ratio which varies from location to location. In Jakarta it is about 1.6/1, in Bali 1.4/1, and in Kalimantan about 2/1.

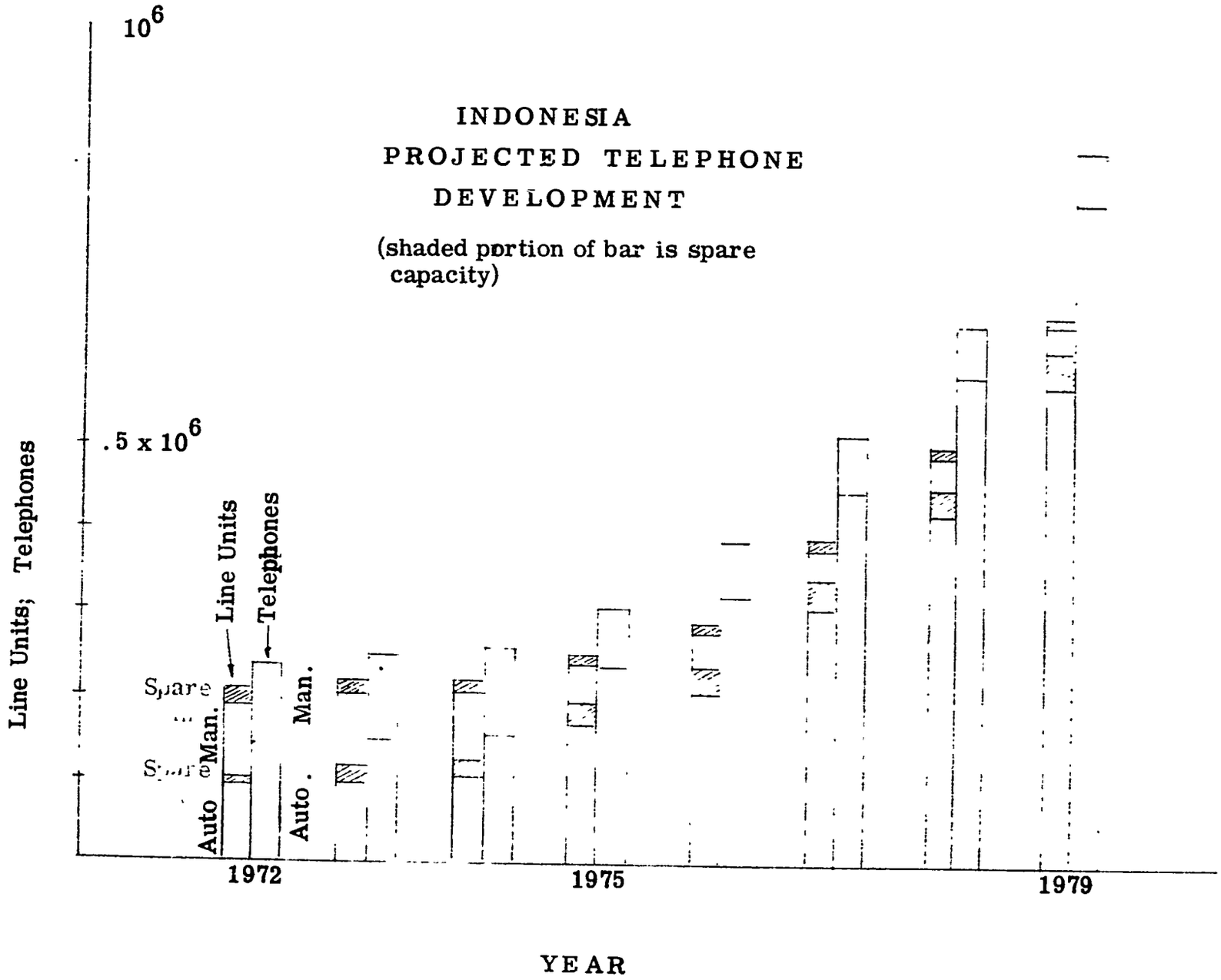

INDONESIA
PROJECTED TELEPHONE
DEVELOPMENT
(shaded portion of bar is spare capacity)
10^6
$.5 \times 10^6$
Line Units; Telephones
Line Units
Telephones
Spare
Man.
Auto
1972
1975
1979
YEAR

Fig. 2

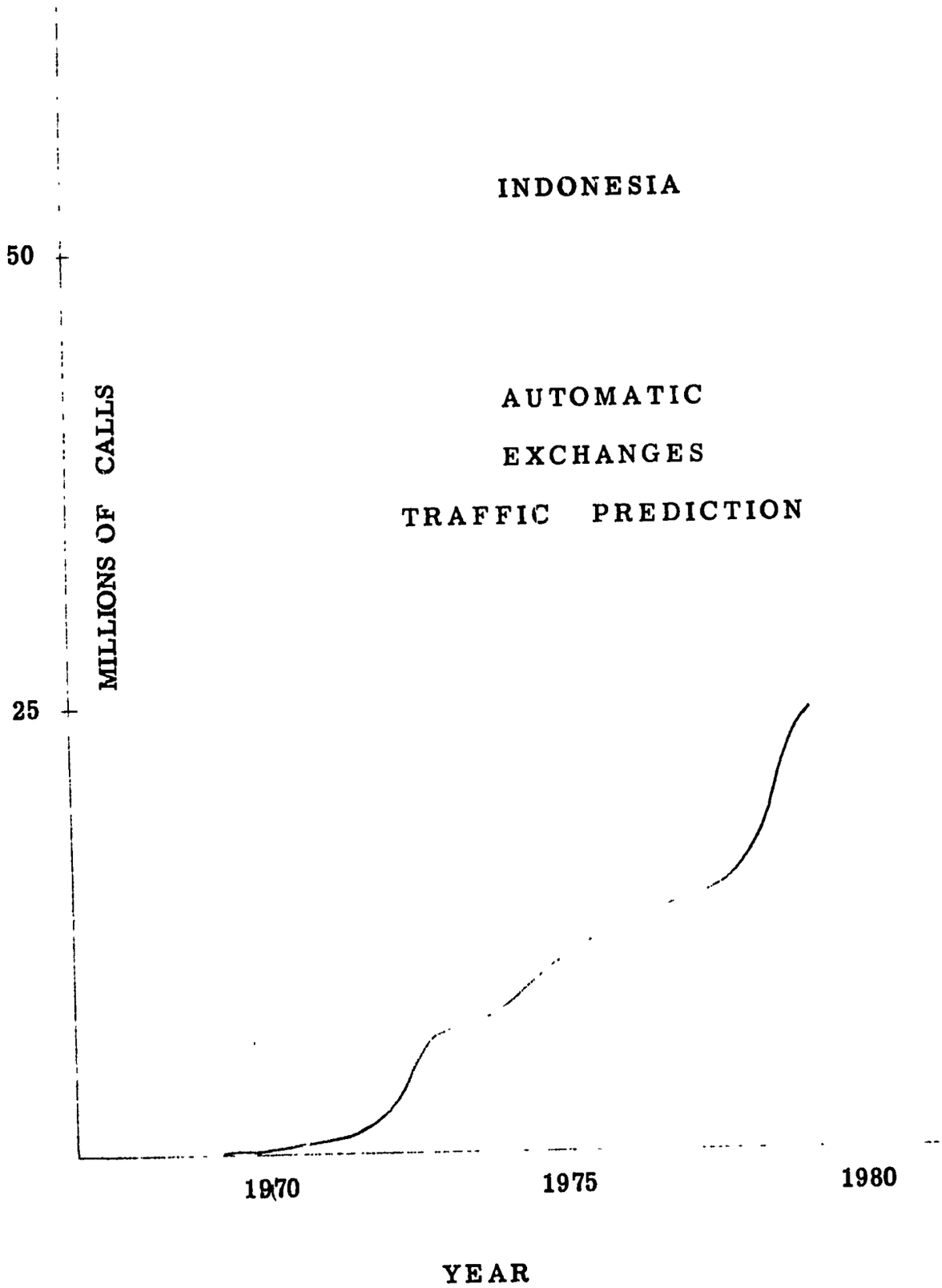

INDONESIA
AUTOMATIC
EXCHANGES
TRAFFIC PREDICTION
MILLIONS OF CALLS
50
25
1970
1975
1980
YEAR

Fig. 3

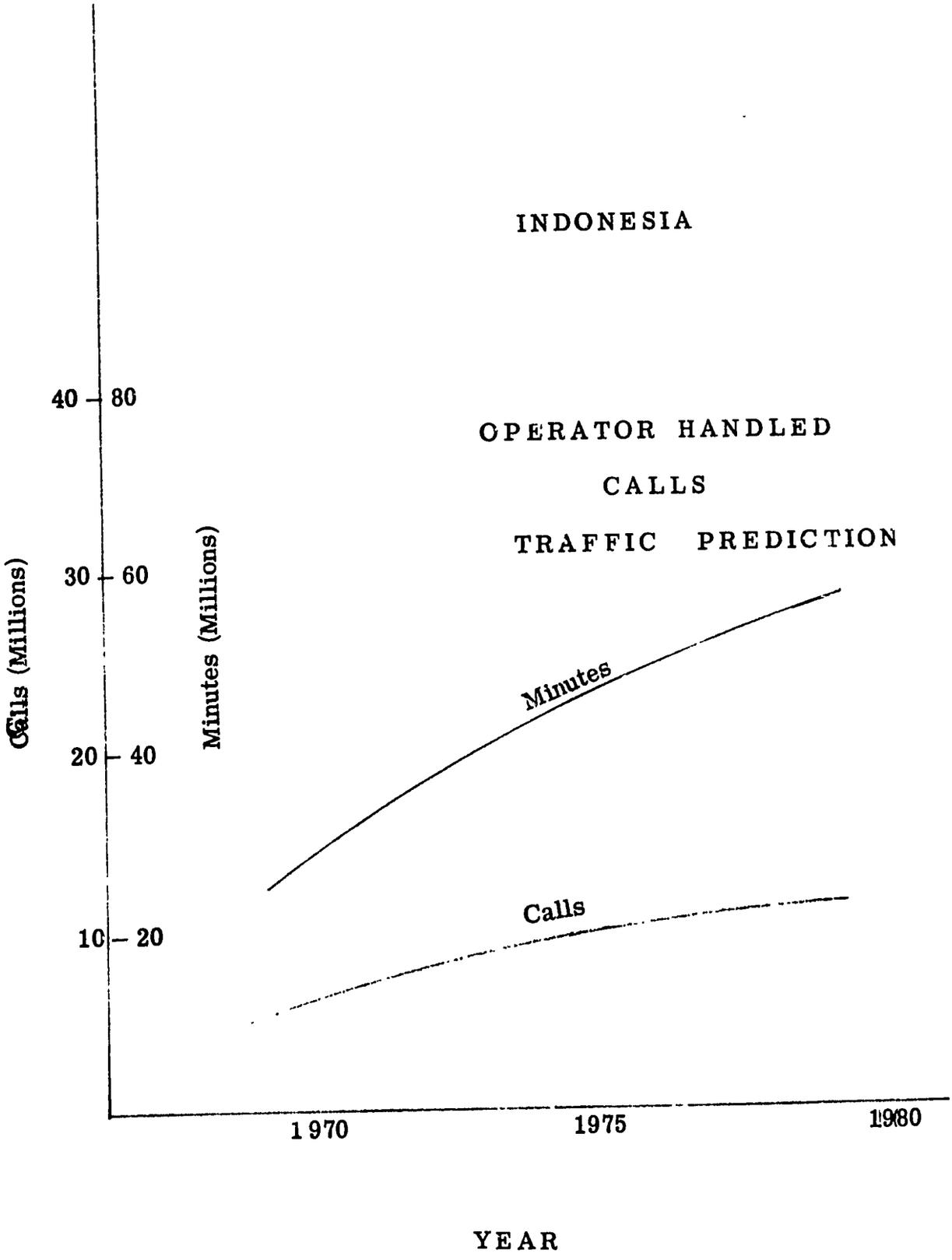

INDONESIA
OPERATOR HANDLED
CALLS
TRAFFIC PREDICTION
Calls (Millions)
Minutes (Millions)
40
80
30
60
20
40
10
20
Minutes
Calls
1970
1975
1980
YEAR

Fig. 4

In order to cope with the projected growth, PERUMTEL has proposed an ambitious expansion to be undertaken during the second five year development plan, Repelita II.[5]

The key features of this plan are:

1. Install 480,000 automatic line units
2. Remove 64,000 obsolete manual line units
3. Install 14, 4 wire S. L. D. D.* trunk exchanges
4. Replace 853 Km of underground cable in Jakarta
5. Provide for 560,000 new telephones, an increase of 248% over 1972
6. Construct 6,763 Km of microwave relay, complete 4,264 Km now under construction or planned under Repelita I, and upgrade 5,245 Km of spur routes for a total new capacity of 7.5×10^6 circuit kilometers (4.7×10^6 miles).

Total cost of Repelita II is estimated to be $470 million. This includes $133 million for closing the gap which exists between supply and demand at the beginning of Repelita II.

2. The PERUMTEL Proposal

The telephone transmission network in 1972 is shown in Fig. 5. By late 1974, a 960 circuit microwave relay system will reach from Palembang to Den Pasar. The Java portion of this relay is now operational; the Sumatra section is to be completed next year. During Repelita II, Kalimantan, Sulawesi and W. Irian will be tied into the system given favorable action on PERUMTEL's proposal or an alternate. Figure 6 shows the transmission system which PERUMTEL proposes to complete by 1979. Note that the 1979 system as proposed uses submarine cable, VHF, tropo scatter and microwave relay.

---

*Subscriber Long Distance Dialing

L E G E N D

rating	Under construction	System
———	- - - - - -	960 Channel microwave
—·—·—	—·—·—·—	Troposcatter
———	- - - - - -	V H F (interim system)

NUSANTARA BROAD BAND SYSTEM
AT END OF REPELITA I

Fig. 5

Transmission Network –
End of 1979 – according to
PERUMTEL

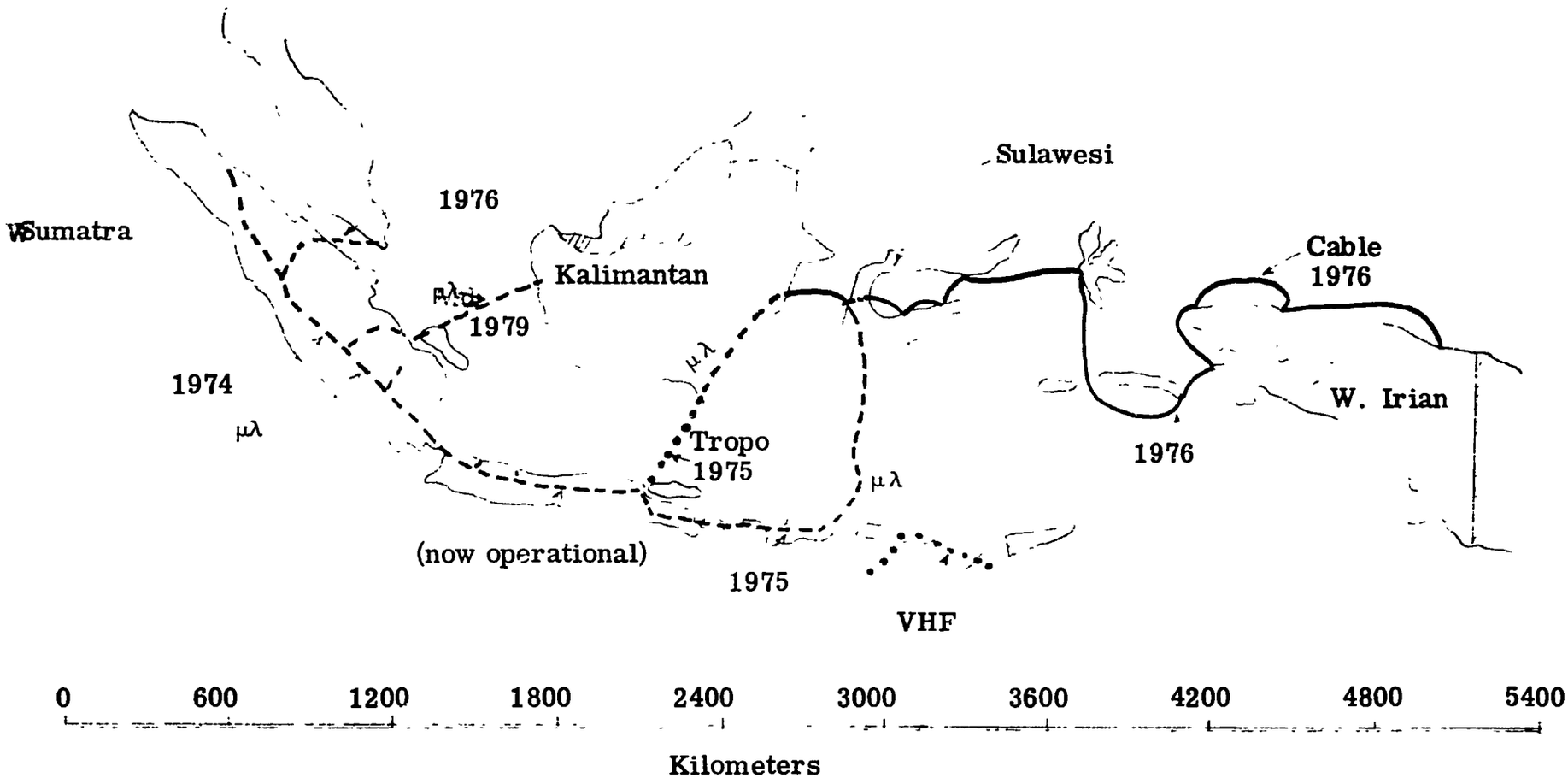


Fig. 6

Table III shows the estimated cost of the proposed transmission system. The cost estimates of the microwave sections, on a per mile basis, are extraordinarily high; they apparently reflect the difficulty of working in mountainous and jungle terrain. Relays in other countries tend to be in the $4,000 to $6,000 range per mile.

In discussing the submarine cable installation between Kalimantan, Sulawesi and W. Irian, the PERUMTEL plan notes that microwave relay would cost $175 x 10^6. The document does not state specifically that it would follow the same route as the cable and does not state the relay capacity. In deriving the per mile cost of the microwave relay, the stated cable length was used. In actual practice the microwave relay might be somewhat longer because of the necessity of using closely spaced islands for relay points. In any event, the cost per mile is phenomenal.

It is assumed that all trunk microwave will have one 960 circuit bearer* in each direction and a spare.

PERUMTEL has given some thought to the use of a satellite for extensions to the existing transmission system. In its expansion plan, a dedicated satellite was rejected because of difficulties attendant with the matching of such a sophisticated system into a relatively old fashioned network and because of echo problems† associated with double hop overseas calls which would use the Indonesian satellite and Intelsat IV. However, Comsat, Telesat and Hughes aircraft personnel have consulted with various Indonesian agencies in order to explore satellite possibilities. Hughes has made a specific proposal for a domestic satellite; Comsat is expected to explore the use of the Indian Ocean INTELSAT IV for interisland communications. It is probable that considerable further study of alternate transmission systems will precede any extensive action by PERUMTEL.

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*Bearer is a term commonly used in PERUMTEL documents to describe each relay channel of a nominal 40 Mhz bandwidth, capable of carrying 960 voice circuits.

† At least one study[6] concludes that this problem is not severe.

TABLE III

Summary of Proposed Microwave and Cable

Construction during Repelita II

Microwave	Miles/km*	$ Cost per mile/km	Budgeted Total Cost $ millions
Eastern	946/1500	12,608/7,960	11.94
Padang-Pakanbaru	159/252	19,293/12,180	3.07
Pakanbaru-Singapore Tanjungpinang	266/421	14,145/8,930	3.76
Medan-Banda Aceh	276/438	19,166/12,100	5.30
Banjarmasin-Samarinda	362/574	8,830/5,575	3.20
Palembang-Pangkalpinang-Pontianak	580/920	9,709/6,130	5.64
Trans Sumatra	1690/2678	7,606/4,802	12.86
	10,749/6783	10,694/6,748	45.77
Trans Java; 3rd bearer (assumed to be Jakarta-Denpasar)	615/990	1,675/1,040	1.03
Cable			
160 channel	2350/3750	11,500/7,200	27.03
640 channel	"	20,000/12,300	46.9
1840 channel	"	27,400/17,000	64.5†

* Including spurs

† Microwave is quoted at $\$175.5 \times 10^6$ or $74,400 per mile

3. Private Communications Systems

Because of the lack of public telecommunications between islands, many extensive private networks have been developed.

One of the most visible private communications service is the Integrated Oil Communications System (I. O. C. S.)[7] owned by Pertamina and operated by its subsidiary Electronika Nusantara (ELNUSA). ELNUSA's I. O. C. S. system is an HF network with a center at Jakarta and multi-channel HF links to subcenters at Medan, Batam Island, Balikpapan, Ujung Pandang, and Sorong (see map, Fig. 7). These subcenters maintain communications with about 40 offshore oil exploration groups. Cost of this service is of the order of $150 per day per HF link; this is about 0.6% of the daily operating cost of an offshore drilling rig. ELNUSA's current charter restricts its communications operations to service to oil exploration projects. Other activities include electronics installation (TV), maintenance of marine electronics and data processing.

ELNUSA's management is collaborating with PERUMTEL in the investigation of satellite systems to replace and extend the existing HF capability.

Many of the oil, mining, and timber companies operate their own HF networks. One timber company official emphasized the difficulty of communications between base camps and field sites.

The cost of HF licenses are calculated on a mileage basis. One company official quoted license costs of the order of $1,100 per month. There is an expressed need for better communications between base camps and field operations and for direct communications (not through Jakarta) from base camps to overseas points.

B. Broadcast

1. TVRI[8]

TVRI the national television network operates twelve TV stations and 12 translators. These stations are low power by U. S. standards. Maximum power is 10 Kw (2 stations) with most being 1-5 Kw. Translators are generally 100 watts. Total area covered by TVRI on Java is estimated to be 14,600 sq. mi.

Fig. 7 Elnusa Integrated Oil Communications System
(showing coverage of sub centers)

Approximately 50% of the inhabitants or 35×10^6 persons live within this area. Fig. 8 indicates coverage now available.

While coverage of Java is not insignificant, the number of TV receivers is small. In 1971 there were 116,800 receivers registered in Jakarta, 64700 in the rest of Java and only about 8500 on all of the other islands combined. If one excludes the 116,800 receivers in Jakarta, the 3500 in Jogjakarta and assumes that an equal number (3500) are in Bandung and Surabaya (figures not available), then the maximum number of receivers in rural areas in Java would be 50,000. This would be of the order of one receiver per 1000 persons.

The Jakarta TV is on for a few hours in the evening carrying news, entertainment, and to a limited degree education programs. There is no classroom TV. TVRI generates about 50% of its own programming material and buys the other half. Outlying stations rely on tapes or microwave relay for their material. TVRI operates its own trans Java microwave relay system for program transmission. This is a single bearer, one way, link that relies on commercial power, so reliability has been low. An upgrading program is being undertaken (standby power and an additional bearer).

2. RRI

Radio Republik Indonesia (RRI),[9] the radio broadcasting arm of the Ministry of Information, operates about 150 radio stations throughout Indonesia. These are integrated into a single network. Thirteen regional stations with power output in excess of 10 kilowatts and a large number of automatic satellite stations provide essentiallly 100% coverage of the entire archipelago.

Several government agencies use the facilities of RRI for educational broadcasts. These include:

1. The Department of Information

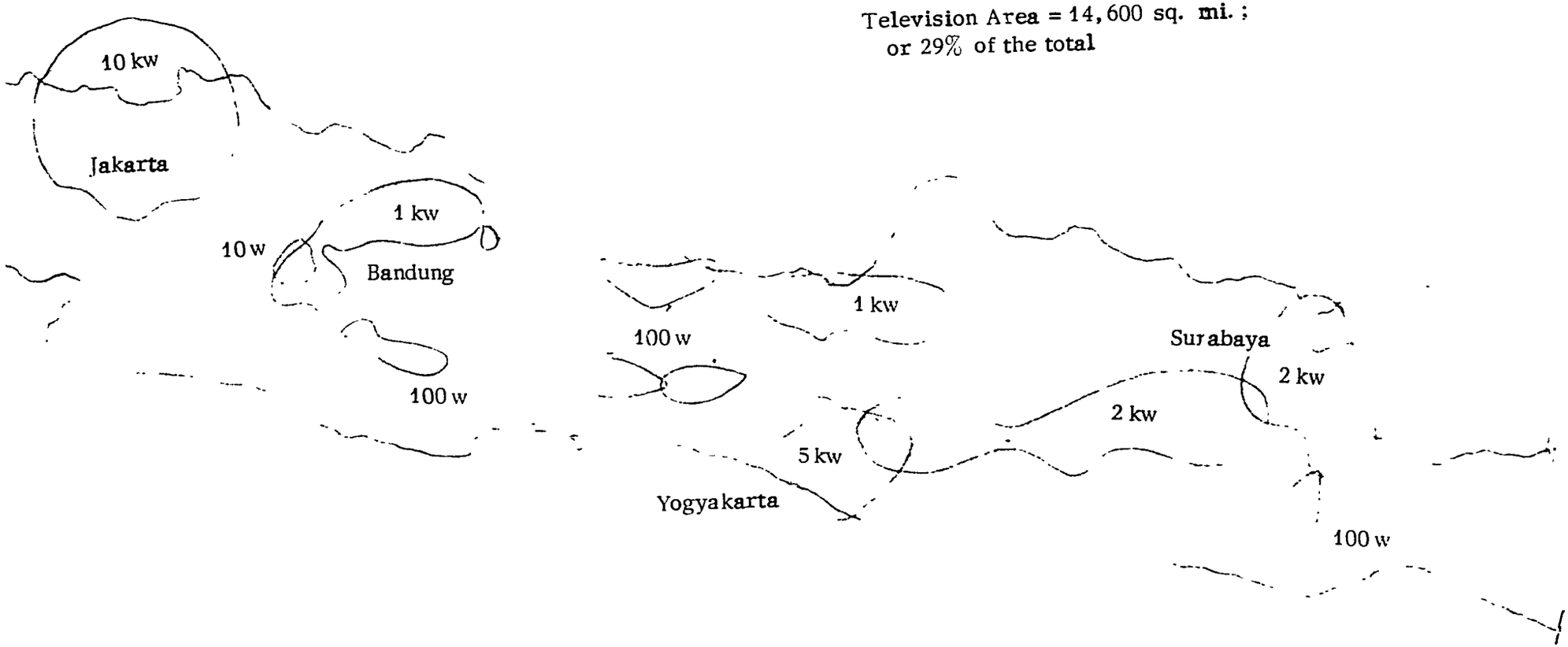
Experimental broadcasting to schools in regular subjects, such as Indonesia, General Knowledge, and Civics, and, to out-of-school audiences,

Fig. 8 Java Television Coverage
(from tvri 1972-1973 yearbook[8])

Scale: 1" = 50 miles

Area of Java w/o Madura = 50,000 sq. mi.

Television Area = 14,600 sq. mi.;
or 29% of the total



educational programs on agriculture, foreign languages and other subjects of general interest to youth and adults.

2. The Department of Agriculture

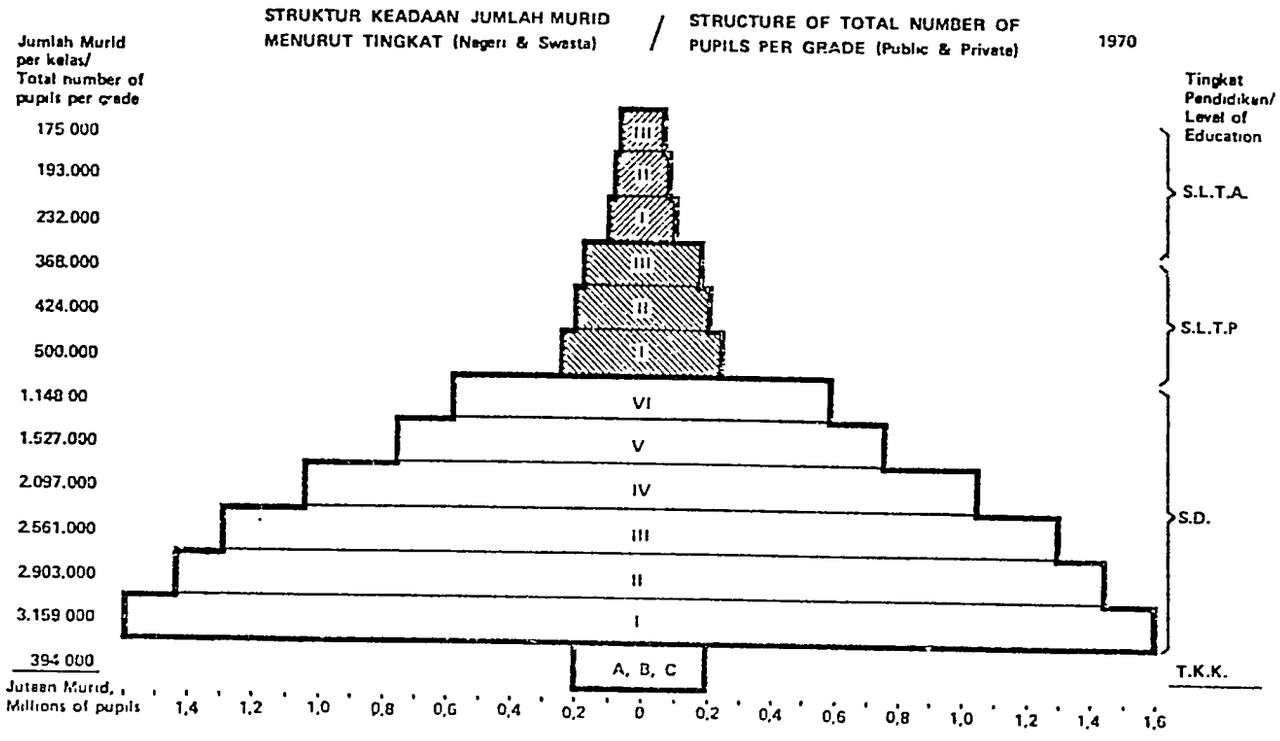
Rural broadcasting to inform rural residents on items of general interest including farm conditions, market news, and weather.

3. The Department of Education and Culture

Experimental instructional programs for students and teachers. Current project is in Jogjakarta and Semerang.

4. Jakarta Special Capital Government

Experimental instructional broadcasts to 55 schools in Jakarta. Subjects include Javanese language, Singing, Civics and Agriculture. Total broadcast time for all of 1973 is 21 hours.



(From "Statistik Pendidikan," Departemen Pendidikan Kebudayaan Republik Indonesia 1972)

Fig. 9

Based on extremely sketchy data, it is the author's opinion that the rural broadcasting serves a useful function and is popular. The instructional broadcasts appear to suffer from problems associated with receiving equipment, and programming. In general, the programs are of such short duration and so infrequently scheduled that it is hard to see how they can have an appreciable affect on the instructional process.

In addition to the RRI radio stations in Indonesia, there are over 300 stations sponsored by commercial interests, local governments and universities. These carry programs of general appeal – news, music and other items of public interest.

As of 1971 there were approximately 3,000,000 receivers in Indonesia; half of these are on Java; 500,000 are in Jakarta.

IV. The Education System[10,11]

A brief summary of the current education situation in Indonesia is included as a background for a later discussion of the uses of TV and radio as aids to formal and non-formal education in Indonesia.

The Indonesian school population grew from 9×10^6 in 1960 to 15×10^6 in 1970, but the proportion of school age children enrolled in primary schools remained nearly constant at 65% during that decade. The drop out rate is high, as is generally the case in LDC's. See Fig. 9 . There are 64,000 primary schools in Indonesia (11,000 of these are private) with a total of 347,500 teachers and about 14,000,000 students. Countrywide student teacher ratio in primary grades is about 40/1. Urban school buildings are often in use from 7 AM to 6 PM so that several shifts can be accommodated.

Teachers' salaries are about 60,000 Rupiah per year ($150); they constitute about 80% of the school budget. With a 40/1 student teacher ratio, the yearly cost per elementary student is then about $\frac{75,000}{40} = 1875$ rupiah or $4.50 per year, or about 0.5 cents per student hour. Entrance fees, books and supplies will increase this figure somewhat.

This extremely low cost per student hour must be kept in mind when making proposals for using educational technology. If the cost of education is not to increase with the introduction of technology, then the operating budget for the technology must be found by increasing student teacher ratios. In Indonesian elementary schools where the teacher component of costs is only .5 cents per hour, a student teacher ratio increase of 2 is required to break even when the cost of the new technology is only 0.25 cents per student hour.

Suggestions have been made for the use of radio in Indonesian schools as a means for increasing student teacher ratios and for teacher upgrading. One experiment,[12] with the foregoing objectives, is being planned by the Office of Educational Development of the Department of Education. The project proposes to use radio as a supplementary aid in the improvement of teaching skills and at the grade IV, V, and VI level as an aid in teaching citizenship, reading, composition, and language skills. A proposal[13] has also been made for an experiment in teaching mathematics by radio.

In an independent study,[14] Jamison suggests that radio be used as the basic medium of instruction for Indonesia and that this technique be implemented with a nationwide multi-channel network.

To the best of our knowledge, there has been no serious discussion of the use of television as a major instructional aid though hardware proposals have been received by the Office of Educational Development.

Given the existing economics and the present school population, it will be difficult to introduce any noticeable amount of technology into the system without significant increases in costs. Even a $200 tape recorder, operating full time (1000 hours/year), without maintenance, for five years — and with a tape library of 200 hours at $1 per hour — will cost .2 cents per student hour when used in a classroom of 40 students. This means that costs increase by 40% when the tape is in use. Some arrangement to increase class size during tape use would be required if costs are not to increase. This is not easy; since tapes would be used only a fraction of the time a severe scheduling problem arises. The foregoing economic arguments

are valid only where costs are as stated. One might expect to reach a different conclusion at higher grade levels where costs are usually highest. It is our presumption however that the most serious staffing problem does exist at the lower levels.

Radio is probably the only technology which can be introduced without noticeable increase in school costs. The major disadvantage of radio (over tapes) is the rigidity of scheduling, but this difficulty can be alleviated somewhat by repeated broadcasting.

V. Telecommunications Expansion Considerations

A. General

There is no question that the Indonesian telephone system is over-age and overworked. PERUMTEL has been unable to meet commercial and government demand and as a result a number of special systems, private and government, have been constructed. Expansion of microwave relay on Sumatra, Java and Bali will improve the long distance service in those areas soon.

Extension of service by microwave relay to the other islands is hampered by long overwater paths between islands and by unfriendly terrain on the islands.

With the advent of an improved transmission system on Sumatra, Java and Bali, attention is now focussed on the expansion of public telecommunications service to Kalimantan, Sulawesi, and W. Irian. The PERUMTEL proposal for this expansion is conventional in that it provides service to population centers using standard telephone com-pany recipes for predicting traffic.

It is suggested that the situation to the north and east of Jakarta may be so fluid and unpredictable that conventional wisdom may not produce a transmission system that is responsive to the need.

Much of the traffic from outlying areas will be generated by commer-cial users who can afford to pay (as they now do) relatively high charges for adequate, reliable, telephone and telex circuits. An oil rig costing $1000 an hour to operate must be able to communicate, without delay, information regarding progress and maintenance problems. One can expect to find new towns rising in remote areas, as a result of industrial activity, that will surpass the need of existing cities for communications.

In view of these uncertainties in Indonesian growth patterns, it would seem important that any transmission system which is installed have maximum flexibility to adapt to changing conditions.

It would be highly desirable also for any expanded service to be so comprehensive that it will satisfy the needs of all (or nearly all) potential customers in order to achieve economics of scale. Those who now operate private systems must see a believable promise of better service, and/or lower cost to a degree that offsets the forfeiture of their independence in any proposed public system before they agree to give up their current practice.

B. Ground Based Expansion

PERUMTEL, as noted earlier (page 4), has proposed a ground based transmission system to be developed and installed during the 1974-1979 time period. This system would provide for the extension of telecommunications service to all major cities in Indonesia and for extension of television service to Kalimantan and the Sulawesi (through microwave relay and television broadcast stations) at a budgeted cost of about $73 million. This system as we view it, would provide for conventional expansion of service in a manner that would be expected in a more fully developed country where large inhomogeneities in population density or isolated industrial needs are unusual. The system is less attractive in a country like Indonesia where isolated needs (customers) may develop unexpectedly. The backbone system may also not be the most desirable for industrial customers in Indonesia for these customers probably do not follow the general rule that the product of number of calls times the calling distance is a constant. Industrial sites in the northern and eastern islands are more likely to have their most important and most frequent traffic with Jakarta or their headquarters office wherever it may be.

The microwave system is best suited for situations where the calling frequency decreases with distance and it is best suited for geographic situations where long spurs to isolated customers are not required. This is the situation in Java and Sumatra, so the installed and planned microwave relay there makes good sense, even though costs in

Sumatra, as noted below, are exceptionally high. Spur routes are especially costly in the unfriendly geography that is typical of most of the Indonesian Archipelego. The difficulties encountered in jungle-mountain territory are signaled by the high cost per miles of the trans-Sumatra microwave link. This was originally budgeted at about $7,600 per mile, but it is the author's understanding that actual costs are running far above that figure. A link from Padang to Pakanbaru, a 120 mile spur off the Sumatra backbone system, is planned for REPELITA II and budgeted at $19,000 per mile – an extraordinary figure.

There is also a concern that a fixed system may not be able to respond to changing conditions in an area where difficult terrain is the rule. Further, there may be a question about the match between the basic capability of the trunk line concept and the pattern of traffic which will exist in Indonesia. There is a potential for a significant amount of traffic in a radial pattern - that is, from Jakarta and Surabaya to dispersed remote sites; as noted above, this is not the geometry to which microwave is best suited.

C. Satellite Based Expansion

1. General

Communications and television distribution, via satellite, to and between outlying islands of Indonesia is technically feasible. The Indian Ocean INTELSAT IV or a domestic staellite could be used for such service.

A satellite system can satisfy our assumed requirement for a system capable of adapting quickly to changing needs. It follows that the satellite system design must be such that it will support operation of a large number of inexpensive earth stations (>100). If the system

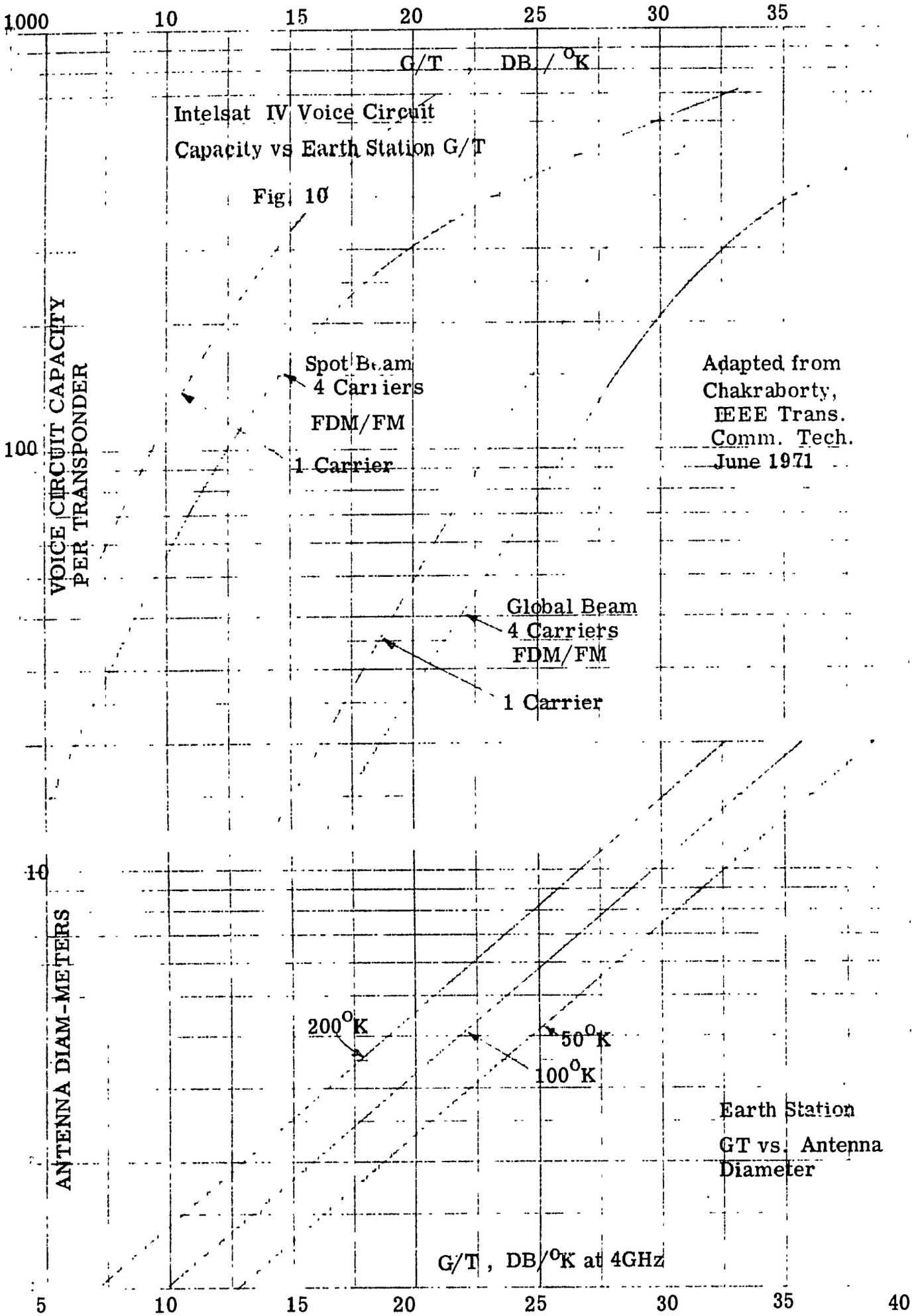
design requires expensive earth stations then one is led to the construction of an extensive network of spur routes from a relatively small number of earth stations, thus nullifying one of the major advantages of the satellite approach (its flexibility to meet new needs). It should be stated explicitly that the philosophy expressed here arises from the belief that one of the major user groups – in terms of need, ability to pay and numbers – is made up of remotely located industrial users.

2. Technical Considerations

It is necessary to digress briefly to outline some of the constraints and costs associated with satellite earth terminals for readers who are unfamiliar with this area.

There are two fundamental limitations on the performance of an earth terminal. These are the earth station antenna size (area) and the sensitivity (noise temperature) of the receiving system. The bigger the antenna the greater the power collected from the satellite. The lower the noise temperature the higher the signal to noise ratio for any given antenna size and incident power density. A measure of earth station performance where performance is defined as the number of voice channels each satellite receiver-transmitter can relay, is then the antenna gain (G) (which is proportional to area) divided by the system noise temperature (T). This relation is shown graphically in Fig. 10* for an earth station operating at 4 GHz and an INTELSAT IV satellite. One enters the lower left ordinate at the chosen antenna diameter moving to intercept the system temperature line and reading the indicated G/T. Noise temperatures generally range from a low of about 60° K in very sensitive receivers to a high of $400\text{-}500^{o}$K in

*Adapted from Chakraborty IEEE Transactions on Comm. Technology, June 1971


1000
100
10
10
15
20
25
30
35
G/T , DB / °K
Intelsat IV Voice Circuit
Capacity vs Earth Station G/T
Fig. 10
VOICE CIRCUIT CAPACITY
PER TRANSPONDER
Spot Beam
4 Carriers
FDM/FM
1 Carrier
Adapted from
Chakraborty,
IEEE Trans.
Comm. Tech.
June 1971
Global Beam
4 Carriers
FDM/FM
1 Carrier
ANTENNA DIAM-METERS
200°K
50°K
100°K
Earth Station
GT vs. Antenna
Diameter
G/T , DB/°K at 4GHz
5
10
15
20
25
30
35
40

lower performance units. Once the G/T is known, the voice channel capacity of a standard satellite receiver/transmitter (transponder) can be determined by moving vertically to the upper section of the graph. If the transponder is being used by only one earth terminal, the curve labeled "single carrier" is used. If there are four users then the curve labeled "four carriers" is used. Other numbers of users would lead to slightly different voice channel capacities, but the two curves plotted show the single carrier case and provide a reasonable approximation of the single carrier and general multi carrier case.

Note that the traffic carrying capacity of the INTELSAT IV global beam is approximately an order of magnitude below that of the spot beam when low performance (low G/T) earth stations are in use. This lower capacity is a direct result of the lower power density delivered to the earth surface by the global beam. The downlink global beam from the INTELSAT IV has a 17.5° beamwidth and so illuminates essentially all of the visible earth; the spot beam has a beam width of 4.5° and when pointing straight down (towards the equator) covers a circular area about 1800 miles in diameter. Using the smaller beam leads to a power density at the earth's surface which is 10 times (actually 11.5 db) that of the global beam.

Starting with a small earth station and a global beam one can achieve the same improvement in voice channel capacity by increasing the antenna area by a factor of 10 or by switching to the spot beam from the global beam.

The INTELSAT IV is used here as an example, but of course the general considerations apply to any satellite system. It should be noted further that the INTELSAT IV spot beam delivers about the same power

to the earth's surface as the Canadian ANIK satellite. Proposals for a domestic Indonesian satellite have recommended a radiated power level near that of ANIK. This suggests that each domestic satellite transponder would have nearly the same channel capacity as each INTELSAT IV transponder radiating through a spot beam antenna.

It is clear from Fig. 10 that even very small antennas will collect enough power to provide adequate voice channel capacity for a remote industrial "telephone booth." Unfortunately, the low performance capability of any earth station exerts a constraining effect on the voice circuit capacity of any other earth station with which it is communicating. When a high performance earth station transmits to a low performance (in terms of voice channel capacity) station, it must be restricted to the degree necessary to provide adequate signal to the lowest performance user. If a high performance station is to transmit to a low performance earth station, it will be limited to a transmission with only as many voice channels as the low performance station is capable of receiving. Thus a high performance station might use the total power of a satellite transponder to transmit 10 voice conversations to a low performance station but a transmission to another high performance station could carry (say) 800 voice channels.

This limitation would not be a major concern with an INTELSAT IV spot beam or a dedicated satellite when using earth stations with G/T in excess of 15 db/^{o}K but would be a concern with the INTELSAT IV global beam.

3. Earth Station Performance/ Economic Considerations

The basic major components of the earth station are the antenna/receiver, the multiplexing equipment (which separates the composite multichannel signal into separate voice circuits in the down link receiver and performs the reverse function in the uplink transmitter), uplink transmitter, and general civil engineering. We cannot provide detailed cost figures on these components but it is worth noting some general considerations.

Antenna costs increase with the antenna area and take a step function upward at the point where the area increases by an amount such that its beamwidth (field of view) becomes so small that active or programmed tracking of the satellite is required. INTELSAT IV maintains its position to within $\pm 0.5^{\circ}$, so if the antenna beamwidth is of the order of 2° or so then no tracking should be required. A 2° antenna about 3 meters in diameter would have a G/T of about 16.5 db/$^{\circ}$K with a 200° K system temperature. Such a system would support 200 voice channels when using an INTELSAT IV spot beam with four carriers. With a system using the ANIK satellite which is held to a position variation of $\pm 0.1^{\circ}$, a minimum antenna beamwidth for no tracking is about $.5^{\circ}$ which corresponds to a diameter of about 12 meters and a G/T of 28.5 db/$^{\circ}$K – this system would carry about 580 voice channels.

If one is concerned about a large number of low performance (small antenna) stations, the tracking problem is not an issue, for beamwidth will be so wide that no tracking will be required even with fairly imprecise ($\pm 0.5^{\circ}$) satellite station keeping. With antenna diameters in the 25-35 foot diameter category, the difference between $\pm 0.1^{\circ}$ and $\pm 0.5^{\circ}$ station keeping may well make the difference between tracking and no tracking by the earth stations.

Multiplexer equipment, suitable for use with the conventional multichannel FM used in satellites is estimated to cost of the order of $1000 per channel, with cost increasing nearly linearly with increasing numbers of channels.

Earth stations designed for use with INTELSAT global beams have 85-100 ft antennas and cost $2-4 million. It is our understanding that Telesat thin route stations (28' antennas) cost of the order of $400,000.

Trunk stations for domestic service have been estimated to cost $600,000 - 700,000. It is the author's opinion that the low performance telephone booth station must cost less than $100,000 before a satellite system can be advertised as an adaptable network concept with significant cost or adaptability advantages over microwave relay, or with cost advantages over HF networks now in existence. This will be discussed in the next section where satellite options are considered.

D. Satellite Options

Three satellite communications options which could be considered by the Indonesians are:

1. Purchase, orbit, and operate a dedicated satellite. This would be similar in design and capability to the Canadian ANIK. It would have an earth coverage pattern such that Indonesia, and the Phillipines if desired, could receive the satellite signals. There would be approximately 12 transponders on board, each capable of supporting from 800 to 1000 voice circuits when operating with a full size earth station (G/T = 40 db). Hughes Aircraft has made a study of such a system.

2. Lease a spot beam transponder, on a long term basis, on the Indian Ocean INTELSAT IV. This would amount to the lease of the equivalent of one of the transponders that would be used on a dedicated satellite (above).

3. Lease a global beam transponder on the Indian Ocean INTELSAT IV. The global beam is cheaper than the spot beam by a factor of about two, but its performance, in terms of circuit capacity, when working with small earth stations (20 db G/T) is less than one tenth of that available from the spot.

There is about an order of magnitude step down in traffic capacity for each option, as one moves from option 1 to option 3, assuming the use of relatively small earth stations.

The cost of the three satellite options is best understood with the aid of Fig. 11. This figure shows parametrically the system capital cost for basic elements. The assumptions are as follows:

1. An arbitrary system life of 14 years is chosen for terrestrial components.

2. Dedicated satellite system requires 3 launches, over the 14 years of the system use, at $\$20 \times 10^6$ each launch. An overhead for control station purchase operation and management during that period is estimated at $\$10^7$.

3. The lease cost of an INTELSAT IV spot beam transponder – the case shown – is estimated at $2 \times \$10^6$ per year for the 14 year system life. This 28 million is listed as a capital cost in order to make a comparison with a dedicated system. Cost of a spot beam is estimated to be twice that of the global beam. It is not known if INTELSAT would agree to lease a spot beam, nor is there any certainty that the $\$2 \times 10^6$ figure for a yearly lease could be negotiated. That figure is based upon a recent grant of a $\$1 \times 10^6$ lease of a global beam for domestic use. This lease is preemptible however.

4. For comparison, the cost of a microwave network costing $\$10^4$ per mile with access station spacing of 100 and 50 miles, is also shown.

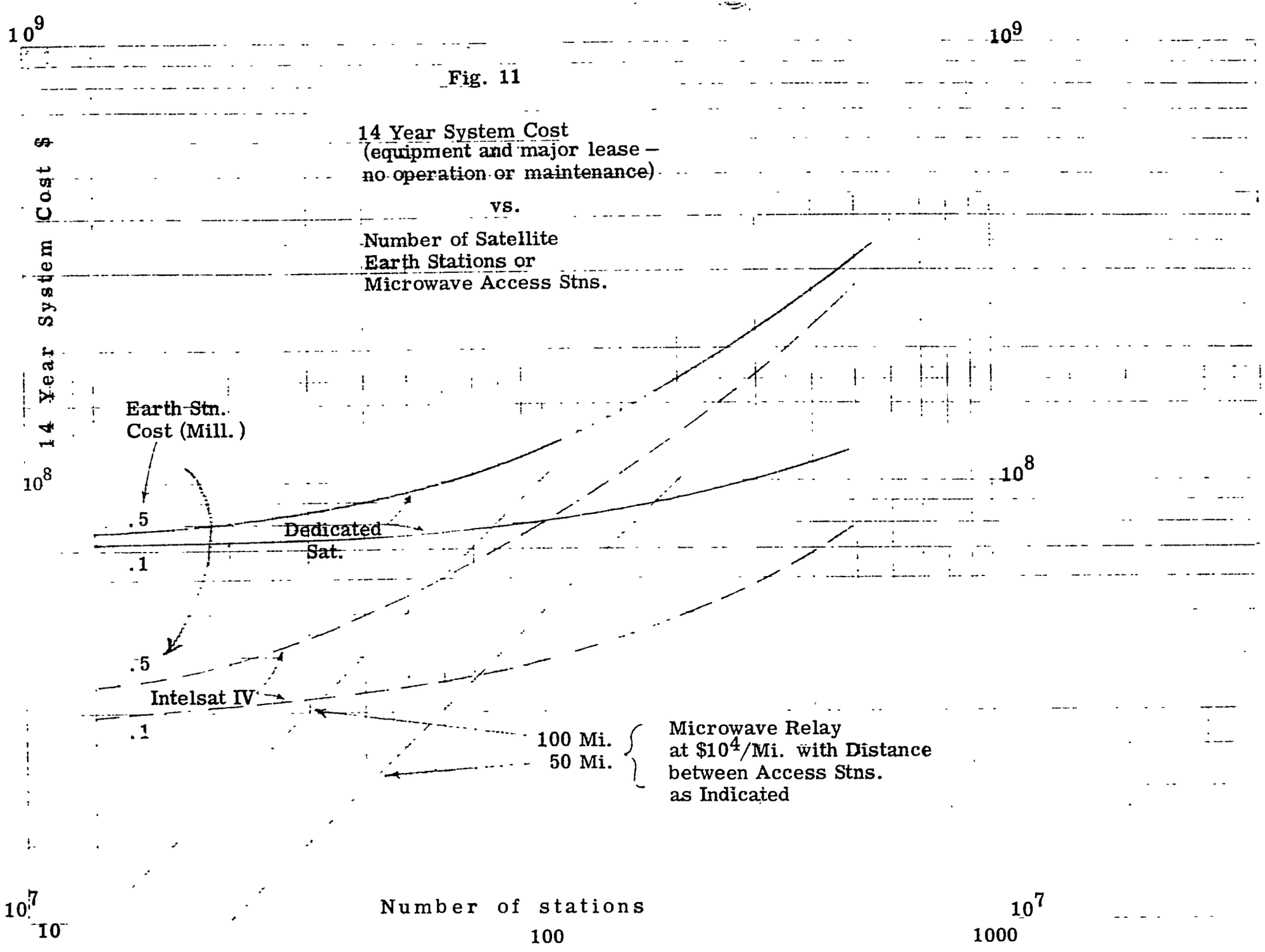
5. It is difficult to imagine more than 5,000 to 10,000 miles of microwave relay in Indonesia, so with the access station spacing shown, there would be a maximum number of access stations of 200.

6. The per mile cost of the microwave relay, $10,000 per mile, is high by U.S. standards and low based on Indonesian experience and projections. (See Table III.)

7. The cost of peripheral equipment, including multiplexers, is assumed to be the same for all systems.

8. Use of a spot beam is implied, but the beam used is important in this graph only insofar as it affects satellite and earth station costs.

Fig. 11


14 Year System Cost
(equipment and major lease –
no operation or maintenance)
vs.
Number of Satellite
Earth Stations or
Microwave Access Stns.
14 Year System Cost $
10^9
10^8
10^7
Earth Stn.
Cost (Mill.)
.5
.1
Dedicated
Sat.
.5
Intelsat IV
.1
100 Mi.
50 Mi.
Microwave Relay
at 10^4/Mi. with Distance
between Access Stns.
as Indicated
Number of stations
10
100
1000

The objective of Fig. 11 is not to provide a comparison of equivalent systems but to give an idea of the order of magnitude of investment required in each case once a determination is made of the circuit capacity and the number of access stations that will be required. The same information is used in Fig. 12 to show the cost per station. Obviously as more and more stations are added to the satellite network, the system cost per station decreases as the cost of the satellite is shared by more stations. The microwave system cost per station is, to a first order, invariant with system length as shown*

The satellite system costs are shown for earth stations costing $100,000 to $500,000. Trunk stations with antennas 35' or so in diameter have in the past been estimated at $600,000 to $800,000 while conventional thin route earth stations have cost $200,000 - $400,000. It is anticipated that increased production and more cost effective designs can bring these costs down significantly.

E. Comparative Discussion of Satellite Options

1. General

The following discussion considers some of the costs and benefits of the stated satellite options

2. INTELSAT IV

INTELSAT IV in its present position of 61° east is just on the horizon when one looks at it from the easternmost border of W. Irian. Figure 13 shows the INTELSAT elevation angle above the horizon as a function of the azimuth of an observer located on the equator. The graph also shows the satellite beam boresight angle from the vertical over this range of earth azimuths. This curve is of no concern for global beam use but it is of interest for the spot beam. The curve shows that if the 4.5^{o} wide spot beam is centered at about 7° from the vertical the beam will cover the region from Banda Aceh to the eastern border of W. Irian. As noted before, the low elevation angle would

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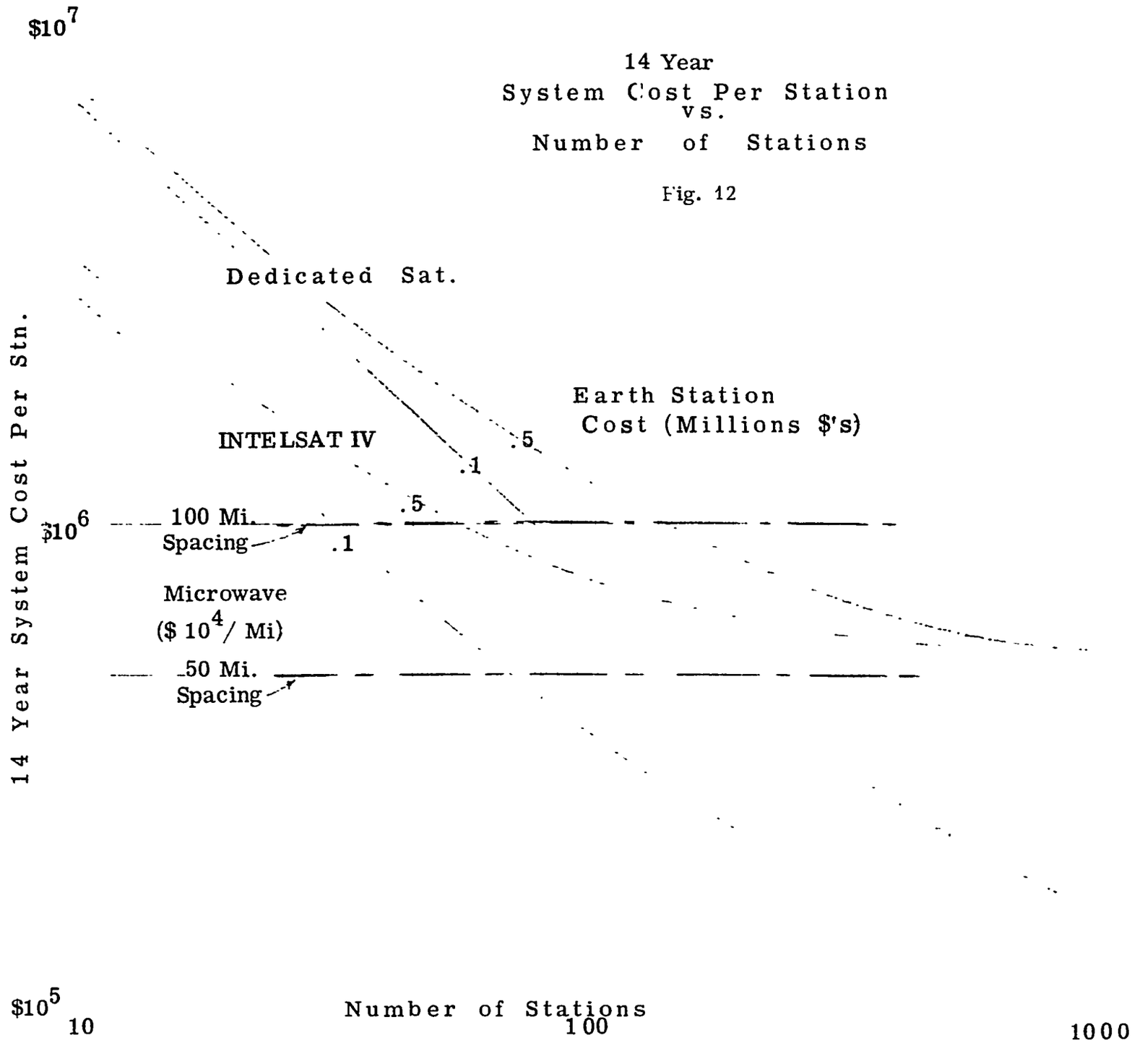
*as in Figure 11, the beam used (spot or global) is of importance only as it affects costs.


$10^7
14 Year
System Cost Per Station
vs.
Number of Stations
Fig. 12
Dedicated Sat.
Earth Station
Cost (Millions $'s)
INTELSAT IV
.5
.1
.5
$10^6
100 Mi.
Spacing
.1
Microwave
($ 10^4/ Mi)
50 Mi.
Spacing
14 Year System Cost Per Stn.
$10^5
10
Number of Stations
100
1000

restrict the utility of the satellite much beyond 130-135° east longitude.

Figure 14 is a map showing the earth coverage of the spot beam of the Indian Ocean INTELSAT IV assuming it remains in its present position of 61° E longitude. The coverage is elongated in the E-W direction because of the low elevation angle. In the north south dimension, the coverage extends for about 1900 miles, enough to include the Philippines if that is desired.

This coverage diagram leads one to consider the possibility that the governments of Indonesia, the Philippines, and Malaysia use the same beam. They could share a transponder, or each could use one or more transponders (there are 4 transponders available for spot beam use on the INTELSAT IV). This possibility is attractive since the INTELSAT IV has only two spot beam positions; it would be desirable, when a beam is committed, to have it used as widely as possible.

The global beam of the INTELSAT IV is unattractive because of its low power and consequent low traffic carrying capacity per transponder when used with low performance earth stations. Though the spot beam may cost twice as much to lease as the global beam, its carrying capacity, when used with the small stations we would expect to proliferate, is a factor of ten over the global beam.

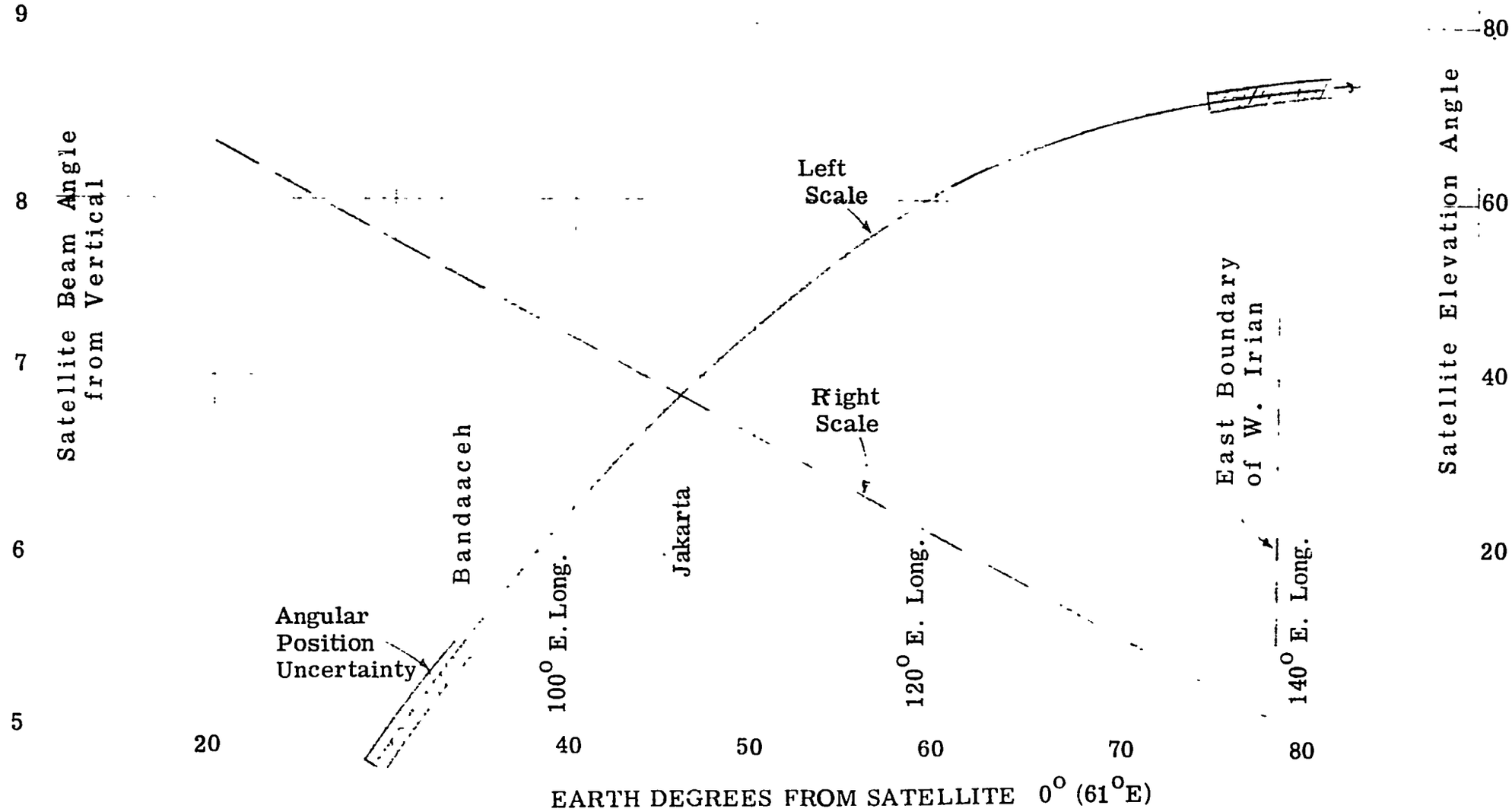
The lease cost per voice channel per year, based on a $\$2 \times 10^6$ yearly lease cost and a 300 voice circuit per transponder capacity, is $\frac{\$2 \times 10^6}{300} = \$6670$. This figure assumes that all channels are fully utilized, an unlikely circumstance.

3. Domestic Satellite

A domestic satellite similar to ANIK is attractive in that it would cover all of Indonesia, the Philippines and Malaysia if desired, with no horizon restrictions since it would be directly overhead. Circuit capacity would be 10 times that of a single INTELSAT IV transponder. One or more nationwide TV channels would be assured.

Fig. 13

INTELSAT IV ELEVATION ANGLE



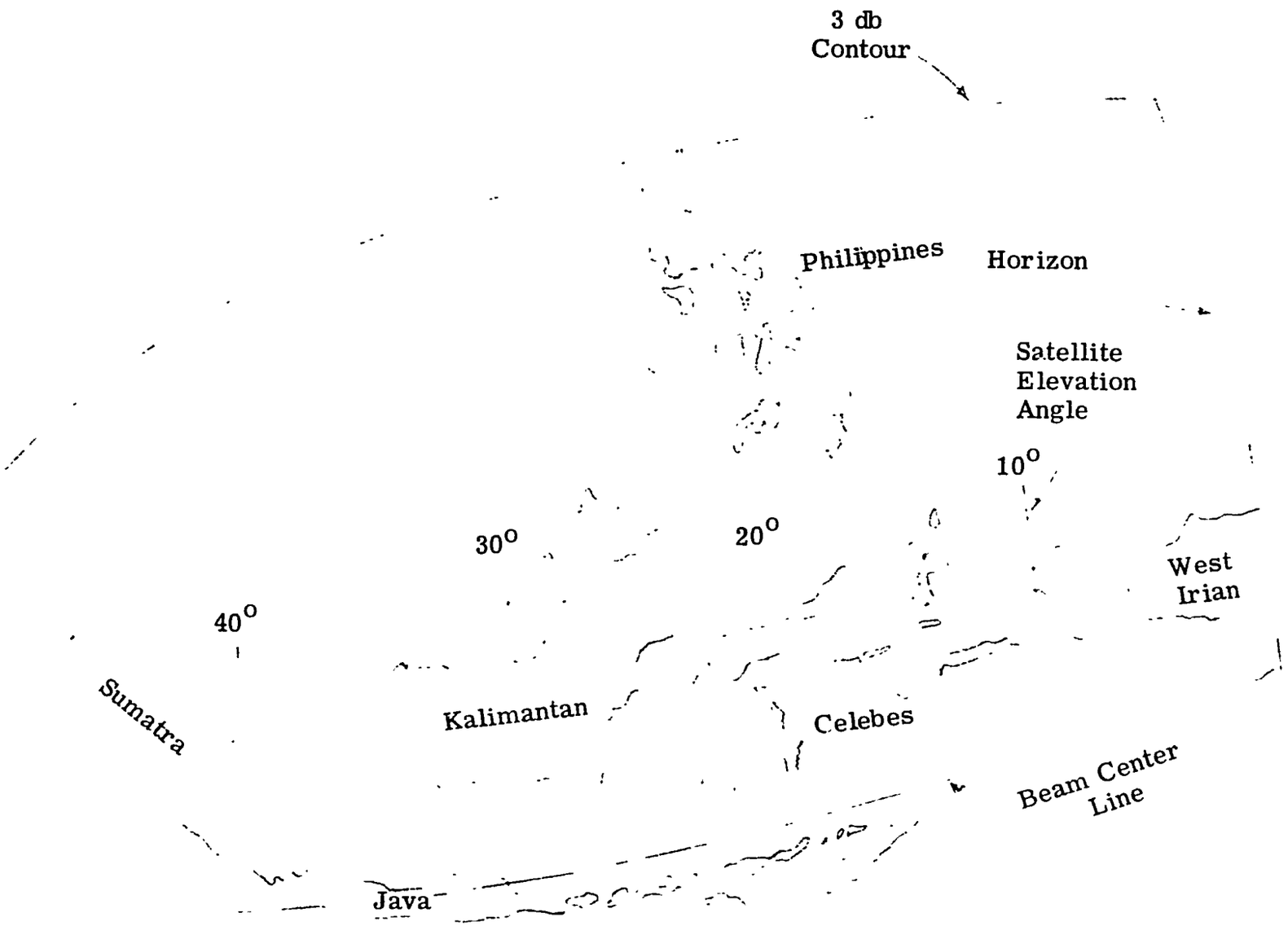


Fig. 14 Indian Ocean INTELSAT IV Spot Beam Coverage

Unfortunately capital costs are high. Over a 14 year period one would expect to make 3 launches at a cost for each of the order of \$20 million each for a total of \$60 million. General system management and satellite station keeping/monitoring will probably add another \$10 million (including the \$4 million master station). Earth station costs excluding the master station, should not be significantly different from those used with the INTELSAT IV spot beam. The cost per circuit-year (satellite only) based on 10 active, 300 circuit, transponders and a 14 year life (3 launches) is $\frac{70 \times 10^6}{10 \times 300 \times 14}$ = \$1670 exclusive of interest charges. These charges are unknown to us since neither the schedule of capital outlay or the interest rates are determined.

4. Cost Comparison Between Dedicated and INTELSAT IV Satellites

A comparison between a dedicated satellite and INTELSAT IV may be made on the basis of satellite cost per voice channel. Using our assumption that an INTELSAT IV spot beam costs $\$2 \times 10^6$ /year and that the 14 year cost of a domestic satellite is $\$70 \times 10^6$ (3 launches plus master station and operational expenses) one can generate the graph of Fig. 15. With INTELSAT IV, the cost per voice channel decreases until a transponder is fully occupied. It then takes a step function upward as the next transponder is leased to meet anticipated domestic traffic. The exact form of the graph is dependent on the assumed number of voice channels per transponder.

The cost per voice channel in the dedicated satellite decreases steadily with increasing traffic until the traffic limit of the satellite is reached. This limit is assumed to be 1000 voice channels if there are 100 channels per transponder and 3000 if there can be 300 channels per transponder.

The graph shows the situation for 100 channels and 300 channels. If 100 channels per transponder is achievable, then the domestic satellite

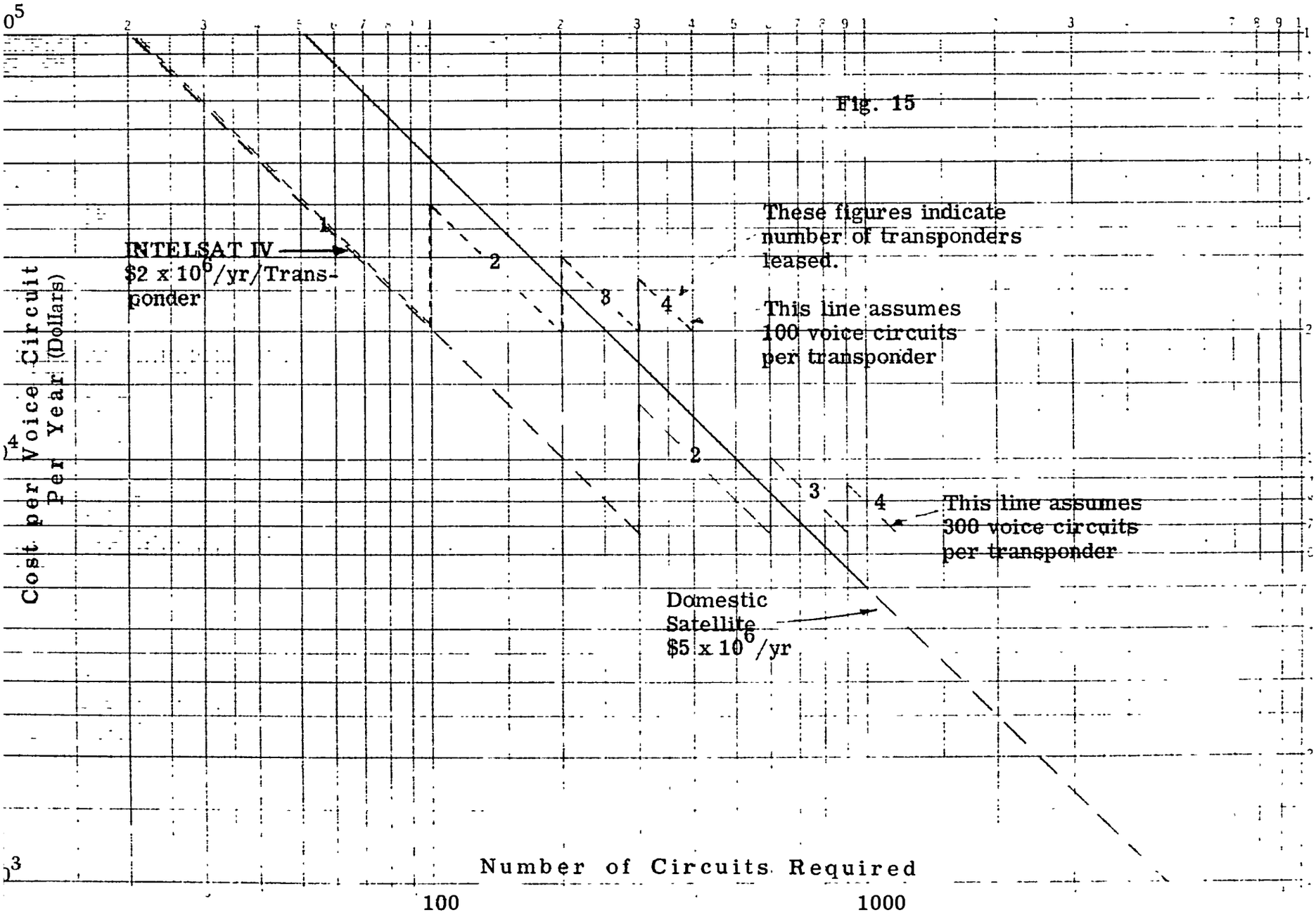


Fig. 15
These figures indicate number of transponders leased.
INTELSAT IV
$2 x 10^6/yr/Transponder
This line assumes 100 voice circuits per transponder
This line assumes 300 voice circuits per transponder
Domestic Satellite
$5 x 10^6/yr
Cost per Voice Circuit Per Year (Dollars)
Number of Circuits Required
100
1000

is cheaper than the INTELSAT IV if more than 200 circuits are required. With 300 channels per transponder, the domestic satellite is cheaper on a per channel basis when more than 600 channels are required. Since we can only speculate on INTELSAT charges over the next 14 years, this graph should be taken as illustrative rather than definitive. Further, interest charges could raise the domestic channel costs by 30-40% thus pushing the crossover point out to a higher number of channels.

Cost for a television channel for one year is simply the transponder cost in the INTELSAT IV case, or according to our estimate, 2×10^6. For a domestic satellite, using our cost estimates, one expects that the allocated cost per channel is 0.5×10^6/year for either telecommunications or television use. This figure is simply the estimated cost of the satellite per year divided by the number of usable channels ($5.0 \times 10^6/10$).

There is of course no assurance that one or more INTELSAT IV spot beams will be available to Indonesia.

VI. Summary/Conclusions

The development and implementation of a telecommunications network in a lesser developed country requires a substantial amount of speculation since growth patterns cannot be predicted with high accuracy. In Indonesia, these uncertainties coupled with difficult geography lead us to suggest serious consideration of the use of a satellite communications system designed in a manner to minimize growth problems and to provide a maximum of flexibility in serving a wide range of earth stations.

Such a system could be initiated with the lease of an INTELSAT IV spot beam transponder, assuming no legal or political obstacles to such a lease. The spot beam is to be preferred over the global beam because of its greater initial circuit capacity and because a later switch to a domestic satellite could

be made without changing earth station parameters or performance (only the antenna needs repositioning).

The INTELSAT global beam transponder could be considered for initial use if there were no concern with the implementation of small "telephone booth" stations for isolated industry use. The low power of the global beam makes these small stations unduly expensive. The satellite system, started with INTELSAT IV, can at a later date make use of a second INTELSAT IV transponder for TV distribution. As a system use increases, or as more users request service, the shift to a dedicated satellite can be made without transients. The high capital investment in a domestic satellite does not have to be carried during the initial phases of the system implementation when traffic will be light.

It is our opinion that any satellite system which does not provide for inexpensive (less than $100,000) earth stations will not satisfy one of the basic needs in Indonesia, that is communication to and from remote industrial locations.

If a satellite is leased or bought for use in Indonesia then educational broadcasts, both radio and TV, could be made through that medium. However, available radio and TV network is now not used to any extent for educational purposes. If there were a belief that radio or TV broadcasts would be valuable to the educational system then they could be broadcast at very low marginal cost increase, through existing systems. If the need exists but software and systems planning difficulties are inhibiting ETV and educational radio then the first area of development should be in programming, not in hardware.

Acknowledgement

The author acknowledges with thanks the generous assistance given by the many persons in Jakarta and Singapore whose names and addresses are listed in the Appendix.

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