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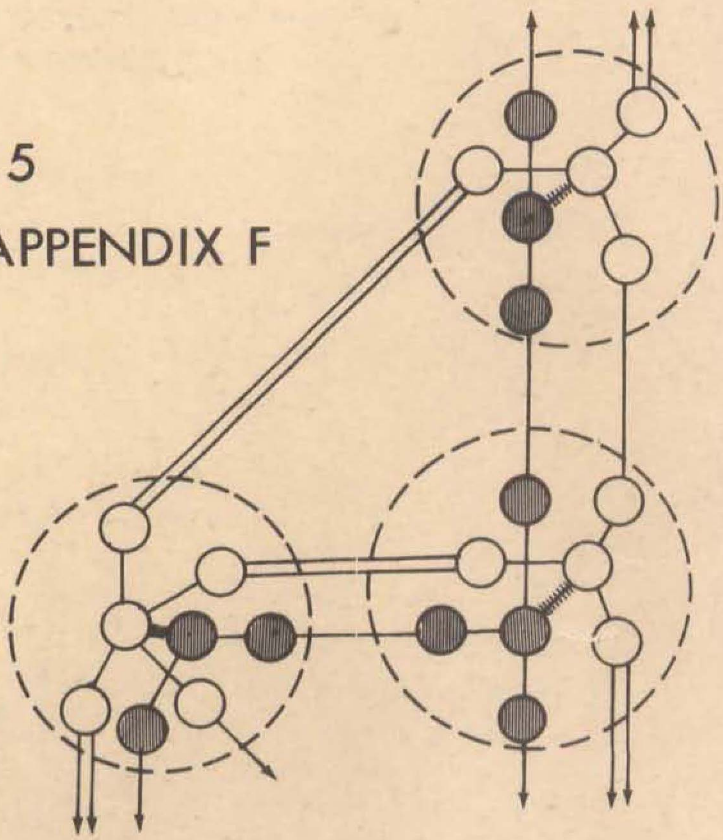
Communications Research Centre

DOMESTIC LONG DISTANCE COMMUNICATIONS NETWORK STUDY

VOLUME 5

APPENDIX E AND APPENDIX F



CRC REPORT NO. 1274-5

Department of [illegible]ons
Ministère des Communications

OTTAWA, SEPTEMBER 1975

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COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS
CANADA

DOMESTIC LONG DISTANCE COMMUNICATIONS NETWORK STUDY
VOLUME 5 – APPENDIX E AND APPENDIX F

by

Communications Systems Research and Development Staff

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(Technology and Systems Branch)

CRC REPORT NO. 1274-5

September 1975
OTTAWA

NOTE

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THE PROJECT TEAM

Rather than attributing authorship of the component parts of this report we have chosen to describe the roles of the various people who have contributed to the project as well as to the writing of the report. Three people have been part of the project from start to finish and have contributed to almost every part of it: Dr. A.R. Kaye (Project Leader), Dr. R.R. Bowen and Dr. G.A. Neufeld. Dr. T.A.J. Keefer was solely responsible for the forecasting of voice circuit requirements. E.A. Walker and R.L. Hutchison contributed to the development of the terrestrial network model and J.L. Thomas to the satellite models. R.V. Baser and P.R. Whalen did a great deal of the computer programming and production work involved in the study.

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APPENDIX E

THE SENSITIVITY OF THE DLDCNS RESULTS TO THE ESTIMATED PARAMETERS

E.1 INTRODUCTION

This appendix deals with the sensitivity analyses that were carried out as part of the study to determine if the results would significantly change when the assumptions and estimated parameters were varied. The effects of variation in the traffic forecasts, method of costing (average versus marginal costing for the satellites), variation in the discount rate, and variation in the criteria for network survivability were discussed in Chapers 4 and 5 of the Full Report (Volume 2). Here we discuss other assumptions and estimated parameters whose variation might be expected to change the results of this study but which, upon further study and analysis, were found to have no significant effect on the results reported in Volume 2. However it is not obvious why their variation has no effect and hence explanation is required. The purpose of this Appendix is to document the variations we made and to explain why they do not change the results.

E.2 DIVISION OF TRAFFIC BETWEEN THE CARRIERS

We assumed that the present situation with respect to competition in the long-distance network will persist into the future without substantial change. As stated in Chapter 3 of the main report (Volume 2), the networks of TCTS and CNCP were thus assumed to develop separately with a division of traffic essentially as at present. Telesat Canada was assumed to act as a carrier's carrier; either TCTS or CNCP traffic or both could be routed by satellite wherever it was cost-effective to do so. In order to study such a scenario, it was necessary to make some assumptions regarding the portions of the total long-distance traffic which would be carried by the two primary carriers. The result of this assumption was a division according to the following table:

[redacted]

Message Traffic (including private line, telex, and data)	84% TCTS	16% CNCP
CBC TV circuits	TCTS	
All other TV		CNCP

We needed to determine if a different division of traffic would alter the results of the study.

First, consider the division of TV traffic between TCTS and CNCP. Television traffic falls into that category of traffic which, although it is designated as TCTS or CNCP traffic, is more cost-effective to carry by satellite. This result holds regardless of how the TV traffic is divided between TCTS and CNCP. In fact, we found that if the cost of the satellite were as much as three times its assumed cost, it would still be more cost-effective to route TV traffic on the satellite. Thus, the results of the study are not dependent upon the division of TV traffic between TCTS and CNCP.

Next consider the division of message traffic between TCTS and CNCP. We found that variations as to how the message traffic was divided had no real effect on how the national communications network will evolve insofar as long-term transmission facilities are concerned. We initially assumed a division of message traffic that allocated 84% to TCTS and the remaining 16% to CNCP. We then allocated both more and less message traffic to TCTS. For example, when we allocated 90% of the message traffic to TCTS and the remaining 10% to CNCP, the effect was to advance the date at which some of the TCTS systems filled to their ultimate capacity by one to perhaps two years. The reverse effect on CNCP was observed, and there was no change in the satellite system requirements before these saturation dates. For the carriers, it is the type of change to which they would adapt their short term plans as the change occurred, should it ever occur. Furthermore, this is rather insignificant when we take into consideration the uncertainty in the traffic forecasts themselves, a topic that is fully discussed in Chapter 4, Vol. 2 of this report. Any change in the rate of growth of the traffic is at least as significant as any change in the percentage of total traffic carried jointly by TCTS and CNCP.

[redacted]

E.3 ALLOCATION OF COSTS TO LOCAL AND LONG-DISTANCE TRAFFIC ON EXISTING MICROWAVE SYSTEMS

Much of the equipment in the existing TCTS microwave radio trunk systems is shared by local and long-distance traffic. The equipment that is shared (the towers, buildings, land, access roads) has a fixed cost that is independent of how much traffic the system carries. We distributed these fixed costs according to the percentage of long-distance traffic compared to the total traffic on each link in the network. We found that all the existing systems will continue to be used because they are cost-effective and are necessary to provide a network that is adequately protected to ensure a reliable service. However, we also found, that the results of the study do not depend on how these fixed costs are divided between local and long-distance traffic. The explanation is as follows.

Let us consider the case where all the fixed costs are allocated to local traffic. The cost-effectiveness of the existing systems for long-distance traffic is then determined only on the basis of the incremental costs. But this is really no different than how we obtained our initial results because, although we included a fixed cost, we found that all existing systems would continue to be used either for network protection or because they are cost-effective. Hence we effectively determined where the traffic would be routed only on the basis of the incremental costs, which are independent of how small the proportion of the fixed costs that are allocated to long-distance traffic.

Now consider the other case where all the fixed costs are allocated to the long-distance traffic. From our analysis, we found that although the electronic equipment may be updated or even replaced, the existing microwave systems will continue to be used because they provide the most cost-effective alternative and are necessary to provide an adequately protected network. Thus our results are not dependent upon the distribution of fixed costs, of the existing microwave systems, between local and long-distance traffic.

E.4 SHUTTLE AND TUG TECHNOLOGY

Although there is some uncertainty about the development of the shuttle and tug, it is a major new development in satellite technology which may significantly reduce satellite system costs in the next 10-15 years. This technology will not be available for satellites that TELESAT launches immediately following the present ANIK series, but may become available for satellites launched after that, that is, after 1985 (see section C.5.2 of Appendix C). The shuttle and tug technology could

[redacted]

reduce the cost of satellites significantly. We analyzed what would be the effect of a significant reduction in satellite costs. We found that it does not imply an increase in satellite capacity for long-distance communications traffic. As discussed in Volume 2, by the late 1980's the amount of voice traffic through the satellite system will already be limited by network reliability in a minimum-cost network. A further increase in the proportion of message traffic routed on the satellite would lower the level of network protection. Thus the effect that the lower cost of satellites using shuttle and tug technology would have is to remove any possible doubt as to the cost-effectiveness of routing message traffic via satellite, as suggested by this study. It would not increase the amount of message traffic routed through the satellite. Hence the results of this study are not dependent upon the possible introduction of shuttle and tug technology, except to reduce the overall cost of the network.

In the network scanario in which the present institutional arrangements continue between the carriers, no significant amounts of voice traffic are expected through the satellite system in the early 1980's (see section 5.1 and Chapter 4 of the main report). However, in the late 1980's or early 1990's, when the long-haul 4 GHz, 6 GHz and 8 GHz systems saturate, it is expected that the satellite system would be used extensively for voice traffic. Lower satellite costs brought about by shuttle-tug technology would make the satellite system an even more attractive alternative to construction of one or more new trans-Canada 12 GHz terrestrial digital radio systems.

E.5 ALLOCATION OF RADIO SPECTRUM

The radio spectrum is an important resource for communications. The main assumption that we made regarding the future availability of spectrum is that a 500 MHz wide band in the 8 GHz range will be available for medium capacity digital terrestrial radio transmission for TCTS. We found that this band at 8 GHz along with the presently allocated spectrum in the 4 GHz range is adequate for long-distance transmission on terrestrial systems well into the 1990's.

We investigated the implication of spectrum at 8 GHz not being available for long-distance digital transmission for TCTS. The following are other alternatives, none of which are as economically or technologically attractive as using the 8 GHz for long-distance digital terrestrial transmission.

i) Use of 4 GHz - the use of 4 GHz is not as attractive for digital transmission as the 8 GHz band. The 4 GHz band is already used for analogue transmission, so there would be additional costs and technological transition problems associated with changing the existing analogue circuits over to digital circuits. The 4 GHz band is also unattractive so long as only one polarization can be used at 4 GHz because of fading compared to use of dual polarization at 8 GHz. Neither the need to restrict the use of a digital 4 GHz system to single polarization, nor the actual testing of a dually polarized system at 8 GHz, has been shown to the authors' knowledge. However, because the necessary Fresnel zone clearance at 8 GHz is only 70% of that at 4 GHz, and because the infrastructure being used was designed for a single-polarization analog 4 GHz system, it is tentatively assumed that dual polarization is possible at 8 GHz but not at 4 GHz. The result is that a 4 GHz system has effectively only 70% of the spectrum available at 8 GHz. To arrive at the 70% figure, we assume a 700 MHz wide band at 4 GHz and a 500 MHz wide band at 8 GHz. Using dual polarization, there is effectively a 1000 MHz wide band available at 8 GHz compared to only 700 MHz at 4 GHz. If from this one subtracts the system capacity that would be used by long-distance traffic presently routed through the 4 GHz system, the capacity for new traffic on the 4 GHz system is no more than half that of the 8 GHz system.

ii) Use of 12 GHz - It would be feasible for TCTS to install a 12 GHz digital radio system across Canada if the required spectrum were made available to TCTS. However the installation of a 12 GHz system would be significantly more expensive than an 8 GHz system. The reason is that whereas an 8 GHz digital radio system is an 'add-on' to the existing TCTS 4 GHz radio system in that it uses the same microwave towers, a 12 GHz system would require a completely new set of towers, land sites, and access roads. This would require a large capital expenditure. Furthermore, a 12 GHz digital network that was adequately protected would require a second and parallel 12 GHz system, or the network would need to make heavy use of the satellite for message traffic, the latter alternative being more cost-effective. However, even using a single 12 GHz digital radio system, together with heavy use of the satellite for message traffic, is significantly more expensive than installing a dual 8 GHz digital system and not using the satellite at all for message traffic (use the satellite only for TV and northern requirements). As discussed in Vol. 2, using dual 8 GHz digital radio systems together with the satellite for message traffic is slightly more cost-effective than using only the dual 8 GHz digital radio systems for message traffic. The capital cost of installing the first radio channel on each of two 8 GHz digital systems across the country is estimated to be a total of $31M for the two systems (using a distance of 3000 miles at a cost of $5.2K per mile - multiplied by 2 to take into account dual systems). The capital cost of installing the first radio channel on a single 12 GHz digital system is estimated to be $109M (using a distance of 3000 miles at a cost of $36.3K per mile). In order to have an adequately protected network, the overall network using the 12 GHz system would further incur the cost of a second 12 GHz system or the additional cost in the satellite system to facilitate heavy use for message traffic. But even without this additional cost for network protection, the above costs demonstrate that using even a single 12 GHz system is far more expensive than using dual 8 GHz systems that would provide an adequately protected network, and that would provide adequate transmission facilities well into the 1990's, as discussed in Volume 2. There is one notable exception, and that is within the Toronto-Montreal corridor, where 12 GHz digital systems may be required sooner. However this is a relatively short distance, does not involve the satellite, and is independent of the remainder of the network.

E.6 SENSITIVITY TO THE ESTIMATED COSTS OF TERRESTRIAL AND SATELLITE SYSTEMS

The purpose of this section is to show how the results presented in Volume 2 depend upon variations in the estimated costs of terrestrial and satellite systems. As discussed in Volume 2, the results show that it is significantly more cost effective to route television traffic by satellite than by terrestrial systems. We found that satellite costs could be increased by a factor of three over the costs described in Volume 2 and that it would still be more cost effective to route television via satellite. Hence we may concentrate on the sensitivity of routing message traffic on the satellite to variations in satellite and terrestrial system costs.

Any decrease in satellite costs or increase in terrestrial system costs implies that the satellite would attract even more message traffic than in those scenarios described in Volume 2 where message traffic is routed through the satellite on the basis of marginal costing. However, as discussed in Volume 2, the amount of message traffic carried on the satellite in these scenarios is already limited by the necessity for network protection. Thus any decrease in satellite costs or increase in terrestrial system costs does not increase the amount of message traffic routed via satellite beyond the amount discussed within the scenarios discussed in Volume 2.

We next considered what happens when we increase the satellite costs or decrease the terrestrial system costs. Both these variations imply that the satellite becomes less cost effective for message traffic. A decrease in the cost of terrestrial systems could be due either to improvements in technology or due to allocating less of the metropolitan junction plan costs to long distance traffic, and thereby allocating more of the metropolitan junction plan costs to local traffic. In either case, the effect of any such change is to reduce the advantage of routing message traffic in southern Canada via satellite. Furthermore, the effect is to reduce the present value of the saving made by using the larger satellite systems for southern message traffic in the scenarios discussed in Volume 2. To illustrate, we compared the annual costs of the network scenarios given in Tables 4.14 and 4.15 (Volume 2) with the annual costs of the same scenarios but with the satellite system cost increased by 10% and, at the same time, the terrestrial system costs decreased by 10%. Tables E.1 and E.2 correspond to Tables 4.14 and 4.15 respectively and show the effect of these changes in costs when compared to Tables 4.14 and 4.15. Comparing Tables E.1 and E.2 with Tables 4.14 and 4.15 shows that the change in satellite and terrestrial system costs reduces the advantage (in cost savings) of routing southern message traffic on the satellite. There are however two important points that must be emphasized here. The first point is that we must remember this comparison assumes the terrestrial network uses an 8 GHz digital radio system which is an add-on system to the existing microwave radio system. If a completely new coast-to-coast structure is being considered for the terrestrial network (such as for a 12 GHz digital radio system), then the satellite is definitely cost effective for southern message traffic. The second point is that there is a link in the Canadian network where the satellite should be used for southern message traffic regardless of relative cost to ensure an adequately protected network. Newfoundland should be connected to either Montreal or Toronto by satellite because there is presently only a single terrestrial system connecting St. John's to the rest of Canada.

E.7 DEPENDENCE OF VOICE CIRCUIT ROUTING ON THE COST OF SOURCE-ENCODING EQUIPMENT FOR VOICE SIGNALS

In Section 4 of Volume 2 it was shown that it is cost-effective to use the satellite system rather than the 8 GHz digital radio add-on system for traffic increases in the 1980's between Vancouver, Calgary or Edmonton in the west and Toronto or

Table E.1

Cost of Networks to Meet Requirements of 1985
Preferred Forecast with Satellite System Costs
Increased 10% and Terrestrial System Costs Decreased 10%
(Compare With Table 4.14)

Voice Traffic Through Satellite	Satellite System	Network Annual Costs in 1985, Millions of 1973 Dollars		
		Satellite System	Terrestrial Network	Total Network
50%	Single Augmented RCA	28.2	36.8	65.0
50%	Dual Augmented Anik	29.4	36.8	66.2
33 1/3%	Single RCA-Type	26.8	38.6	65.4
33 1/3%	Dual Anik	28.9	38.6	67.5
0%	Single Augmented Anik	20.4	45.2	65.6

Table E.2

Cost of Networks To Meet Requirements of 1990
Preferred Forecast With Satellite System Costs
Increased 10% and Terrestrial System Costs Decreased 10%
(Compare With Table 4.15)

Voice Traffic Through Satellite	Satellite System	Network Annual Costs in 1990, Million of 1973 Dollars		
		Satellite System	Terrestrial Network	Total
50%	Single Hybrid	37.2	56.9	94.1
50%	Dual RCA-Type	38.1	56.6	94.7
33 1/3%	Single	34.8	60.6	92.7
33 1/3%	Dual Anik	32.1	63.2	95.3
0%	Single RCA-Type	28.1	69.4	97.5

Montreal in the east. That analysis was based on the assumption that SPEC source-encoding equipment or its equivalent would be used on either a satellite link or a terrestrial link, and on the available information in 1974 that the installed cost of SPEC equipment would be about $200 per voice-circuit-end. However, information which became available later indicated that this cost would likely be about $400 (1973 dollars) per voice-circuit-end, and may be as great as $700 (see Section D.4.2, Vol. 4). Because of this large variance in the estimate of the cost of SPEC equipment it is important that we determine the sensitivity of the results to variation in the cost of SPEC equipment.

Before we address that problem directly, let us determine under what conditions SPEC equipment would be used as part of either a terrestrial or a satellite system, other costs remaining unchanged. This is important to establish, because the results in Chapter 4 of the main report, Vol. 2, are valid for any SPEC costs that are attractive in either a satellite or a terrestrial system, since in that situation they are a common cost to either system and so do not enter into a choice between potential systems.

Consider first a terrestrial system. Suppose that x is the capital cost per voice-circuit-end of SPEC equipment, y is the incremental capital cost per route-mile without the addition of SPEC equipment, and N is the number of route-miles of the proposed link. (Capital costs can be compared here, because we are considering two possible additions to the electronic portion of a system at a given time). Since capacity is doubled by the use of SPEC or its equivalent, SPEC would be used whenever

$$4x < Ny \qquad \text{(E.1)}$$

or

$$x < \frac{y}{4} N \qquad \text{(E.2)}$$

Since the incremental capital cost of digital radio systems is about $1.60 per voice-circuit-mile, (see Table B.4.8), SPEC should be used whenever

$$x < \frac{1.6NN}{4} = 0.4N \qquad \text{(E.3)}$$

It is now necessary to consider a specific route to determine N, so let us consider the Edmonton-Toronto route, the shortest of the above mentioned high-capacity end-to-end routes that may use the satellite system. For this route N ≃ 1720 miles if one ignores the metropolitan junctions. In that case SPEC would be used whenever x, the capital cost per voice-circuit-end, is less than $688 or approximately $700. Since this is the upper bound on the estimate of the capital cost of SPEC, an "early" cost with low volume of sales, it can be assumed that SPEC would be used on the above-mentioned long-haul terrestrial links.

[redacted]

Let us now examine the use of SPEC in a satellite system. Suppose that x is the cost of SPEC per voice-circuit-end, y is the cost of the space portion of a satellite voice circuit without the use of SPEC, and z is the annual cost per voice circuit of that portion of a ground station and backhaul system which requires only half the capacity when SPEC is used. In such a system SPEC is used whenever

$$4x < y + 2z \tag{E.4}$$

or

$$x < \frac{y}{4} + \frac{z}{2} \tag{E.5}$$

The annual incremental cost of a satellite system which does not use SPEC, y, is about $800, twice the $400 costs shown in Chapter 4, Vol. 2. As shown in Vol. 4, Appendix D, z ≃ $140, and so, from (E.5), SPEC is used when its annual cost per voice-circuit-end is less than about $270, or capital cost less than about $1,000. As indicated in Section D.4.2, it is very likely that the cost of SPEC will be less than this value, and so it will be extensively used in a satellite system towards the end of that system's operational life, as the system becomes saturated without the use of SPEC.

Thus we have shown that it is cost-effective to use a system such as SPEC in either a satellite or a terrestrial system over the complete range of its cost estimates, and so the results presented in Chapter 4 of Volume 2 and in Volume 1 are valid for any anticipated variation in SPEC cost.

[redacted]

*   *   *

APPENDIX F

COST-MINIMIZING NETWORK SYNTHESIS TECHNIQUES

F.1 INTRODUCTION

In this appendix the methodology used to optimize the network in the Domestic Long-Distance Communications Network Study (DLDCNS) is described. Development of the optimization methodology was continuously improved throughout the study, and is itself a significant by-product of the study. The purpose of this appendix is to indicate how the various network synthesis techniques developed during the study were combined to form the present technique.

F.2 AN OVERVIEW OF THE SYNTHESIS TECHNIQUE USED

In order to synthesize a cost-effective Canadian satellite/terrestrial network for the 1980's, the following steps are necessary:

i) A description of what is meant by an optimum network is specified. This description must be or lead to a quantitative measure by which networks can be compared.

ii) A description of the existing network is determined. This description must:

a) describe the network as it is in 1973.

b) be "expandable" as far as 1990, in that subsystems that may be introduced into the network in the 1980's can become part of the model.

c) specify the capabilities and the relevant costs of each system in the network,

d) be complex enough to accurately model the essential features of the network, and yet simple enough that different expansion options may be easily chosen and evaluated.

iii) A description of the most likely traffic loads on the network, and the upper and lower bounds on that traffic estimate, must be made. This traffic includes:

a) heavy-route long-haul voice, data, and leased-line requirements in southern Canada, both interprovincial and intraprovincial;

b) television distribution by the networks such as CBC, CTV and Global TV, and by the cable TV companies and education departments of the provincial governments.

c) thin-route telephone and data service to remote communities.

iv) A synthesis procedure for network expansion must be developed. A necessary part of this procedure is an algorithm for routing traffic through a constrained network at minimum cost. As well, however, it is necessary to develop strategies to determine what network options to investigate and to consider the large number of possible satellite systems in an organized way.

Each of these four areas of activity are discussed in detail below.

F.3 THE MEASURE USED TO COMPARE FEASIBLE NETWORKS

The basic objective of the DLDCNS is to determine the expansion of the long-distance network which would be of greatest national benefit in the long term. This is interpreted to mean expansion of the network to meet predicted traffic requirements in the 1980-1985 time-frame at minimum cost to the nation, with some consideration of how the network might expand in the post-1985 time-frame.

Essentially, the approach used to compare alternate network expansions is to:

i) ignore all costs that were incurred prior to 1980, since these costs cannot be recovered by changing the network in the 1980's. (Salvage of large microwave systems for sale elsewhere has never been done to date in North America to the author's knowledge. DND has sold mid-Canada system communication links to TCTS, but they are used in place.)

ii) of the costs after 1980, consider only amortization, refurbishment, maintenance, and operations costs, and ignore corporation profit and income tax "costs"

The costs considered are only those real costs that may change by a re-design of the network. Further, the costs are only costs to the nation as a whole. Items such as profit and taxes are simply a redistribution of wealth within the country. Transfer payments of this type are not normally included in Federal government cost-effectiveness studies.

Having specified what costs are to be considered, the next step is to determine in general terms the method used to determine the optimum system. The "optimum" system is that which meets the traffic requirements, signal quality requirements, and network protection requirements, at minimum cost. The cost that is minimized is the present value (in 1980) of the amortization, refurbishment, maintenance, and operations costs in the 1980-87 time-frame. Consideration was also given to making this system compatible with the network in the 1973-1980 time-frame and post-1987 period. This was done in the following way:

Step 1: Determine the annual costs of existing and new radio, cable, waveguide, and satellite systems as a function of installed circuit capacity. (This will be discussed in more detail below.)

Step 2: Determine the minimum cost network for each of the "spot" times 1980, 1985, and 1990. (This was done with the optimum routing algorithm and the demand-cost strategy, as explained below.)

Step 3: If these three "spot optimum" networks are not compatible, in that major systems are in an earlier network and not in a later one, or if the satellites in the different networks are not the same, then the "spot optimum" networks are modified so that they are compatible and the present value in 1980 of their costs is minimized.

F.4 PREDICTED END-TO-END CIRCUIT REQUIREMENTS ON THE LONG-HAUL NETWORK

The raw information on which network requirements in the 1980's must be based are voice and data requirements prior to 1973, population growth and economic growth forecasts for the 1973-1990 interval, predictions of the end-to-end circuit requirements of the common carriers for the 1973 to 1980 interval, and stated requirements of the television networks in the 1980's. Interprovincial and intraprovincial public switched voice, total voice circuit end-to-end and television distribution requirements have been described in Appendix A.

It is assumed that these requirements are exogenous variables, i.e. they are independent of transmission costs. One reason for making this assumption is that long-haul transmission rates are determined by many factors, only one of which is transmission costs.

F.5 MODEL OF THE LONG-HAUL COMMUNICATION NETWORK

At present, the long-haul heavy-route communication network in Canada consists of two 4 GHz radio systems owned by the members of TCTS, a 6 GHz radio system owned by CN/CP, and the Anik 4/6 GHz satellite system owned by Telesat Canada. In almost all cases these systems are operating far below their ultimate capacity of 16,800 full-duplex voice circuits on the 4 GHz systems and 10,800 voice circuits on the 6 GHz system. These ultimate capacities may be further increased as new electronic equipment becomes available. Some of these improvements are described in Appendix B.

The terrestrial systems include hundreds of radio repeater sites. Rather than include each of these locations as nodes in the long-haul network model, only nodes which are one or more of:

i) major population centres and so a source of significant long-haul telephone traffic,

ii) a regional distribution centre for CBC television programs, or

iii) an important network branch point,

are included. The simplified network includes 20 nodes and 26 connecting lines, as shown in Figs. F.1 and F.2. The reason for including the nodes in the network are shown in Fig. F.1. Four nodes in Quebec and the Maritimes are not traffic sources, but are included because they are major branch points. Several of the links of Fig. F.1 have several systems in parallel, as shown in Fig. F.2.

The nodes shown in Figure F.1 and F.2 are not single repeater sites; some metropolitan nodes cover hundreds of square miles and include as many as ten junction repeaters and switching centres. These complex nodes have been replaced by star nodes, with one branch of the star going to each other major node that is directly connected to the node being represented. Separate star representations are used to model the TCTS and the CN/CP networks. The now rather artificial network is partly shown in Fig. F.3. This network model is developed to allow various network expansion options to be investigated, rather than to accurately represent the network in the field node by node.

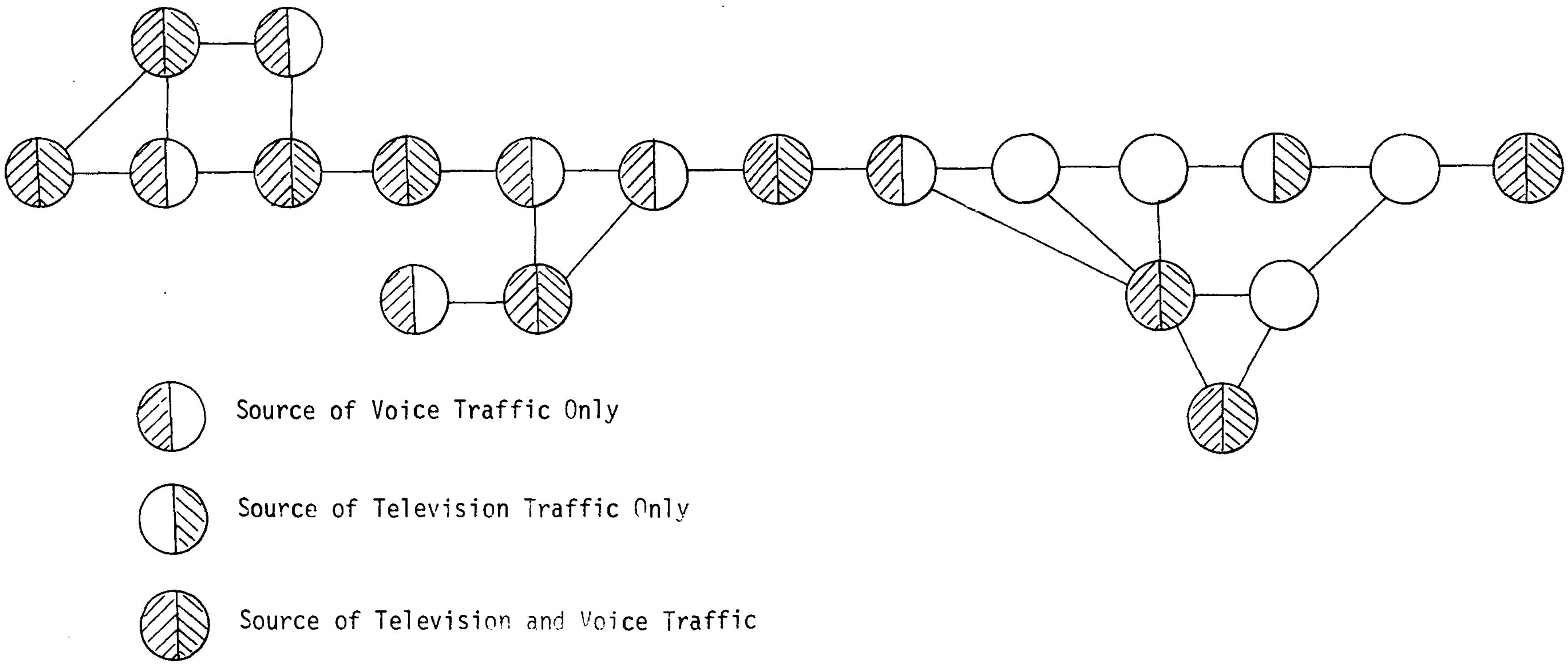
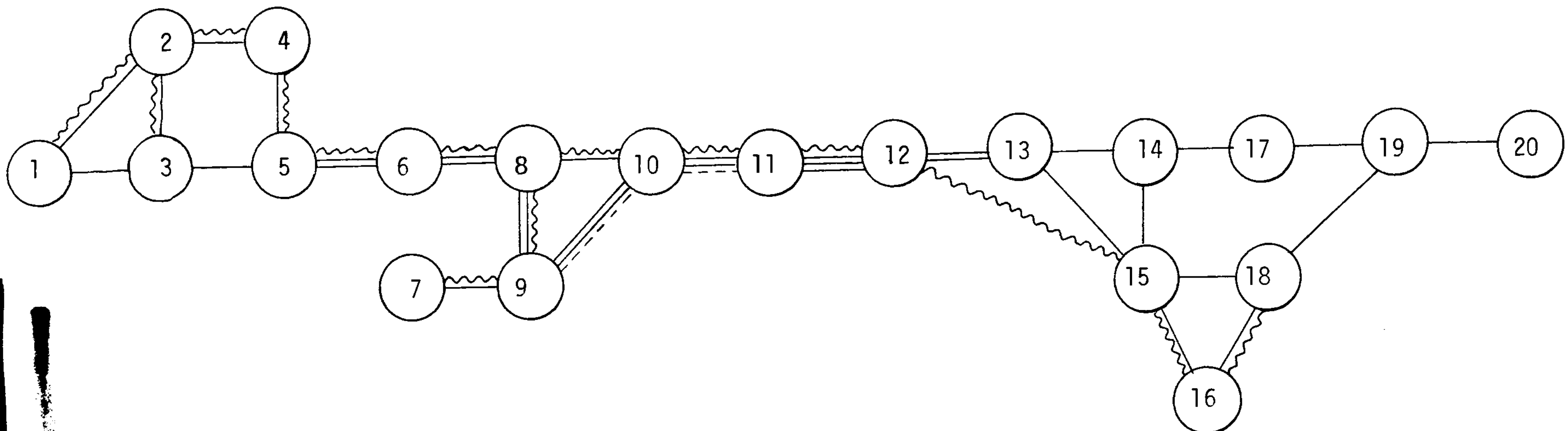


FIGURE F.1

SIMPLIFIED NETWORK MODEL WITH 20 NODES AND 26 LINKS



NOTES:

1. Vancouver	6. Winnipeg	11. Montreal	16. Halifax
2. Edmonton	7. Windsor	12. Quebec City	17. Sept Isles
3. Calgary	8. Sudbury	13. Riv. du Loup	18. Sydney
4. Saskatoon	9. Toronto	14. Riv. Blanche	19. Cornerbrook
5. Regina	10. Ottawa	15. Moncton	20. St. John's

LEGEND:

———	4 GHz Radio System 16,800 voice circuit capacity
∿∿∿	6 GHz Radio System 10,800 voice circuit capacity
------	Digital Coaxial Cable System 20,160 voice circuit capacity

Figure F.2

EXISTING TERRESTRIAL CAPACITY OF THE LONG-HAUL NETWORK

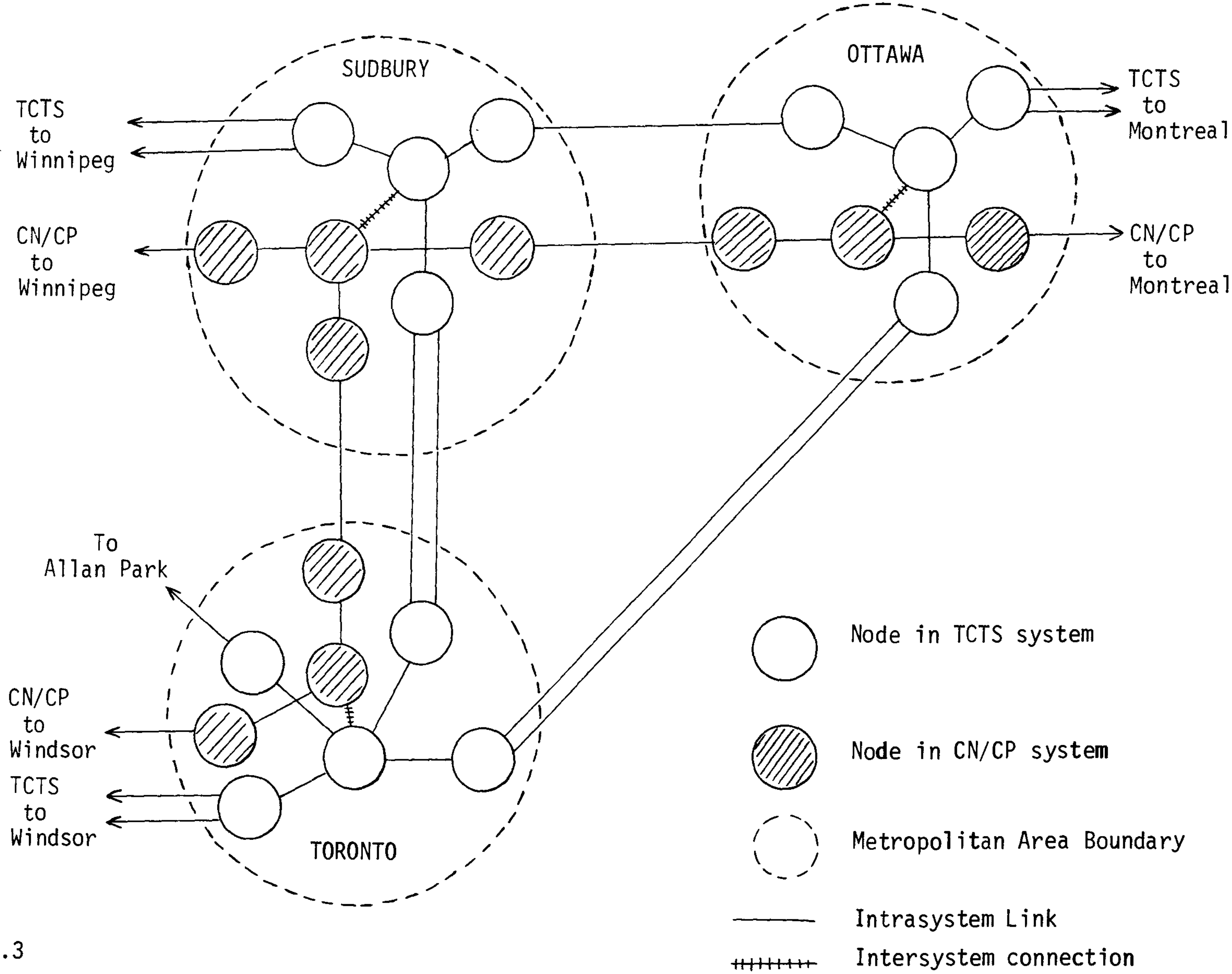


FIGURE F.3

MODEL FOR THE TORONTO-SUDBURY-OTTAWA REGION

The ground stations of the satellite system are modelled as extensions of the network shown in Figures F.1 to F.3. Satellite ground terminals in southern Canada will carry one or more of the following kinds of traffic:

i) television transmit and receive,

ii) television receive only,

iii) multiple-access voice, likely TDMA,

iv) dedicated use of two satellite transponders between two ground stations.

The cost of ground station equipment varies widely among that required for the four types of traffic. For instance, television receive-only is much less costly than television transmit and receive. Because of this, a satellite ground station and the terrestrial backhaul system to the terrestrial long-haul network is modelled as shown in Figure F.4. Branches of the network representing the ground station are labelled a to e, and nodes are labelled A to F. Television receive-only traffic is carried on branch a, television transmit-and-receive on branch b, multiple-access voice on branch c, and dedicated-transponder voice on branch d. All traffic to the satellite is carried on branch e. Node F represents the node at the metropolitan junction to which the ground terminal is connected.

The satellite is represented by a separate node in the network. Nodes A, B, C, and D of each ground station (see Fig. F.4) are connected to the satellite.

F.6 COMMUNICATION LINKS AND THEIR COSTS

The network model is such that all costs can be associated with a link of the network, and ownership of each link in the network except the intersystem connections of Fig. F.3 can be specified. The long-distance links are assumed to be one of the following:

i) analog microwave radio links existing in 1973,
ii) new analog microwave radio links,
iii) new digital radio links,
iv) new digital coaxial cable links,
v) new digital millimetre waveguide links.

The numerical values of the annual costs of these systems, and the technique used to determine those costs from available data is described below. Capital costs of these systems, on which the annual cost calculations are based, are given in Appendix B.

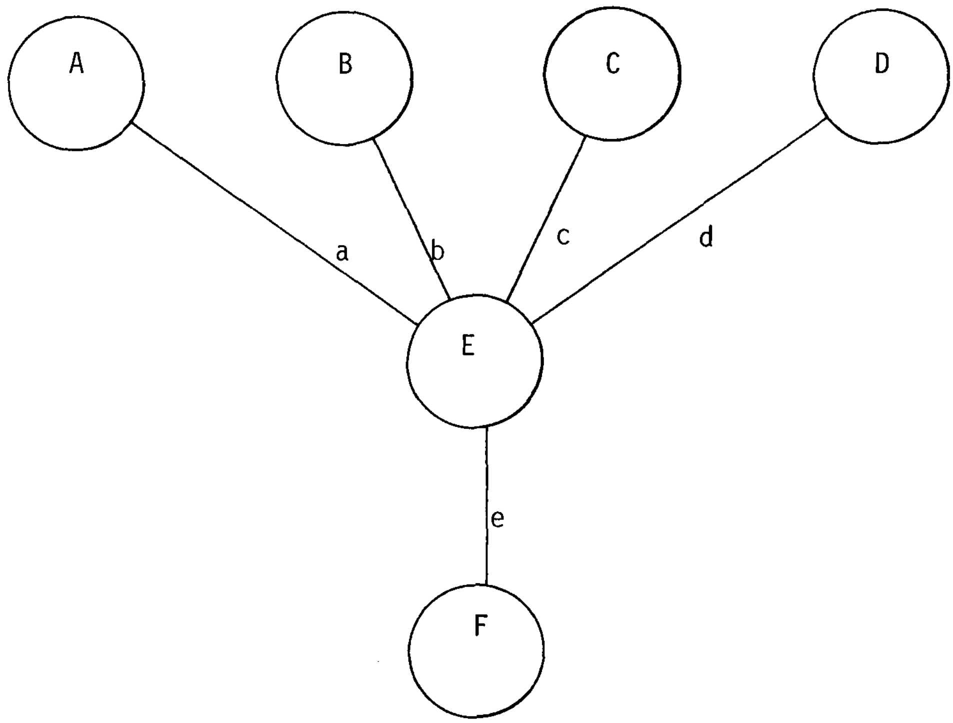


FIGURE F.4

NETWORK MODEL OF A SATELLITE EARTH STATION

F.6.1 EXISTING TERRESTRIAL SYSTEMS

Let us first consider existing analog microwave radio systems, owned by either TCTS or by CN/CP. Information is available giving the location of each repeater site in these systems, the frequencies used, and installed equipment at each frequency band. In the TCTS systems 4 GHz is used for long-haul traffic, and 2 GHz, 6 GHz, 7 GHz and 8 GHz are used for local traffic. The first step in determining the annual cost of such a system is to determine the capital cost of each repeater site if it were built in 1973. The cost of the building, tower, roads, etc. are divided between long-haul and local systems in proportion to the number of radio channels used by each. This information can be used to determine the equivalent new capital cost of the long-haul portion of the links shown in Figures F.1 to F.3, as a function of installed capacity on that link. It is assumed that each 4 GHz radio channel can be loaded with 1,200 voice channels or a TV program with several audio channels, and that each low 6 GHz radio channel can carry 1,800 voice channels or a TV program with audio. In the near future these figures are expected to be increased to 1500 and 2100 voice circuits respectively. This loading is possible with modern transceivers with TWT output amplifiers, in contrast with the 480 channel and 960 channel loading of older transceivers.

The capital cost of a 4 GHz radio link as a function of installed link capacity is the step-function shown in Fig. F.5. Larger costs are incurred when introducing the sixth and the eleventh operating channel. The step-function cost curve is approximated by the ramp, also shown in Fig. F.5.

The next step is to convert this capital cost function to an annual cost function, again in terms of installed link capacity. If the amount of traffic carried on the link as a function of time over its complete lifetime were known, then the average annual cost of a voice circuit over the system's lifetime could be determined. However, that information is <u>not</u> known a priori; for the time interval between when the system is installed and the present time, this information is known by the carriers (if they have in fact kept these records) but not by DOC, and for the future the traffic carried on an individual route as a function of time is a <u>result</u> of the study, rather than an <u>input</u>. Thus a simpler method of determining annual costs must be determined. Such a method, used in this study, is to assume that amortization costs, refurbishment costs, and maintenance and operations costs, which together form the system annual costs, are together a fixed percentage of the system capital costs. The result is a system annual cost function in terms of installed system capacity. This function for each link in the network, together with a description of the network topology, and the

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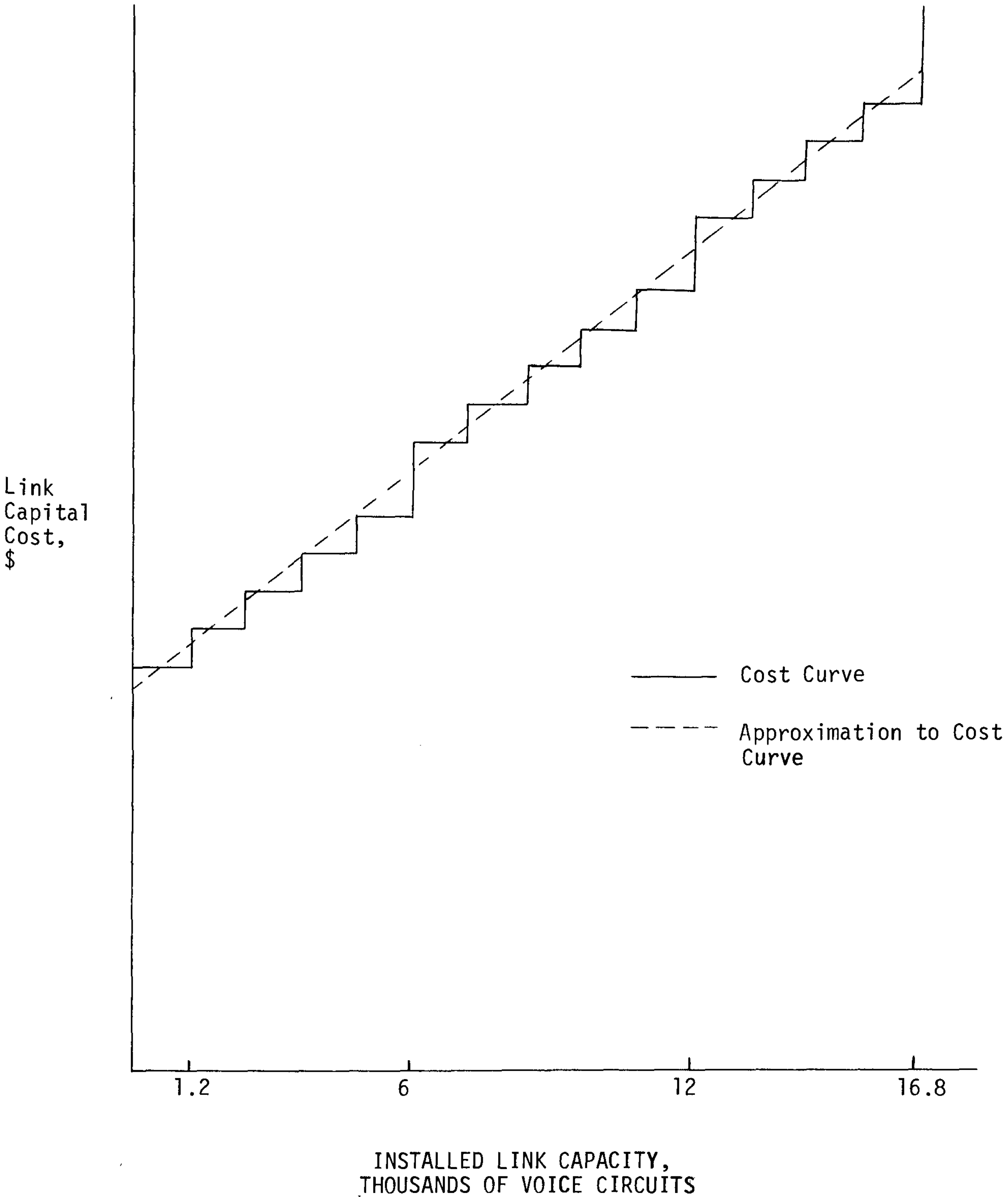

FIGURE F.5

CAPITAL COST OF A 4 GHz RADIO LINK

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end-to-end traffic requirements of the network, forms the input data for the optimal routing algorithm.

Let us now consider how to determine this annual cost function in detail, bearing in mind that we are only going to consider <u>future</u> costs of the network. Consider first the initial step in the capital cost curve. This is the cost of the building, roads, prime power, tower, antenna, etc. For an existing system it is only necessary to consider M&O costs of these items. M&O costs are assumed to be a fixed percentage, α, of the capital costs of the system. (No information is available on different values of α for roads, buildings, antenna systems, and electronic equipment: an overall value of 13% is assumed.)

Consider next the annual costs of electronic equipment that is already installed. It is not necessary to pay complete amortization costs of this equipment, because its purchase was in the past, and past costs are not considered. However, it is necessary to refurbish this equipment at some future date because of obsolescence. These refurbishment costs are

$$A_R = \frac{Ci(1+i)^{-N_1}}{\left\{1 - (1+i)^{-(N_1 + N_2)}\right\}} \tag{F.1}$$

where C is the refurbishment capital cost

i is the interest rate or opportunity cost of money,

N_1 is the number of years before refurbishment is necessary,

and N_2 is the lifetime of the new electronic equipment.

The values chosen for N_1 and N_2 are averages over all existing systems. It is tentatively assumed that N_1 is seven years, N_2 is fifteen years, and i is 10%. The effect of inflation on A_R is not included in (F.1) since all costs are given in 1973 dollars. Using these values of the parameters in (F.1), A /C is 5.8%. If this cost is added to the maintenance and operations cost, the total cost of presently installed electronic equipment is 18.8% of its capital cost.

The last item to consider is the cost of new electronic equipment to increase the capacity of the link. The annual cost of this equipment is the full amortization cost plus the M&O costs, a total of

$$C\left\{ .13 + \frac{i}{\left\{1 - (1+i)^{-N_2}\right\}} \right\} \tag{F.2}$$

Again the effects of inflation are not included. With $i = .10$ and $N_2 = 15$ years as in (F.1), these total annual costs are 26.1% of capital costs.

The relationship between the simplified cost curve and the annual cost curve as functions of installed capacity are shown in Fig. F.6.

F.6.2 NEW TERRESTRIAL SYSTEMS

New terrestrial systems are those for which the detailed route has not been determined, no microwave sites have been installed, no cables laid for coaxial systems, etc. In that case the procedure is to determine a capital cost and then an annual cost per mile, and multiply the cost per mile by the airline distance between end terminals, times a factor of 1.2 to take into account detours in the actual route.

The cost per mile of any new long-haul system is assumed to be of the form

$$C(m) = C_0 + C_1 m, \quad m \leqq M \qquad \to \infty, \quad m > M \tag{F.3}$$

where m is the number of installed full-duplex voice circuits, and M is the maximum capacity of the system. The infinite cost for $m>M$ is a mathematical representation of the finite capacity of the system. Similarly, the annual cost per mile of a long haul system as a function of its installed capacity can be written in the form

$$A(m) = A_0 + A_1 m, \quad m \leqq M \qquad \to \infty, \quad m > M \tag{F.4}$$

where

$$A_0 = C_0 \left\{ \alpha + \frac{i}{(1 - (1+i)^{-N_3})} \right\} \tag{F.5}$$

$$A_1 = C_1 \left\{ \alpha \quad \frac{i}{(1 - (1+i)^{-N_4})} \right\} \tag{F.6}$$

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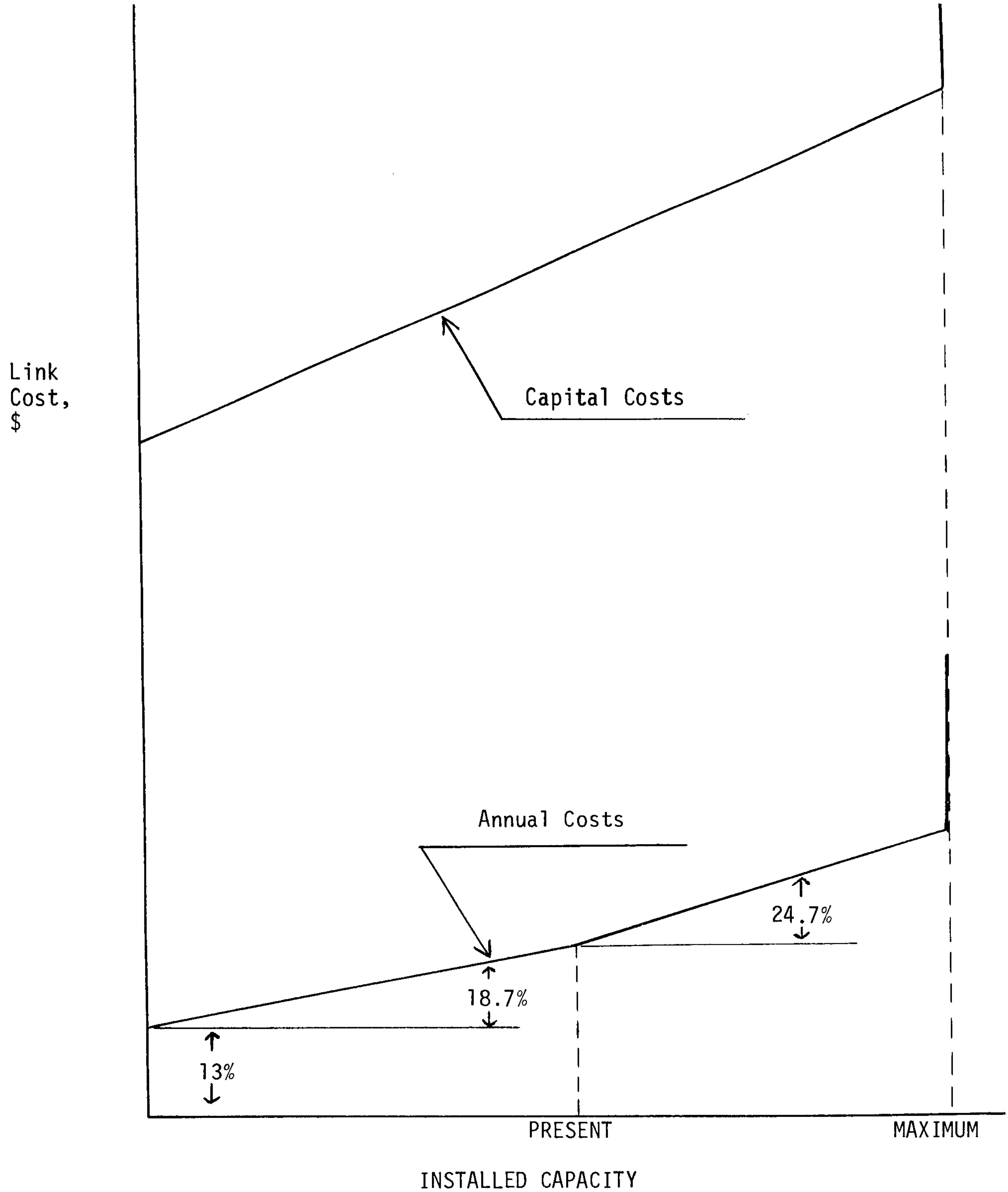

FIGURE F.6

ANNUAL COSTS OF AN EXISTING RADIO LINK

[redacted]

where α is the ratio of maintenance and operations cost per year to capital costs,

i is the interest rate or opportunity cost of money,

N_3 is the lifetime in years of the initial portions of the system such as the buildings, roads, cables, antennas, etc.

N_4 is the lifetime in years of the electronics of the system, perhaps determined by obsolescence of the equipment.

Different transmission media can be modelled by specifying the values of the parameters C_0, C_1, α, M, N_3 and N_4 for that medium. Media modelled in this way include TD 4 GHz radio, TH 6 GHz radio, 11 GHz digital radio, LD-4 digital coaxial cable, and millimetre digital waveguide systems. In each case it is assumed that N_3 is 25 years and N_4 is 15 years. Estimates of the other parameters are given in Table F.1.

TABLE F.1

Parameters of Heavy-Route Transmission Media

Medium	C_0	C_1	α	M
4 GHz Radio	$17K	$1.10	0.13	16,800
6 GHz Radio	$17K	$1.10	0.13	10,800
11 GHz Digital Radio	$18K	$1.25	0.13	32,256
LD-4 Coaxial Cable	$51K	$1.12	0.10	20,160
Millimetre Waveguide	$74K	$0.23	0.10	240,000

The M&O costs are assumed to be 10% for cable and waveguide systems, and 13% for radio systems. The latter are more exposed, and use TWT amplifiers rather than solid state amplifiers. Both of these differences contribute to a higher M&O cost. Based on the information in Table F.1, and assuming that the cost of money is 10%, the annual costs of the five media in Table F.1 are given in Table F.2.

TABLE F.2

Annual Costs per Mile of Heavy-Route Transmission Media

Medium	A(o)	M	A(M)
4 GHz Analog Radio	$4,100	16,800	$8,900
6 GHz Analog Radio	4,100	10,800	7,200
11 GHz Digital Radio	4,300	32,256	14,800
LD-4 Digital Cable	$10.8K	20,160	16,000
Millimetre Waveguide	$15.5K	240,000	28,300

F.6.3 SATELLITE GROUND STATION COSTS

The network model of a satellite ground station was described in Section F.5 and shown in Fig. F.4. Links a, b, c, and d represent the electronic equipment to transmit and receive the traffic through the satellite. Link e represents the antenna, the building, access road, prime power system, and backhaul system. The capital cost and technical description of these links has been specified in Appendices (C) and (D). The conversion from capital costs to annual costs is described below.

There are two possible frequency bands that could be used in a given ground station, the 4 GHz and 6 GHz band, or the 12 GHz and 14 GHz band. If 12 and 14 GHz are used the ground station can be located anywhere without interfering with the terrestrial microwave system. In contrast, if 4 and 6 GHz are used long terrestrial bakchaul links are required, but many of these backhaul links and ground stations have already been built for the Anik system.

Consider first a new ground station designed to operate in either band. From Appendices (C) and (D) a capital cost function C(m), a function of the number of voice circuits or television channels flowing through the link, can be determined. The annual cost functions for these links are

$$A(m) = C(m) \left\{ \alpha + \frac{i}{1 - (1+i)^{-N_5}} \right\}$$

where α is the M&O rate, i is the interest rate, and N_5 is the system lifetime for cost purposes. Again, inflation is not accounted for. The values chosen for these parameters are $\alpha = 0.13$, the same as that for terrestrial radio systems, $i = 10\%$ as before, and $N_5 = 7$ years. N_5 is set at 7 years because that is the likely lifetime of the satellite, not because the system would have to be replaced after 7 years. With these values on the parameters, $A(m) = 0.33\ C(m)$.

The alternative is to use an existing ground station and backhaul system. In this case it may be necessary to improve the existing site by improving the antenna, increasing the capacity of the backhaul link, adding new transmitters, etc. Let $C_1(m)$ be the capital cost function of the existing equipment as a function of m, the number of circuits through the link, and $C_2(m)$ be the corresponding cost function of the new equipment. The annual cost function of the link is then

$$A(m) = \alpha\left\{C_1(m) + C_2(m)\right\} + \frac{iC_2(m)}{1 - (1+i)^{-N_5}} \qquad (F.8)$$

No amortization costs are associated with existing equipment from the Anik system because these costs have already been incurred and are not recoverable by removing the facilities. If we use the same parameters as were used for a new ground station, (F.8) becomes

$$A(m) = 0.13\ C_1(m) + 0.33\ C_2(m) \qquad (F.9)$$

If the amortization time for new ground stations is increased from 7 years to 14 years, the time-frame for two satellite systems, then equations (F.7) and (F.8) become

$$A(m) = 0.26\ C(m) \qquad (F.10)$$

for an entirely new ground station, and

$$A(m) = 0.13\ C_1(m) + 0.26\ C_2(m) \qquad (F.11)$$

for an existing ground station.

F.6.4 SATELLITE SPACE SEGMENT COSTS

The space segment of the satellite includes the satellite or satellites themselves, and the terrestrial facilities to control the system, i.e. any part of the system not directly associated with a ground station which carries network traffic.

The satellite space segment is a well defined system with a specified lifetime for the actual satellite. Thus the annual cost is fixed, and not a function of traffic through the satellite, because there is no opportunity to modify a satellite during its lifetime.

Consider first the cost of the satellites themselves, in orbit. The present value of this portion of the system is

$$P_S = C_D + \Sigma_{j=1}^{N} (C_S + C_I + C_L) (1+i)^{-Dj} (1+\gamma)$$

$$+ C_S (1+i)^{-D_{N+1}} \qquad (F.12)$$

where C_D is the portion of the satellite development costs that the manufacturer charges to the system in question,

C_S is the cost of producing another satellite of the same type, and of transporting that satellite to the launch site,

C_I is the incentive charge by the manufacturer for a satellite operating successfully in orbit,

C_L is the cost of launching the satellite, including cost of the launch vehicle, use of the launch site, payment of launch personnel, etc.

D_j is the planned time interval between the time for which the present value is calculated and the time that the J satellite is launched.

i is the interest rate,

and γ is the cost of insuring the launch, as a fraction of the cost of a satellite and its launch.

The annual cost of this portion of the system is

$$A_S = P_S \frac{i}{1 - (1+i)^{-L}} \qquad (F.13)$$

where L is the lifetime of the system. If we set N = 2, two satellites in orbit, $D_1 = 0$, $D_2 = 0.5$, $D_3 = 1.0$, $i = 10\%$, $\gamma = 15\%$, twice the expected failure rate of a Thor-Delta launch, and L = 7 years, the annual cost of the satellites in orbit is

$$A_S = .21\, C_D + .65\, C_S + .46\, (C_I + C_L) \qquad (F.14)$$

As well as the above, the space segment costs include the amortization and the M&O costs of the T.T.&C. station and the satellite control centre. (In the Anik system the T.T.&C. station is at Allan Park and the control centre is on River Road, Vanier.) The T.T.&C. station can be costed in much the same way as a traffic-carrying ground station, in that only M&O costs of the existing portion of the new T.T.&C. station are charged. In contrast, new portions of the existing station, or a completely new station must be charged both amortization and M&O costs. If this amortization is over 14 years, the lifetime of two successive similar satellite systems, and an M&O rate of 13% is used, the annual costs are

$$A_{TTC} = 0.13\ C_0 + 0.26\ C_N \tag{F.15}$$

where C_O is the cost of the old portion of the T.T.&C. station and C_N is the cost of the new portion.

The total annual cost of the space segment of the satellite system, then, is

$$A_{SS} = 0.21\ C_D + 0.65\ C_S + 0.46\ (C_I + C_L) + 0.13\ C_o + 0.26\ C_N + A_{CC} \tag{F.16}$$

where A_{CC} is the annual cost of the control centre.

F.7 THE OPTIMAL ROUTING ALGORITHM

The optimal routing algorithm routes the traffic through the satellite/terrestrial network at minimum annual cost. The input to the algorithm is:

i) a complete description of the network topology as outlined in Section F.5,

ii) an end-to-end traffic description, as discussed in Section F.4,

iii) the annual cost of each link in the network as a function of traffic carried over that link, as described in Section F.6.

The output of the algorithm is:

i) a description of how telephone traffic between each pair of end points is routed through the network, and how each television signal is distributed through the network.

ii) a statement of the amount of traffic carried on each link of the network,

iii) the annual cost of the complete network.

The algorithm used to produce this output is a heuristic one, rather than one which is based on linear programming. It is described in reference (2) and (3) and is an extension of the algorithm described in reference (1), generalized to route television as well as telephone traffic at minimum cost. The heuristic approach rather than the standard L.P. approach was taken because of the much larger amount of computer time used by the L.P. programs available. (In a test run with a network of six nodes and eleven links the heuristic algorithm required only about 1% of the time required by the L.P. program to optimize the network.) The Canadian long-haul network model as described for optimization in the computer has about 60 nodes and 120 links, including 17 traffic-generating nodes. The increase from the 20 nodes and 26 links shown in Fig. F.2 is due to inclusion of satellite ground stations, metropolitan models, and dummy links introduced to model several parallel systems. The heuristic algorithm can optimize traffic flow through this network in about one minute of Sigma 9 time. About 10 to 15 minutes of programmer time is required to prepare the input data and to do the initial interpretation of the output data.

F.8 THE DEMAND-COST STRATEGY

The optimal routing algorithm discussed above specifies how traffic should be routed through a network that has a specified topology and link costs. However, determination of the various satellite options and the associated satellite link costs is a major part of the project. In contrast with terrestrial systems, costs and characteristics of satellite systems change significantly as new satellite options are considered. Use of the demand-cost strategy allows for considerable network optimization work to be done without detailed knowledge being available on the satellite system, and prevents the necessity for duplication of effort when considering a different satellite.

Rather than developing a cost function for the satellite links, as was done in Section F.6 for the terrestrial links and for the ground stations, let us suppose that the cost of transmitting a voice circuit through the satellite is x dollars, with no constraint on the amount of traffic through the satellite. The network can be optimized with the optimal routing algorithm for any specific value of x, and repeated for several values of x. The required number of voice circuits through the satellite in an optimized network can be thought of as a function of x, the "offering price" of a satellite circuit. The graphical representation of this function, plotted with x on the vertical axis and the number of satellite voice circuits on the horizontal axis, is referred to as the satellite demand curve. (The reason for choosing the axes this way will be evident later.) It is expected that such a curve will be similar to that shown in Fig. F.7, and will have the following general characteristics:

i) it is a uniformly non-increasing curve, in that only by reducing x can the traffic through the satellite be increased.

ii) A value X_{MAX} exists such that if the annual cost per voice circuit is greater than X_{MAX} there will be no traffic through the satellite, the terrestrial network being cheaper in all cases.

iii) The traffic through the satellite is limited to some finite maximum value even if x is reduced to zero, since at this point it carries all the traffic and the terrestrial network carries none.

iv) The curve is a series of discrete steps, as shown in Fig. F.7. One reason for this is that as soon as a television signal is routed through the satellite the number of equivalent voice circuits is increased by a large amount. The other reason is that as soon as x becomes small enough to attract a voice circuit between a pair of nodes, say between Vancouver and Halifax, it will either take as much of that traffic as is allowed for network protection reasons, or enough that a link somewhere is no longer required, whichever is smaller.

There will be different demand curves, of course, for different traffic requirements and different terrestrial and ground station link costs.

As well as these demand curves, the actual cost of the space portion of the satellite system can be determined, as described in Section F.6.4. There are a number of satellite options, each optimum for a specific amount of satellite traffic, ground station G/T, and modulation scheme. Thus for a given ground segment of the satellite system one can specify the minimum cost of the space segment as a function of satellite traffic, as shown in Fig. F.8. For a given satellite the cost curve is constant, and increases in discrete steps as a new more complex satellite becomes necessary. The dotted curves indicate the cost of the larger systems below the capacity at which they are optimum.

If the total annual costs shown in Fig. F.8 are divided by the number of circuits through the satellite, the result is an annual cost per satellite voice circuit curve, as shown in Fig. F.9. At each value of traffic through the satellite Fig. F.9 indicates the minimum possible annual cost of a voice circuit, the cost through a satellite that is optimum for that amount of traffic.

Suppose we now overlay the curves in Figures F.8 and F.9, as shown in Fig. F.10. In this figure the demand curve is the amount that could be charged for a voice circuit at each value of traffic, and the cost curve is the minimum amount that must be charged. From the demand-cost-strategy viewpoint there are three classes of points on the cost curve. These are:

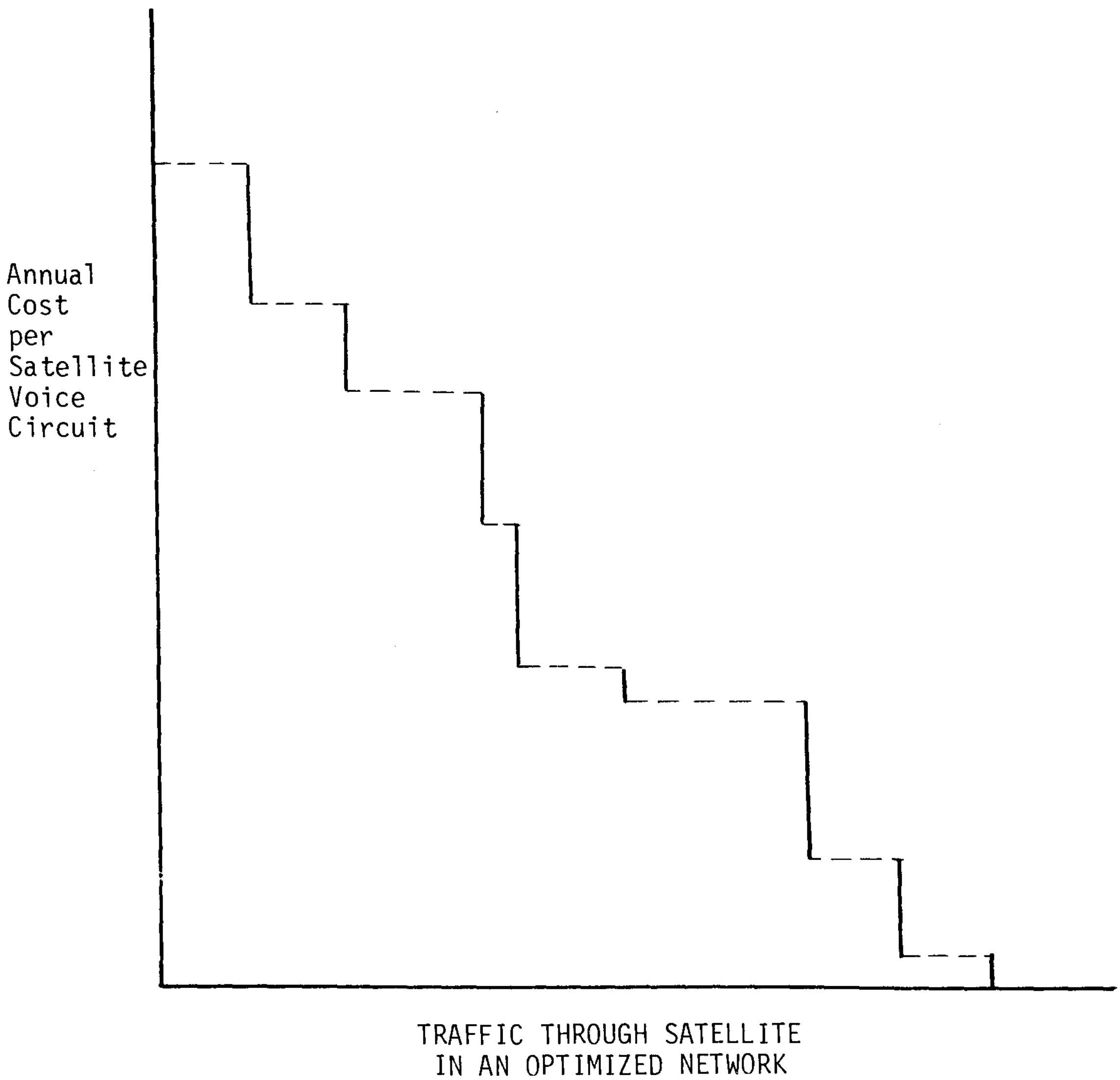

FIGURE F.7

SATELLITE DEMAND CURVE

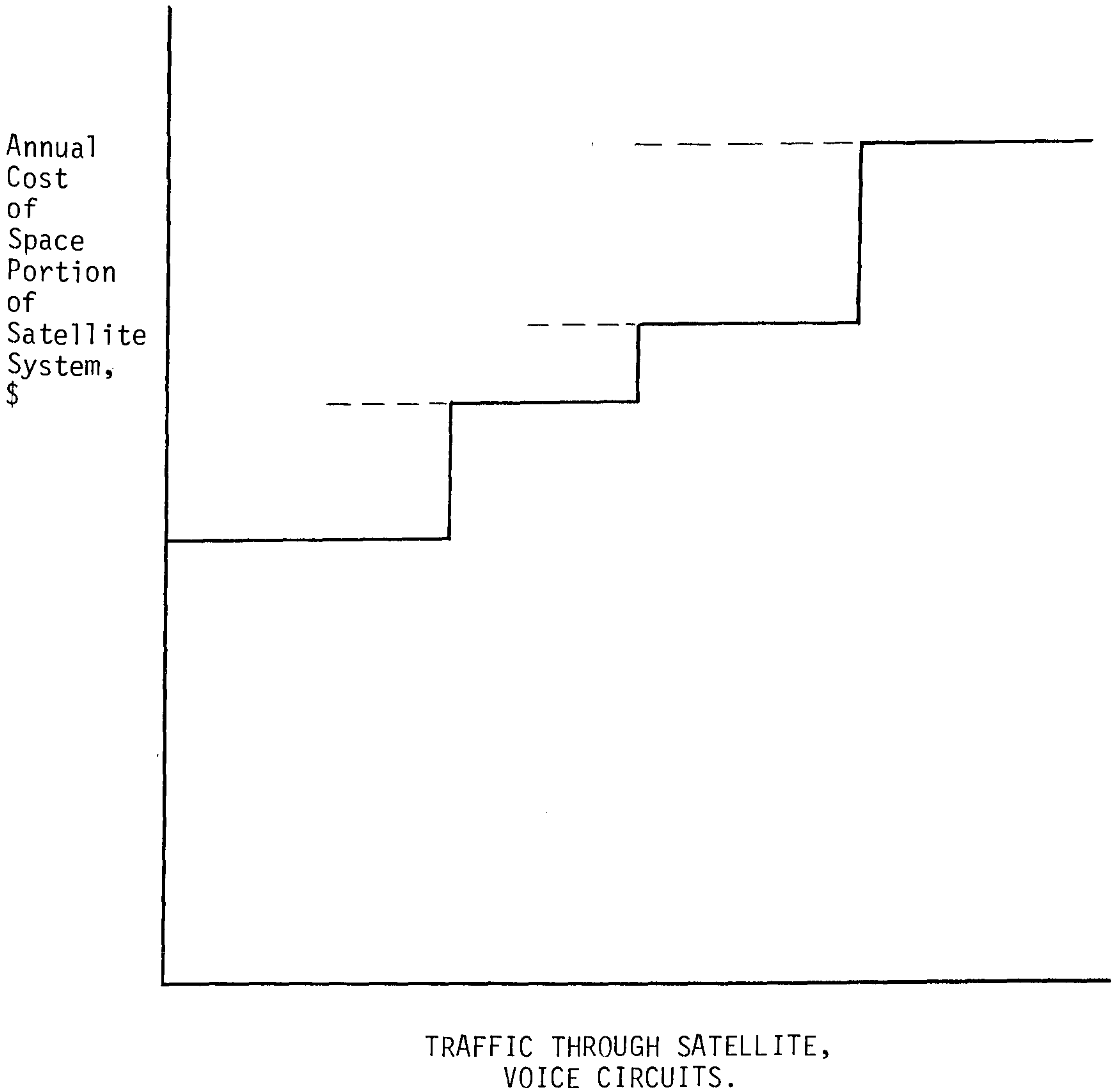

FIGURE F.8

SATELLITE COST CURVE

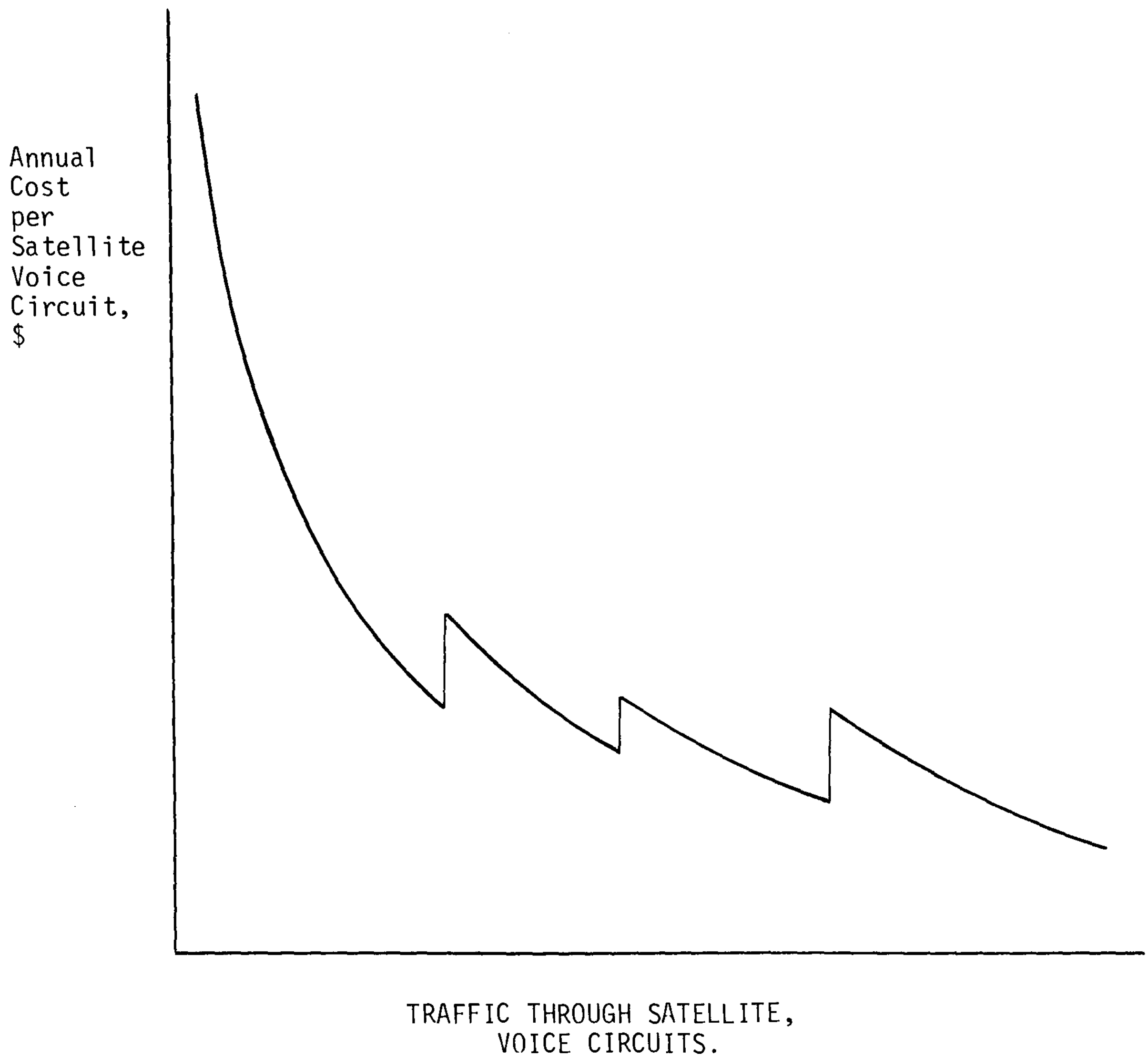

FIGURE F.9

SATELLITE COST CURVE

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i) points at which the cost curve is below the demand curve, such as point a;

ii) points at which the cost is above the demand curve, such as point b;

iii) points at which the cost curve and the demand curve are equal, such as point c.

Points a are feasible points, but at the satellite costs of point a the total network cost could be reduced by increasing the amount of satellite traffic above that indicated by point a. Points b are not feasible, since no satellite system can meet the costs required by the network. Points c are optimum in that at point c the total network annual cost is minimized. There may be several points c, in that the cost curve and the demand curve may intersect several times. Of this set of locally optimum points, the globally optimum one is that with least satellite voice circuit annual cost. This is also the point with largest satellite capacity, since the demand curve is a non-increasing function.

Several network constraints and requirements must be specified before a demand curve and a cost curve can be determined. These include the total traffic through the network, the types of system used in the terrestrial network, the amount of network protection imposed, etc. The optimum network, subject to these constraints, is specified once the optimum point c has been determined. Point c on the demand curve can be used to specify the terrestrial network and location of the satellite ground stations. Point c on the cost curve specifies the type of satellite to be used. Cost-demand curves for several networks subject to different constraints and requirements can be obtained, and these results used to determine the globally optimum network and to determine the cost of imposing certain constraints on the network.

F.9 CHOICE OF SATELLITE SYSTEM PARAMETERS

Choice of several basic satellite system parameters such as operating frequency (12 and 14 GHz or 4 and 6 GHz), and ground station antenna diameter, can be determined by using the demand-cost strategy. A satellite system demand-cost curve such as that shown in Fig. F.10 is for a specified set of terrestrial link costs, including the costs of the ground station links. As ground-station antenna diameters are decreased, and/or the 12/14 GHz band is used instead of the 4/6 GHz band, it is expected that ground-station costs will decrease and satellite costs will increase. For each frequency band and for various antenna diameters the optimum point c of Fig. F.10 can be determined. Associated with each such point is a total network cost. The

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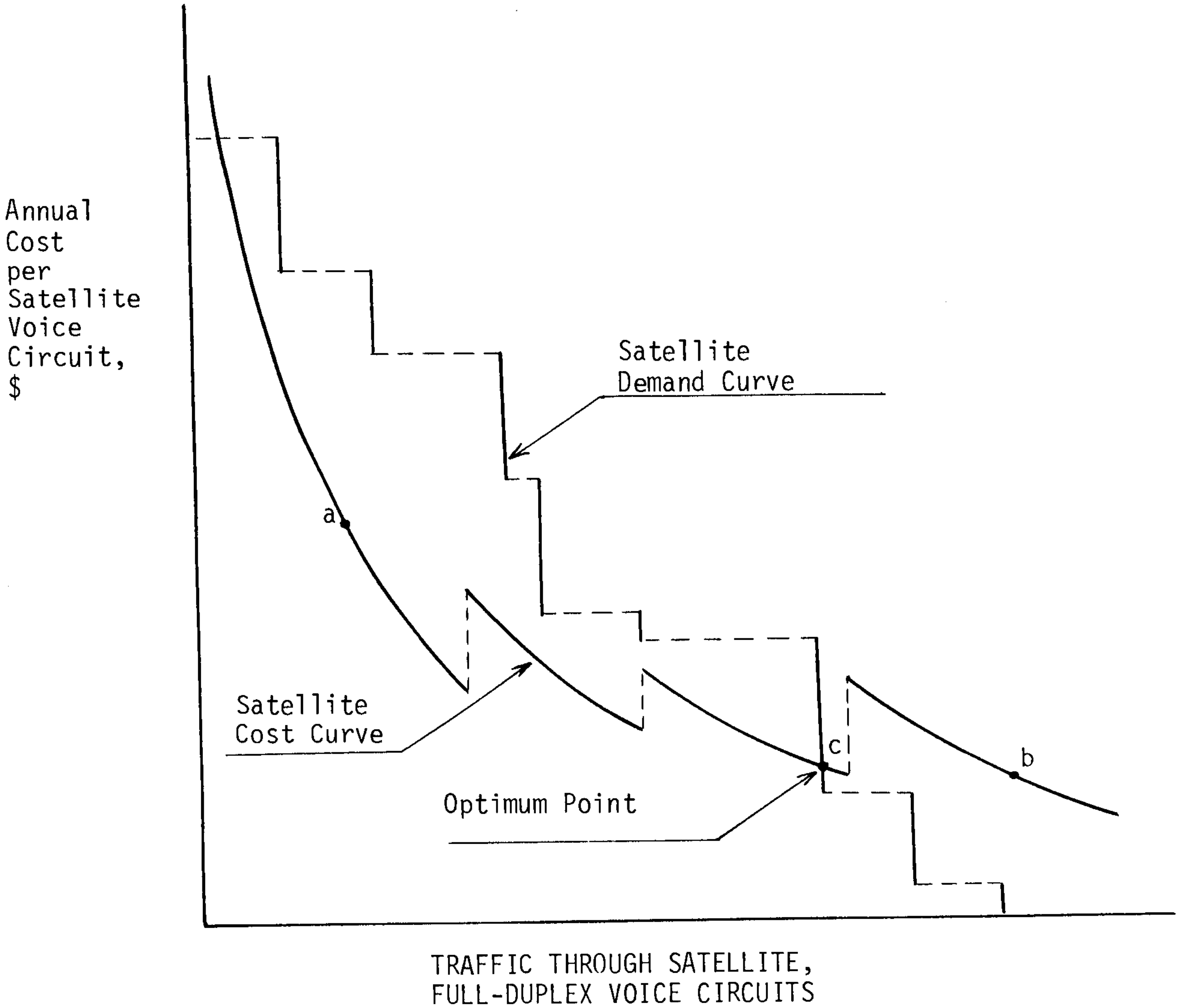

FIGURE F.10

OVERLAY OF SATELLITE COST AND DEMAND CURVES

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network with the lowest of these costs is the one chosen. Once this network is determined the optimum satellite frequency band and satellite antenna diameters are known.

F.10 OPTIMIZATION OVER THE 1980-1985 INTERVAL

The network model and links costs described in Sections 5 and 6 are expected to be valid for the complete 1973 to 1990 interval. However, the optimization of the network, described in Sections F.7, F.8 and F.9, is for a specified traffic input. Since the traffic through the network is expected to increase significantly during the interval of interest (see Section F.4, and Appendix A), a network optimized for one point in time may not be the same as the network that is best for that point in time when optimization over the complete 1973 to 1985 interval is considered. For instance, the optimum satellite for 1980 may be smaller than that required in the minimum-cost network for 1985.

For the above reason it is necessary to take the optimization procedure a step further as described under "Step 3" in Section F.3. The technique used is to select a number of satellite/terrestrial network development scenarios which, while not optimum at all three of the "spot times" of the study, represent orderly and feasible evolutions. This process is not mechanized, it depends mainly on sound engineering judgement and insight. Once the evolutionary scenarios are selected the most cost-effective one is selected on the basis of minimum present-value of annual costs over the time frame. It is the result of this process which is presented in Chapter 4 as the most cost-effective solution to the network development problem.

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[redacted]

CRC DOCUMENT CONTROL DATA

1. ORIGINATOR: Department of Communications/Communications Research Centre

2. DOCUMENT NO: CRC Report No. 1274-5

3. DOCUMENT DATE: September 1975

4. DOCUMENT TITLE: Domestic Long Distance Communications Network Study - Volume 5
Appendix E - The Sensitivity of the DLDCNS Results to the Estimated Parameters
Appendix F - Cost-Minimizing Network Synthesis Techniques

5. AUTHOR(s): R.V. Baser, R.R. Bowen, R.L. Hutchison, A.R. Kaye, T.A.J. Keefer, G.A. Neufeld, J.L. Thomas, E.A. Walker, P.R. Whalen

6. KEYWORDS: (1) Communications
(2) Network
(3) Domestic

7. SUBJECT CATEGORY (FIELD & GROUP: COSATI)

09 Electronics and Electrical Engineering

09 05 Subsystems

8. ABSTRACT: Domestic Long Distance Communications Network Study - Volume 5
Appendix E - The Sensitivity of the DLDCNS Results to the Estimated Parameters
Appendix F - Cost-Minimizing Network Synthesis Techniques

For Abstract see page xv of CRC Report No. 1274-2 - Domestic Long Distance Communications Network Study - Volume 2 - Full Report - Appendix A.

9. CITATION:

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