SYSTEMS STUDY AND EXPLORATORY DEVELOPMENT

OF A SUBSCRIBER CARRIER SYSTEM

TO SERVE LOW DENSITY RURAL AREAS

VOLUME 2 - FINAL REPORT

SED SYSTEMS INC.

SED SYSTEMS INC.
P.O. BOX 1464
SASKATOON SASKATCHEWAN CANADA S7K 3P7
TELEX: 074-2495 • TWX: 610-731-1476

SYSTEMS STUDY AND EXPLORATORY DEVELOPMENT OF A SUBSCRIBER CARRIER SYSTEM TO SERVE LOW DENSITY RURAL AREAS

VOLUME 2 - FINAL REPORT

SED DOCUMENT NUMBER: 792000-TR-104 ISSUE NUMBER: 2

DATED: January 4, 1980
REVISED: March 18, 1980

PREPARED FOR:

Rural Communications Program,
Department of Communications.

PREPARED BY: Wolfgang Stehwien,
SED Systems Inc.

: Russ McGillivray,
Systems Approach Consultants Ltd

APPROVED BY: D.W. Johnson,
Vice-President, Engineering.

The views expressed in this report are those of the contractor only and are not necessarily those of the Department of Communications.

CORPORATE OFFICES
AEROSPACE PRODUCTS DIVISION — (306) 244-0976
SYSTEMS DIVISION

EARTH STATIONS DIVISION — (306) 244-3633
INDUSTRIAL PRODUCTS DIVISION — (306) 664-3600
OTTAWA OFFICE — (613) 238-8241

TELECOMMUNICATIONS DIVISION — (306) 664-4455

OVERALL INDEX OF A SYSTEMS STUDY AND EXPLORATORY DEVELOPMENT OF A SUBSCRIBER CARRIER SYSTEM TO SERVE LOW DENSITY RURAL AREAS

VOLUME 1: EXECUTIVE SUMMARY

A summary of the study including the background to the study, the terms of reference of the contract, an overview of the work performed, and the resulting recommendations.

VOLUME 2: FINAL REPORT

The findings of the study are discussed in this volume. The background to the study and the methodology are also explained. Theoretical and factual background information for both technical and marketing analyses is detailed in several appendices.

VOLUME 3: SYSTEM DOCUMENT

The system concept which resulted directly from the work done during the study is described in this volume. In addition to the functional requirements, circuit details of a breadboard system are also given.

PREFACE

The study was initiated by the Rural Communications Program of the Department of Communications and performed under a contractual agreement with the Science Procurement Branch of the Department of Supply and Services.

The main purpose of the study was to identify whether an opportunity exists to develop a low cost, low capacity, subscriber carrier system for low density areas, and to accelerate its development by reducing R & D investment to a Canadian manufacturer.

SED Systems Inc., with major subcontractors Systems Approach Consultants Limited and Saskatchewan Telecommunications, carried out the work over a 19 month period, during which numerous discussions were held with Canadian and independent U.S. telcos, the Rural Electrification Administration of the U.S. Federal Government and manufacturers.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION 1: INTRODUCTION

This document is the final report on the work carried out under DSS Contract OST78-00018, A SYSTEMS STUDY AND EXPLORATORY DEVELOPMENT OF A SUBSCRIBER CARRIER SYSTEM TO SERVE LOW DENSITY RURAL AREAS. During the course of the study two interim reports were issued and breadboard carrier system was built. This report discusses the findings of the study, and is accompanied by a "SYSTEM DOCUMENT" which describes the breadboard system in some detail.

1.1 BACKGROUND TO THE STUDY

Providing telephone service to rural areas is very expensive, due to the small number of telephones and the long distances between subscribers. Cable prices are rising rapidly, as is the cost of installing them, which is a very labour intensive activity. Cable system costs are also directly proportional to the number of pairs and the wire size used, making the price tag for a typical rural ILS installation ($2000 or more) very unattractive. In order to minimize these costs, telcos provide multiparty line service, where a number of subscribers share the same line, and its cost. However, with communication services continually improving in virtually all aspects, multiparty line service is now being viewed as substandard by the majority of subscribers, many of whom have relocated from urban areas and tend to expect city-like service. Telcos are striving to satisfy the demands for improved service, but within economic limits, thus creating a strong need for technical innovation to reduce the costs of telephone services in rural areas.

The Rural Communications Program has two prime objectives: to determine cost effective ways to improve telecommunications services in rural Canada and to identify opportunities for industrial electronics development. Accordingly, the Rural Communications Program is studying existing and new technologies and systems that could be used to provide these improved services, including microwave and HF radio, satellite, and fibre optics systems.

This continuing work has resulted in the identification of an opportunity for the development of a low capacity, low cost cable carrier system to serve low density rural areas. Discussions with Canadian telcos, the Rural Electrification Administration of the United States, and manufacturers revealed that existing carrier systems are either too large or too small, and generally lack a multiple drop capacity required for distributed systems.

A draft proposal for the development of a small distributed subscriber carrier system was presented to the Canadian telcos and interested Canadian manufacturers to obtain their reactions. It was indicated at that time that the Rural Communications Program was interested in funding a systems study and exploratory development of such a low cost, low capacity system. The aim was to reduce the R & D investment to a Canadian manufacturer, thereby reducing the system cost and accelerating its development. Considerable interest was shown by the manufacturers, and the study contract was subsequently awarded to SED Systems Inc.

1.2 STUDY REQUIREMENTS

The final output of the study was to be a well defined system concept with preliminary designs, and an analysis of its marketability. Several iterations of concept development, refinement, market studies, and telco consultation were deemed necessary to achieve these goals.

Deliverable items included two interim reports on the progress of the work and arising recommendations for subsequent activities, and breadboard circuits to verify the concepts and technologies.

The final report was to provide information on all work activities undertaken during the study. It also was to include a product specification defining the system concept in sufficient detail to allow a development team to develop it to standardization for manufacturing. Circuit drawings and detailed technical information were also to be included. The report was also required to contain a discussion on the feasibility of the system and a recommendation on a course of action to follow.

This report meets these requirements. All detailed technical information is contained in Volume 3 "SYSTEM DOCUMENT", background information and discussions are provided in this volume.

1.3 REPORT OUTLINE

The report is divided into two parts, the main body and the appendices. Discussions about the study, its findings and the proposed carrier system make up the bulk of the main body, whereas detailed factual information, both of a technical and marketing nature, is given in the appendices.

The sections of the main body of the report are structured to provide a logical progression from the problem to the solution. Sections 3 and 4 discuss the market and technical requirements respectively, providing the basis for the formulation of the proposed system concept discussed in Section 5. The market and sales potential for the system derived in Section 6. The study conclusions are summarized in Section 7, and recommendations for a course of action to follow are given in Section 8. An overview of the study and the methodologies used to arrive at these findings is provided in Section 2.

The first four appendices are technical in nature, and provide some theoretical background to the major issues encountered in developing a suitable system concept. These include T1 transmission on small cable, requirements for interfacing directly to digital switches, modulation techniques, and system powering methods. Appendices E and F deal with surveys performed of Canadian and U.S. telcos and the REA; general profiles of each telco are presented in Appendix F, and engineering practices and reactions to the proposed system are detailed in Appendix E. Appendix G shows the calculations used in the market projections and trends analyses. Finally, installed system costs of various telcos are tabulated in Appendix H.

SECTION 2: CONDUCT OF STUDY

The study was divided into three phases, each terminating with a more refined definition of the system concept, concluding with this report. The work activities within those tasks were also divided into three major categories: systems engineering and concept development, economic analysis, and market analysis. Figure 2.1 shows how these activity categories interact, the arrows indicating the general direction of information transfer. This section provides general information of the study conduct relating to this model, which is then expanded upon in Section 3.

2.1 PARTICIPANTS

Instrumental in the origination of the concept and its early development was the Rural Communications Program of the Department of Communications. SED Systems Inc. was the prime contractor responsible for the management of the study, and also assumed all systems engineering work, including continued concept development and refinement. The Department of Communications provided continuous assistance and critiques. Economic analyses based on the SED manufacturing cost estimates were carried out by the Planning Department of major subcontractor Saskatchewan Telecommunications.

The market analysis was performed by major subcontractor Systems Approach Consultants Ltd. with extensive input from the participating Canadian telcos -

- The New Brunswick Telephone Co. Ltd.
- the Manitoba Telephone System
- Saskatchewan Telecommunications
- Alberta Government Telephones

Input through interviews was also received from -

- the Rural Electrification Administration
- the Commonwealth Telephone Company
- Bell Canada
- British Post Office
- Austrian Telephone Authority

Finally some insight into the manufacturing industry, specifically relating to competing technologies, future trends, and standards, was obtained from Logan Telecom Inc.

2.2 CHRONOLOGY

The study commenced in May 1978, at which time some work towards the concept development had already been done by the DOC and SED through proposal work. The first phase consisted of essentially two complete iterations of the cycle shown in Figure 2.1 during which two concepts, a 7 channel concentrator operating at a bit rate of 320 kbit/s and a 24 channel unconcentrated T1 carrier system, were evaluated for their respective merits.

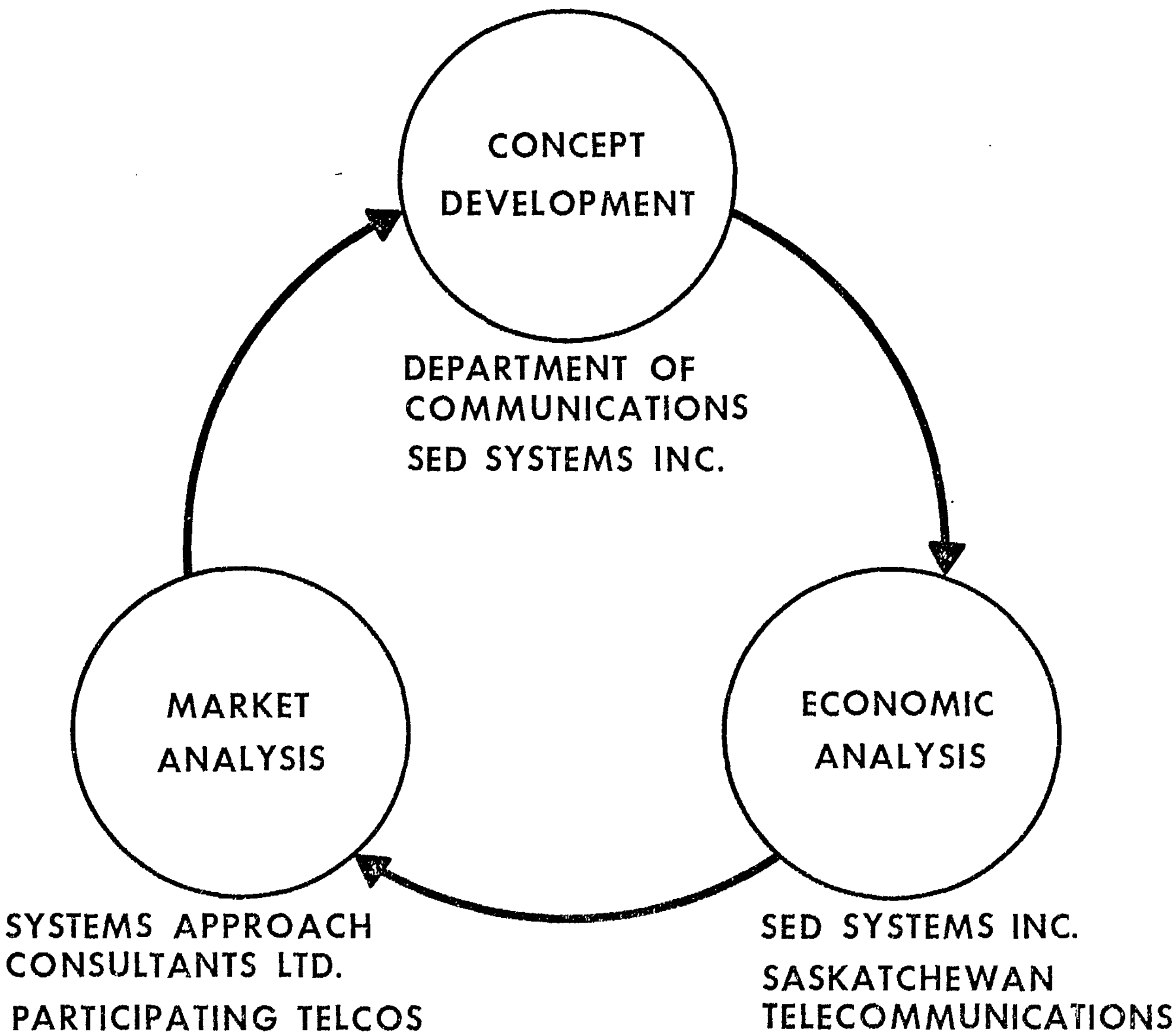

FIGURE 2.1 BASIC STUDY METHODOLOGY

At the completion of Phase 1 in January 1979 a recommendation to pursue a somewhat modified T1 carrier concept was made.

This concept, which was further defined and breadboarded during Phase 2, required a flexible design to allow distributed installations, concentration, subscriber supplied talk battery and ringing power, a choice of coding (modulation) techniques, including 32 kbit/s ADM, and various maintenance features. Concurrently with the design activity, the concept was presented to the telcos for their reaction and input. As a result modifications were made to the specifications and functional design. The breadboard showed the system's feasibility, along with areas requiring further development. Cost estimates were made based on the breadboard design with due allowances for upgrading to production standards. A recommendation to adopt this design was made at the end of Phase 2 in August 1979.

Phase 3 consisted of one more iteration of the development cycle, with equipment prices and installed costs being presented to the telcos for their reactions. Detailed market size calculations were carried out, and a final system design was formulated. The results are documented in later sections of this report.

2.3 ANALYSES

Throughout the study emphasis was placed on the requirements of the operating telcos, who are the only customers for these systems. To this end their continuous involvement was solicited, specifically for providing technical feedback for the system concept. A questionnaire addressing technical issues was distributed during Phase 2 with good results.

The market assessment employed a variety of analyses to arrive at a market and sales potential for the system. These included a general trend analysis based on historical changes in the number of telephones in service, a model for the division of these lines into categories of service by various technologies, and surveys of the actual requirements as forecast by the telcos themselves. The close agreement between the final results of the different analyses indicates that these should be quite accurate.

The economic analysis of the carrier system was carried out by a telco (Sask Tel) to obtain realistic cost figures. It included calculations of a standard case for comparison purposes, and calculations for actual exchange areas according to equipment specifications and Sask Tel practices. Sample calculations from NBTel and MTS were also obtained to assess their respective practices.

2.4 DATA SOURCES

Considerable research was done for both the market analysis and the systems engineering tasks. Data for the market potential calculations were obtained from various government sources in both Canada and the U.S. including Statistics Canada, CRTC hearings, U.S. Bureau of the Census, and U.S.I.T.A., as well as from the telcos themselves. Many papers and conference proceedings were also studied.

Technical data was obtained primarily from the literature, including textbooks, periodicals, technical papers, and conference proceedings. Invaluable information on telco experiences was received through the interviews and questionnaires, and to some extent laboratory experiments were performed inhouse to learn about specific phenomena.

Visits to manufacturers and solicitations of advertising material and data sheets were the main sources of the specifications of semiconductors and competing carrier systems. No proprietary information is believed to be included. The volume of this data makes it impractical to include it in the report, however, a supplementary report prepared by Logan Telecom Inc. for Systems Approach Consultants Ltd., which contains most of the relevant material, is submitted along with this document.

References to the published literature and other reports are given at the end of each Section and Appendix.

SECTION 3: PRODUCT AND SERVICE REQUIREMENTS

The logical flow of an industrial marketing research study with its interconnected analyses and outputs is illustrated in Figure 3.1. Briefly, the need for a new product arises because there is a customer with a service requirement which cannot be fully met with available products. Reading across the diagram, the functional requirements defined by this gap in available products leads to a product concept and to a product definition. Along the way, tests are conducted via user surveys and cost analyses to determine whether the customer needs are being interpreted correctly and whether the proposed product really addressed the market gap*. Reading down the diagram, the customers' service requirements define a potential market which can be estimated with the help of various kinds of data analysis. The size of the gap left by conventional products plus the degree of match between product requirements and the proposed concept define the sales potential for the new product, that is, the fraction of the market potential which it could expect to capture.

Following the logic of Figure 3.1, this section addresses the service and product requirement aspects of the market study, while Section 6 contains estimates for the market and sales potentials. Section 3.1 identifies the customers, the telephone companies. Next, the determinants of the telco's purchasing decisions ("customer needs and desires") are examined in Section 3.2, focusing in particular on their rural "service requirements". This analysis is based on interviews with the participating telcos ("user surveys") in order to come to grips with the telco decision processes ("characteristics of potential customers"). Finally, Section 3.3 describes the "available products" for rural service and identifies the gap ("product requirement") to be addressed by small digital carrier.

3.1 THE TELEPHONE COMPANY MARKET

The potential customers for a small digital carrier system are operating telephone companies ('telcos') primarily those in the U.S. and Canada. Potential markets outside of North America will be addressed in Section 6. The following highlights the position of individual telcos within the total market and their relationships among each other and with equipment manufacturers. The latter are important for the market analysis because, generally speaking, vertically integrated telcos such as Bell Canada and AT&T purchase the vast majority of their telecommunications equipment from their associated manufacturers. Clearly, an exception exists where a product gap exists and their own manufacturer cannot, be definition, supply the product. However, the tendency of large telcos to "standardize" their programs on a few products may work against this simplistic scenario by covering over the gap with available (if not strictly optimal) products.

In the U.S. and Canada there are 1,914 operating telephone companies which own 176,560,000 telephones**. Most of these operating companies are very small: in

---

* If this proves to be the case, then the next steps in the product development would be the breadboard model, production prototype, field test version and final production model.

** All telco figures are as of December 31, 1977 unless otherwise indicated.

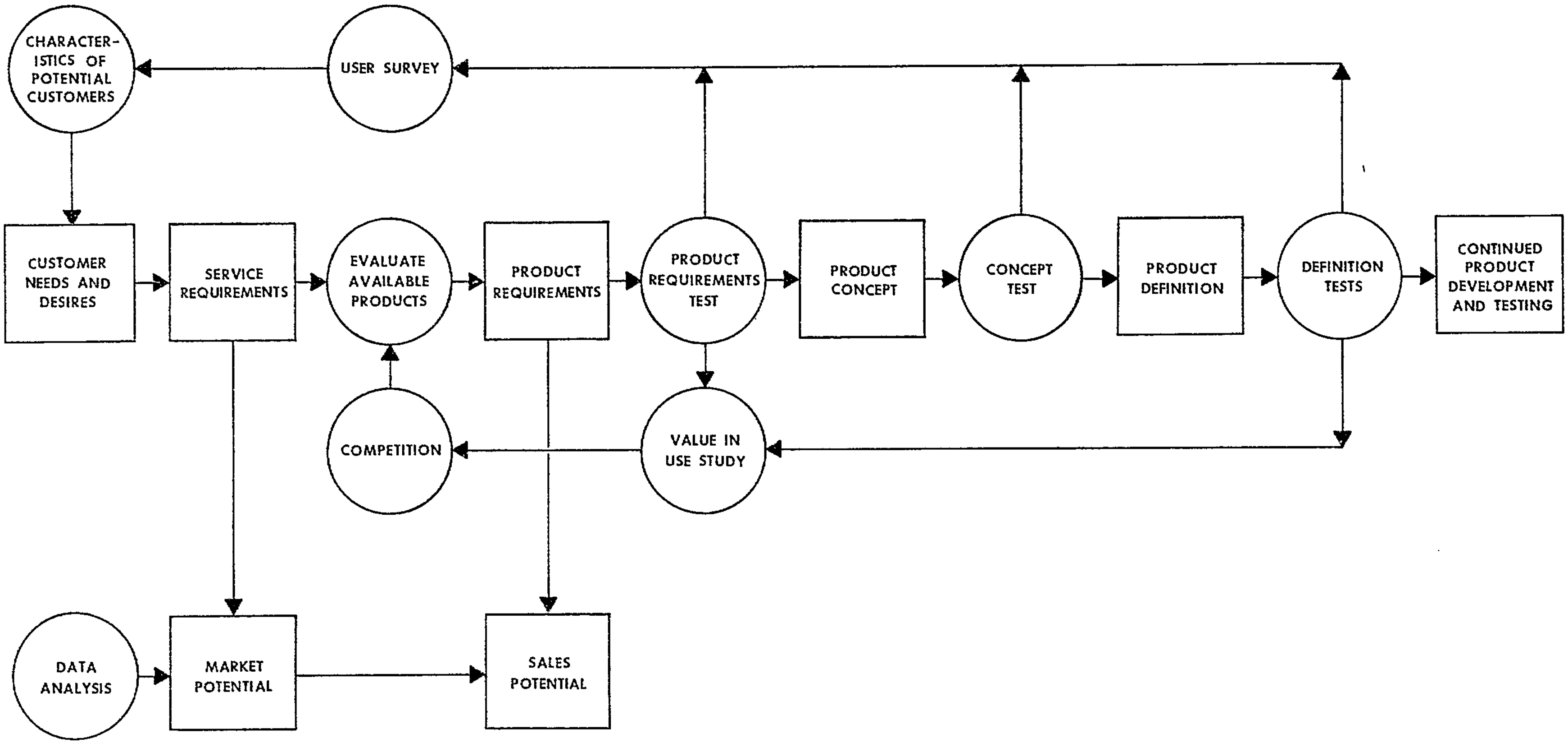

FIGURE 3.1 FRAMEWORK FOR MARKETING RESEARCH

Canada, fifteen telephone systems out of 333 account for 98% of the telephone activity, while the U.S. is somewhat less concentrated. There, 100 companies out of 1,581 account for 95% of the telephones.

In Canada, the large telephone companies fall into three broad categories: Bell companies, GTE companies and government (Federal, Provincial and Municipal) companies. Bell Canada has 59.5% of the telephones in Canada and the other major telcos in which it has a large or controlling interest (The New Brunswick Telephone Co. Ltd. (41% interest), Northern Telephone Ltd. (100%), Newfoundland Telephone Co. (78%), Télébec Ltée. (100%), Maritime Telegraph and Telephone Co. Ltd. (41%) and The Island Telephone Co. Ltd. (52% controlled by MTT)) make up an additional 8.2% of the market. Bell Canada also has a 69% interest in Northern Telecom Ltd., by far the largest Canadian manufacturer of telecommunications equipment (and second largest in North America).

The second largest block of telephone companies in those owned by the Anglo-Canadian Telephone Company which in turn is owned by General Telephone and Electronics Corp. (GTE) in the U.S. These telcos are British Columbia Telephone Company (including the Okanagan Telephone Company with which it merged on December 31, 1978) and Québec-Téléphone which combined account for 12.7% of the total telephones. The manufacturing arms of GTE are GTE Automatic Electric and GTE Lenkurt Electric. The Canadian versions of these companies were purchased by BCTel in September, 1979.

The remaining large telephone systems are government-owned. The three prairie, provincial government telephone systems (Manitoba Telephone System, Saskatchewan Telecommunications and Alberta Government Telephones) derive some of their self-identity from their distinctiveness from the Bell system. They own respectively 4.4%, 3.6%, and 6.5% of the telephones in Canada.

The remaining three government telephone systems are of minor importance: Canadian National Telecommunications operates telephones in the territories and parts of Newfoundland and B.C.; Edmonton Telephones is entirely urban, while the Thunder Bay Telephone System is small. These are 100% owned by the Federal government and the two municipalities, respectively.

In the U.S. a similar mixture of horizontal and vertical integration exists. The Bell System (American Telephone and Telegraph) of 25 operating companies has 82% of the total telephones. Its manufacturing company is Western Electric. The remaining telcos are termed the 'Independents', but in fact many of these are grouped into corporate families of holding companies. The four largest of these are: General Telephone and Electric (17 telcos, 8.4% of the total phones), United Telecommunications Inc. (24 telcos, 2.3% of the market), Continental Telephone Corp, (50 telcos, 1.5% of the phones) and Central Telephone and Utilities Corp. (10 telcos, 1.0% of the telephones). As previously mentioned, GTE owns GTE Lenkurt Electric, but this is the only such vertical tie-in among the four. Interestingly, not only does GTE reach into Canada (through BCTel and Québec-Tel) but Continental owns two small telcos with a total of 38,800 phones in Ontario and Quebec.

3.2 DETERMINANTS OF TELCO DEMAND

This Section addresses three modules of the marketing research study (Figure 3.1), namely the characteristics of potential customers (the telcos), their needs and desires, and service requirements. It is based on a systematic analysis of interviews conducted with telcos which are reported in Appendix F. This section focuses on the determinants of demand for rural subscriber carrier systems, including the influence of rural subscribers, and leads to a clarification of the service requirement.

The market for rural subscriber carrier is, in the first instance, with the telcos themselves. However much they are influenced by subscribers' expectations and demands for improved service or are prodded by regulatory agencies, it is the telcos who make the decisions to invest in plant and equipment. Thus much of the market analysis will focus on the telco as the key decision-maker and on the determinants of the telco decision processes.

The main elements of this decision process are portrayed in Figure 3.2. As shown in the Figure, the purchasing decision is a direct outcome of telco programs for:

- plant upgrading, and
- service improvement.

Plant upgrading programs evolve from analysis of the cost effectiveness of alternative technologies given the existing plant. Cost effectiveness in turn depends on alternative technologies, characteristics of existing plant design standards and demographic characteristics of the rural market.

Service improvement may take the form of upgrading basic service (e.g., eliminating more than 4 party service), accommodating individual subscribers' requests for upgraded or premium service, and accommodating new growth. They are influenced by cost effectiveness considerations and by service policy. Service policy in turn depends on the needs and expectations of the rural market (or more precisely on the telco's perception of these) as well as on the policies and actions of regulatory bodies. These latter tend to reflect pressures for improved service eminating from subscribers.

Details of the decision process leading up to a demand for rural subscriber carrier systems as exemplified by the telcos interviewed will be expanded in what follows. Specifically, service and plant upgrading will be considered in turn. Where possible, implications for the service requirement and hence the market potential will be extracted.

3.2.1 Service Improvement Programs

Virtually the same sequence of service improvement programs was found to have been adopted by all of the telcos interviewed. Each province differed as to the

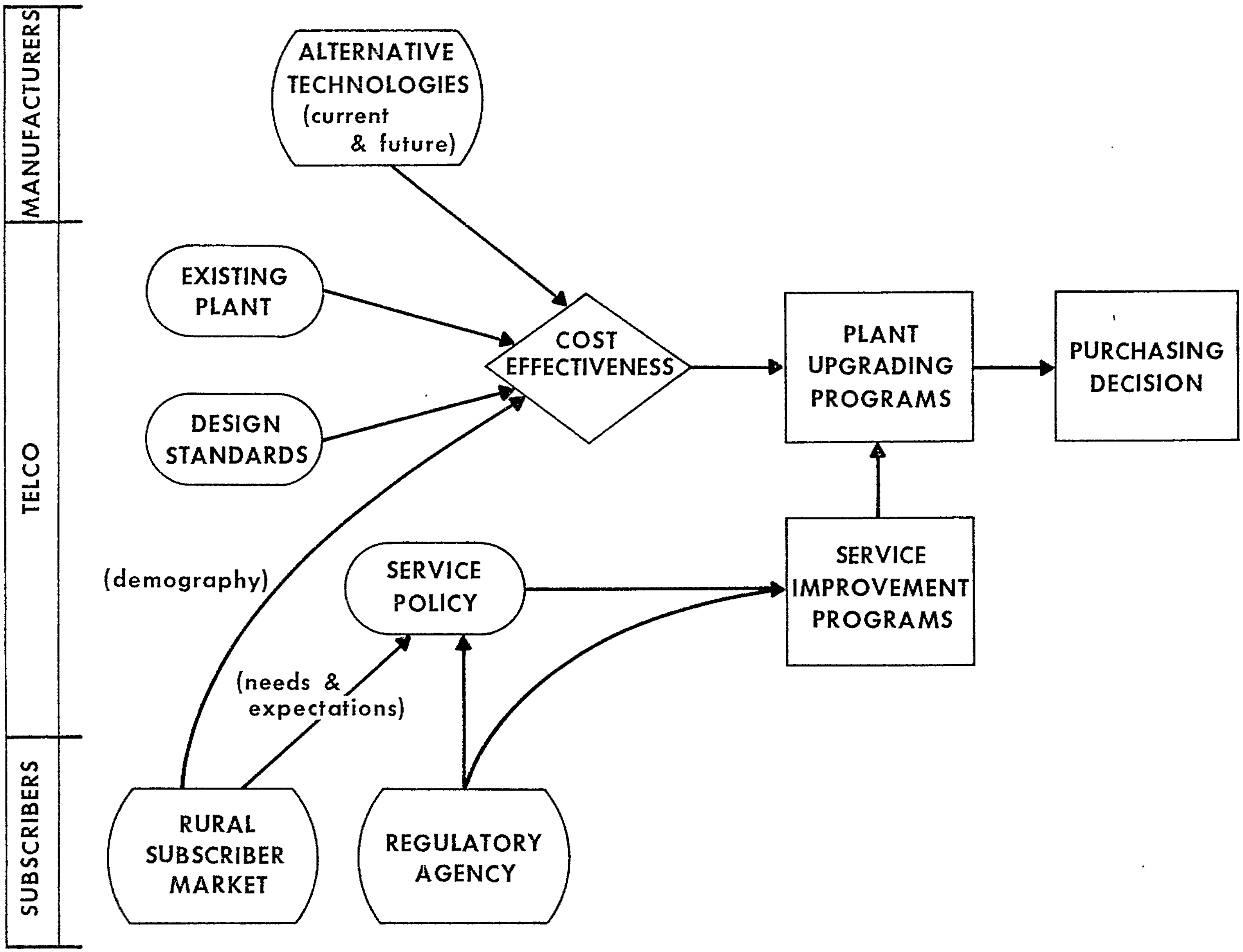

FIGURE 3.2 DETERMINANTS OF TELCO PURCHASING DECISIONS

timetable and urgency placed on individual programs but the sequence was:

- absorb small rural telcos
- upgrade to 4PL as the standard offering
- offer ILS as an option to anyone willing to pay the additional cost
- extend ILS offering to smaller and smaller communities as the standard offering.

Table 3.1 shows the progress on each of these programs by province. At the present time no telco has a program to provide universal ILS.

Rural Subscriber Market

As indicated earlier, it is the telco and not the subscriber market that ultimately determines the market for carrier systems. Nevertheless, a key determinant of the telco's policy and programs towards upgrading rural service, apart from cost considerations, is its perception of the nature of the rural subscriber market.

There are two dimensions to the rural market of importance in leading to service improvement programs. These are the subscriber expectations for telephone service, and the subscriber demand for improved service. (The physical distribution of the population will be considered in connection with plant upgrading).

The subscriber expectation for telephone service is a function of:

- his subjective judgement about what constitutes a minimum grade of acceptable service, and
- the uses to which he intends to put his telephone

The first of these factors is related to his experience or contact with urban grades of service. The second is closely tied to the economic activity in which he is engaged.

With respect to the measure of what constitutes "acceptable service", people who have always lived in rural areas may be quite satisfied with 4-party service, particularly if this has recently been upgraded from multi-party line service (MPL). In a survey of 1486 households on MPL conducted in February 1978, NBTel found that 42% of respondents would be satisfied with MPL or 4-party line service.

However, 75% rated their overall quality of telephone service (on MPL) as "fair" or "poor". More significantly, 39% of those identifying major problems with their telephone ranked access or abuse of the service by others on the party line as their most serious problem. Both of these problems cannot be eliminated with 4-party lines or a privacy device, thus indicating a latent demand for ILS.

This preference for ILS is underscored by the analysis of the current demand for 4-party service (4PL) and ILS at an increased monthly rate. Figure 3.3 shows

TABLE 3.1 PROGRESS ON SERVICE IMPROVEMENT PROGRAMS

TELCO / PROGRAM	AGT	SASK TEL	MTS	NBTel	BELL CANADA
Absorb small rural telcos	Complete except for one other	1983	Complete	Complete	Continuing to absorb small companies in Ontario and Quebec
Upgrade to 4PL	Complete	1983 (except resort areas	1981/82	1982 (current rural residents can continue to purchase 10PL service if they desire)	1981
Offer ILS at additional cost	Discouraged by high charges	Yes	Yes	Yes	Yes
Extend ILS to small communities	No	60 phones or more	15 Subscribers or more (except resort areas)	No specific program. Current practice is about 100 subscribers or more	

that the demand for ILS (over 4PL) is far less sensitive to price than is the demand for 4PL over MPL. The data on which these results are based are the distribution of grade of service by mileage band from the exchange base rate boundary. For example, over 50% of subscribers are willing to have ILS at $14.35 a month against MPL at $5.25 (as evidenced by subscribers at the 3-mile band).

The second major factor influencing a subscriber's expectations for telephone service is the use to which he expects to put his telephone. A study of the rural population by R.W. Wilson, National Telecommunications Branch, DOC, showed that 70% of the rural population are ex-urbanites(6). Some of these are professionals requiring private lines to conduct business. Even areas far from urban centres may also come to expect a more business-like grade of service as farms are amalgamated into large economic units.

The second dimension of the rural subscriber market which influences device improvement programs is the subscriber demand for improved service. This improved service may take a number of forms, for example:

- privacy
- individual ringing
- access
- reliability
- special services (meter-reading, low speed data)
- hardware, e.g. touchtone
- extension phones

Important dimensions to each of these are the relative priority of different improvements, and subscriber willingness to pay. With the prospect of a Rural Interface Device (RID) becoming available and offering privacy and individual ringing at relatively low cost, the priority placed on improved access then becomes the important factor in determining the demand for ILS.

Similarly, demand for special services (and hence for one or more lines to each subscriber) will grow quickly in rural areas once the technology has been proven in urban applications. The public is becoming aware of the possibility of universal access to an interactive data network with the announcement (August 15, 1978) by DOC of Videotex, a two-way TV system operating initially over paired or coaxial cable. Even more pertinent to this study is a second announcement (June 19, 1978) of a field trial of fibre optics technology in rural Manitoba. The trial will deliver ILS, at least five television channels, FM radio and some two-way computer interactive signals to 150 households and businesses. It is said that within four or five years an interactive service such as Videotex could be added to a television receiver at a cost of $200 to $300.

Similarly, once wide band data services have become economical in urban areas (foreseen to be within the next 15 years) the demand for equal service for the isolated but prosperous rural areas of central and western Canada is likely to be insistent. Demand for this will rise in concert with the increase in data services which can be accessed.

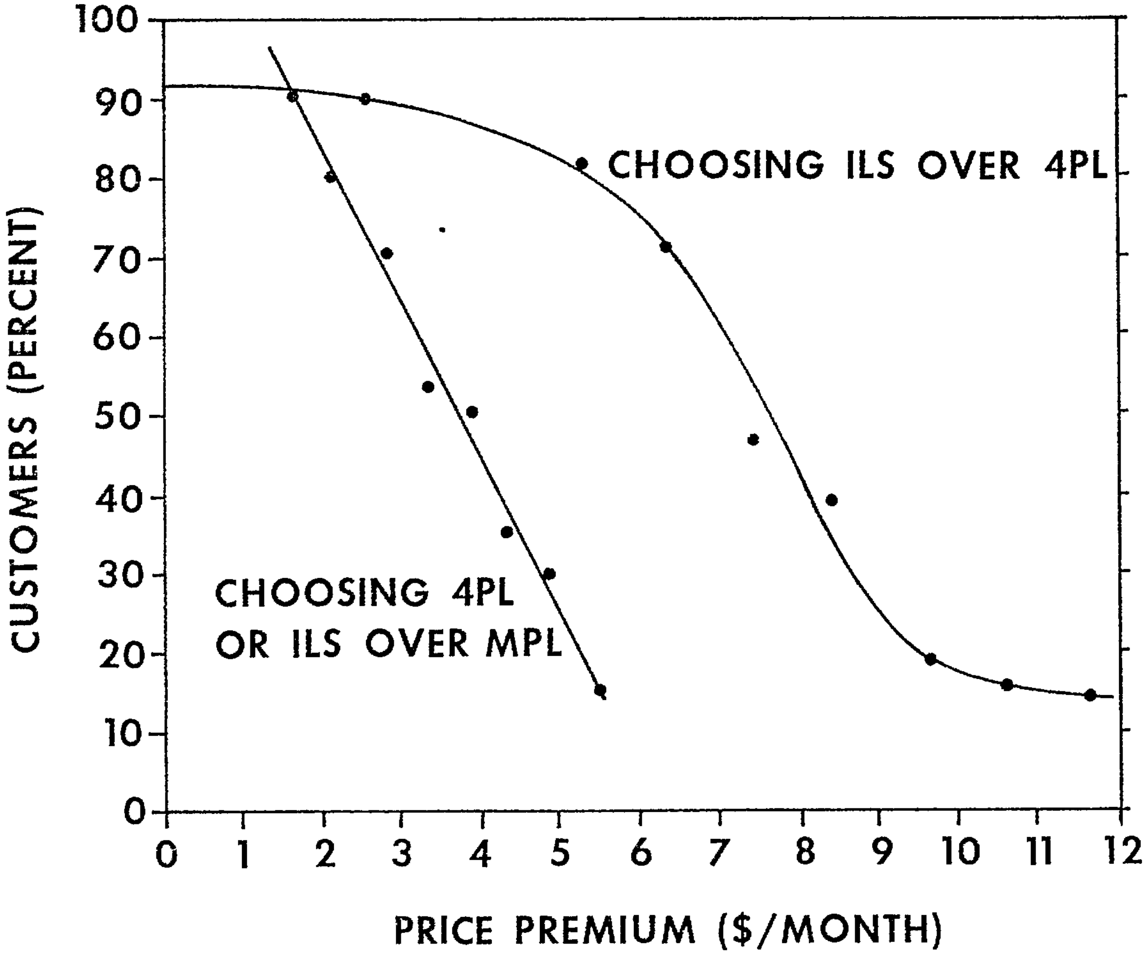

FIGURE 3.3 DEMAND-PRICE RELATIONSHIPS FOR IMPROVED RURAL SERVICE

Subscriber willingness to pay for improved rural service presents the telco with a paradox, since while demand for service is growing, access to the telephone system and a full range of services is coming to be regarded more and more as a universal right. This means that not only will the rural market not pay for itself (as in the case now) but the telcos will not be able to recapture the cost of service improvements.

While most of the telcos can see a renewed demand for improved service (beyond 4PL) in the long-term, none foresee adopting new rural service improvement programs in the next ten years or so. After the heavy investments needed to upgrade service to 4PL the challenge for rural areas will be to accommodate growth as it occurs. This aspect will be discussed in connection with plant upgrading.

3.2.2 Plant Upgrading

As was found with rural service improvement, a common sequence of plant upgradings can be discerned across the telcos interviewed. These are:

- replacing open wire with aerial or buried cable
- conversion from analog to digital switching
- conversion from VF cable to carrier systems

However, more variability among telcos was perceived with regard to plant than with service improvements, for two reasons. First, plant upgrading occurs in part because of economics rather than as a result of a conscious telco program. Thus when existing plant attains its service life, it is replaced with newer, more cost effective equipment. Second, the acceptance of new technologies varies with the experience.

The incremental approach of operating telcos towards upgrading plant suggests that the market for any proposed system will depend on its cost effectiveness in individual installations. The factors (see Figure 3.2) which influence this cost effectiveness are:

- compatibility with existing plant (particularly the installed cable and switching equipment)
- compatibility with telco design and service standards (such as maximum blocking probabilities)
- telco perception or experience with alternate technologies (VF cable, analog carrier, RID, fibre optics)
- demography

The effects of the first two of these factors, existing plant and telco standards, are apparent in the installed cost analysis reported in Appendix H. Examination of the existing plant will usually indicate which design is the least costly for a given route, while telco standards will serve to possibly exclude certain technologies. One example is the high blocking probability associated with giving 4PL service with a concentrated carrier system. However, the impact of the last two factors on the telco purchasing decision are more difficult to assess.

Alternative Technologies

The telco perception of alternate technologies is important and can vary between companies. For example, as a result of experience with trial systems, AGT is committed to installing carrier over cable in new installations, while MTS has not found carrier to be economical. Another example is the interest in using the RID as a stop-gap measure and delaying any major up-grades in rural areas until fibre optics becomes feasible in about 10 years. Whether or not this last prediction is realistic, such thinking can induce a telco to skip a generation of technology (such as digital carrier). This strategy is made possible by the long service life of existing plant such as buried cable.

A second factor in the degree of telco acceptance of technologies is the expected lifetime cost, of which an important part is maintenance. A proliferation of types of systems in use by a telco, and particularly the introduction of new technologies, creates significant maintenance problems.

Demography of Rural Subscribers Market

Demography is a rather obvious determinant of an optimal configuration to serve rural areas. Two phenomena are particularly relevant. One is the clustering of residences into small settlements as occurs for example in New Brunswick along the coast and river valleys. This contrasts with the more uniform distribution of subscribers on the prairies. Thus whereas a small carrier system with single subscriber drops is suitable for Saskatchewan, a larger system with the capability for a number of multiple subscriber drops is more appropriate in New Brunswick.

The second demographic phenomenon of interest is the local growth of a rural population, particularly as occurs with trailer parks. Here the total population can remain constant, but different areas can experience rapid growth with the mobility of the population in response to changing economic opportunities. In areas where this rapid growth is possible, any installation must be highly flexible with respect to loading and remain economic over a range of uses.

3.2.3 Summary

The analysis of telco purchasing decisions suggests that the major determinant of demand for outside plant is the tendency of the telco to think in terms of service improvement programs which tend to be long-term and involve heavy expenditures. Dramatic evidence for the tendency of telephone companies to pursue programs at predictable rates over long periods of time is given in the historical trends in numbers of telephone main stations by grade of service illustrated in Appendix F. For example, Bell Canada's Non-Urban Service Improvement (NUSI) Program is a four-year, $600 million effort to upgrade all rural lines to 2- and 4-party. Halfway through the program, no change can be detected in the historical rate at which 2-party or all-party service have declined. Similarly, contrary to trends in other provinces, party-lines in Alberta have been growing at a steady rate over twenty years.

This approach by the telcos is dictated by economic and technological factors. Since they find that rural service does not pay for itself, decisions on improving service are taken in response to the telco's perceived mandate to provide equitable service across the system than in response to revenue-generating opportunities. Incremental cost-reductions due to improving technology will not alter this basic fact nor, therefore, the demand function for outside plant.

There are also technological factors behind the existence of long-term trends in the telephone industry. First, true break-throughs are rare. In the past, technological improvements have led to gradual cost improvements rather than dramatic reductions. Second, the lead time for major advances is such that the capabilities of the technology are foreseen, and can be anticipated in improvement programs, a decade or more before they are commercially viable. Fibre optics and digital technologies are good examples of this. Third, investment in existing plant is so heavy that new technologies can only be incorporated into the system slowly. This means that because of the continuous need to amortize existing cable plant and associated equipment, telco planning will continue to include V.F. cable and conventional carrier systems long after the introduction of fibre optic systems. Finally, the installed cost of technologies such as carrier is relatively insensitive to hardware cost because of the high cost of installation and conditioning of other facilities to accommodate these technologies.

For all of the above reasons, service improvement programs will continue to be formulated and proceed on the basis of ballpark costs which are largely independent of the technology employed in specific installations. Specifically, upgrading to 4PL will proceed with a mixture of technologies based on the existing plant and local conditions. Further, the existence of a small digital carrier system will not of itself induce the telcos to commit themselves to providing universal ILS in the next decade. Thus a low capacity system must be capable of supporting 4-party service for the foreseeable future. Finally, market estimates for the requirements for new lines in rural areas (Section 6) can reasonably be derived from the past behaviour of the telcos.

3.3 PRODUCT REQUIREMENTS

The previous section outlined a number of the service requirements of operating telephone companies in their rural service areas over the next decade. The main ones are:

- upgrading basic service to smaller and smaller communities and at greater distances from exchanges
- accommodating subscribers' requests for upgraded or special services
- accommodating growth

All of these translate into a demand for more lines as line-loads drop, dedicated channels are required and new subscribers appear. In this section, two more modules from Figure 3.1 are addressed. First, the technologies available for providing new lines in rural areas are discussed. From this, a "gap" is available products is identified which in turn defines the requirements for a small digital carrier system.

3.3.1 Available Products

The technologies available today to provide additional lines in rural areas are summarized in several recent surveys (1), (2). The products fall into four principal generic types:

- VF cable and electronics
- small (1 to 8 lines) analog carrier
- small (24 to 48 lines) digital carrier
- large (128 or 256 lines) digital carrier

In addition, several other products are now appearing or will shortly appear on the market. These are:

- Rural Interface Device (RID)
- Remote Line Switches or Modules (RLS or RLM)
- Fibre optical cable

Strictly speaking, the RID does not add to available capacity. Rather, it alters the demand for upgraded service by providing a party-line customer with many of the features of individual line service (privacy and selective ringing) without, however, increasing his chances of finding his line free (i.e. without improving access). The potential effect of this may be to slow the trend to upgrade party-lines to ILS, although all telcos interviewed believe this delay to be temporary only. This delay factor will be discussed further in Section 6.

Remote Line Modules which work off analog central offices are available (3). However, widespread use is generally foreseen in combination with digital switches. The RLM can be viewed in a number of perspectives - it can be considered as simply an extension of the main switch, a community dial office (CDO) or a subscriber carrier. In the first case the RLM physically extends the line/switching network interface and can be thought of as part of the switch. In the second case it replaces inter-office trunks, and in the third, it replaces exchange cable. This is possible because the switch extends the concentration inherent in the switch out into the field.

In general, the RLM is expected to prove in over subscriber carrier when the number of lines is large and/or the growth is high (4). Indeed, large digital carriers such as DMS-1 can be made to operate as a remote line switch when connected to a digital office. Thus the distinction between large digital carrier systems and RLM's is blurred at best. For the purposes of this study, the market served by RLM's is taken to be a subset of the market served by large digital carrier.

Finally, fibre optics are not expected to provide relief for rural exchange lines for many years. Where fibre is used for trunks, digital subscriber carrier will still be required to provide pair gain to serve subscribers' needs. Thus optical fibre is not expected to affect the market for small digital carrier in the next decade.

The degree to which these technologies (especially the four generic types listed above) satisfactorily meet the requirements of telcos in their rural service programs is discussed in what follows.

3.3.2 Product Gap

Prior to issuing the Request for Proposal for this study, the Rural Communications Program of DOC undertook a review of technologies to serve rural areas, and found problems with all existing types of equipment, leading to specification of a new product requirement (and hence the present study). VF designs are becoming more expensive relative to electronics due to the rising costs of the copper wire and labour. Analog systems have enjoyed popularity up to recently, but costs tend to be high. Analog systems will also decrease in popularity with the trend towards a fully digital network. Large capacity digital systems are intended for high density areas close to urban centres, and are expensive when utilized as a small capacity system. Currently available small digital systems are also expensive and do not have the capability of small multiple remote terminals to provide distributed service in low density areas.

This perception of a gap in the rural telephone equipment market which is unfilled by currently available products was confirmed in the interviews conducted as a part of this study with the REA in Washington and the four operating telephone companies participating in the study (Appendix F).

The participating telcos were unanimous in expressing a need for a small digital carrier system in their rural service plans. Three reasons were commonly cited. First, in their rural service improvement programs, the telcos are reaching out to areas which are not economically served by the available large digital systems. Examples include bringing ILS to small communities (Sask Tel) and resorts (MTS). Second, there is a reluctance to install more cable in rural areas, first because of the cost and disruption involved and second because of the fixed nature of the plant. Carrier systems are preferred where growth is scattered and the population is volatile (MTS). Finally, there is a growing disenchantment with analog carrier systems. Sask Tel cited maintenance problems. AGT was more specific, believing that the new models of analog carrier are over-developed, and hence are becoming unreliable and incompatible with the older versions already in use. The fact that analog systems are still being installed reflects the fact that a digital alternative is not yet available on the market.

The major dissentor from this viewpoint is Bell Canada. For the purposes of the NUSI program they have standardized on the use of cable and DMS-1 carrier. Cost studies were performed with Northern Telecom on the usefulness of a 24-channel system obtained by stripping down the DMS-1, but they were unable to prove in such a system. Several factors are involved here. One is the generally higher subscriber densities in Ontario and Quebec than those found in other provinces. Also at work, however, is the rationality of large integrated telcos standardizing on familiar equipment available from their "family" manufacturer, thus in effect "papering-over" the product gap felt more acutely by smaller telcos. This strategy is believed to lead to lower costs overall, even if in specific locations a non-standard product might be more economical.

From examining the needs of the participating telcos and the REA a number of product requirements emerge. These are discussed below.

3.3.3 Product Requirements and Target Cost

As examined above, the potential customers, the operating telephone companies in North America, have identified a need for an economical small capacity carrier system. More specifically, the carrier system must:

- fill the gap between analog and large digital systems. This suggests a capacity of 8 to 64 lines.
- digital to be compatible with the trend to a digital network and take advantage of the falling cost (relative to analog) of digital techniques.
- be compatible with a wide variety of subscriber densities. Thus the system must be capable of being clustered or fully distributed. Concentration would be of advantage in higher density areas and where growth is expected.
- be compatible with planned rural service programs. Thus it must offer four-party service.
- meet performance specifications. These are dealt with in the next section.
- be cost effective against the available alternatives.

More detail on the target costs for the new carrier are provided in what follows.

Cost Parameters of the Carrier

Prior to initiating this study, the Department of Communications suggested a target hardware cost for a small digital carrier system of $300 per line, excluding the T1 line facility (5). Subsequent talks with the telcos in the course of the present study have shown that costs can go much higher than this and still be of interest. The telcos interviewed were asked to state a cost in dollars installed, per subscriber, which would prompt them to consider seriously the use of a small digital carrier system in any of their rural market segments. The answers varied by 100% reflecting the different operating environments encountered. The following gives the results by source and describes the justification offered for the figures given.

REA

$700 per line. This is about $590 U.S. which is 10% less than analog station carrier which in 1978 averaged $656 U.S. per channel, including repeaters. The 10% discount would render new technology "interesting" to REA borrowers. The U.S. dollars have been converted to Canadian equivalents using an 18% exchange rate premium.

NBTel

$1,000 - $1,200 per line, based on using carrier on aerial cable.

MTS

$550 - $600 per line. This applies in an environment such as an Island Base Rate Area (IBRA) which would include a significant requirement for ILS. In lower density areas, costs may go as high as $1100 per line. These costs include the associated subscriber drops. MTS is unique among the telcos contacted in being willing to tolerate a cost penalty of 10% - 15% for digital carrier over analog carrier or VF designs.

SASK TEL

The cost of new technology must be 20% below the cost of VF and analog carrier to be attractive. Based on the cost analysis performed as part of this study (Appendix H), this means:

- $600-$900 per subscriber for bringing ILS to small communities and resorts, depending on the size of the community
- $860 per subscriber to upgrade farms to ILS
- $1140 per subscriber to accommodate growth in 4PL

AGT

Rough installed costs experienced now are $1300 per line for large digital systems to $2000 for small analog carrier.

The actual installed costs of the proposed system were estimated by several telcos as part of the study. These are reported in Section 5 and Appendix H.

3.4 SUMMARY

A variety of service requirements relating to the telephone companies' rural areas have been identified which lead to a demand for new lines. In addition, a product has been identified to meet a portion of this demand. A forecast of the requirements for rural lines (and the cost of providing them) constitutes the potential market of which the new product can be expected to be suitable for a portion. The market potential of the proposed system is derived in Section 6 after discussion of its ability to meet the telcos' product requirements (Sections 4 and 5).

3.5 REFERENCES

(1) The Loop Plant, The Bell System Technical Journal, Vol. 57, No. 4, April 1978.

(2) A Study of the Available Products and Systems for Rural Telephone Communications, K. Logan and Associates, prepared for Department of Communications, Ottawa, April 1976.

(3) Using CO Switch for Pair-Gain Savings, Wm. H. Draeger and Vern Lenz, Telephone Engineer and Management, Vol. 83, No. 14, July 15, 1979

(4) Communication received from NBTel.

(5) Proposal for a Subscriber Carrier System to Serve Low Density Rural Areas of Canada, J.M. Wallace, Department of Communications, Ottawa, September 9, 1977.

(6) 1978 CRTC Hearings, Document Tour 60 days: "Research Aimed at Improving Rural Communications" (March 24, 1977)(ABC-20), C136.

SECTION 4: TECHNICAL REQUIREMENTS

The foregoing section discussed the market for a small subscriber carrier system and the underlying rural service requirements. This section discusses the technical aspects of these requirements in more detail, and will derive specific goals for a system which can successfully fill the "product gap".

Section 4.1 elaborates on the impact of the basic requirements laid out in Section 3, which are fundamental to the provision of low cost rural service. The constraints placed on a new system by existing technology are then examined in Section 4.2.

4.1 BASIC REQUIREMENTS

The fundamental goal of this study is to define a system which is capable of supplying low cost service to low density rural areas. As a direct consequence of this statement, three absolute requirements can be identified. These are the compatibility with the existing plant and technology, a design optimized for rural demographies, and its timely implementation.

4.1.1 Compatibility

Telephone plant is largely fixed and any carrier system must be compatible with it. This is unfortunate in many respects as we shall see later, however, the large investment in the plant, tradition, and the fear of adverse subscriber reactions, all make compatibility an absolute necessity.

A subscriber carrier system can be divided into three distinct components: the central office end, the transmission line, and the subscriber end. We will address compatibility for each.

Central Office End

Many types of central office switches are in service today, including the oldest generation of step by step switches and the latest generation of all electronic digital switches, and while step by step switches are continuously being replaced, many of them will remain in operation for a long time to come. None of these switches is specifically designed to service customers via subscriber carrier systems, which makes the central office interfaces awkward and expensive. It must look like a telephone set. The switch generally assumes that the subscriber line is directly connected to the subscriber set which may not be so in a concentrated system where a limited number of channels are assigned to subscribers on a demand basis. Variations in the operation of switches built by different manufacturers also add to the cost of providing compatibility.

Most of these problems can be overcome by the introduction of digital switches, at least conceptually. As it turns out, each manufacturer employs different designs and internal data formats, which makes a direct digital interface not as simple as it might be (see also Appendix B).

Transmission Line

Much of today's subscriber loop plant is buried twisted pair cable. Aerial cable and open wire are also used in some areas, with open wire having virtually disappeared. Aerial cable has very similar characteristics to buried plant, and need not be given special consideration.

The most common type of cable for subscriber lines is polyethylene insulated cable (PIC) of various gauges and pair count. Low density rural areas are generally served by smaller cable of heavier gauges. In Canada most of this cable is grease filled to prevent water from entering, whereas in the U.S. both filled and aircore cable is used. Their respective characteristics such as attenuation, crosstalk, resistance must be considered when choosing the transmission type to be used on the cable. In addition, the unfavorable economics of replacing and adding cable make compatibility with existing subscriber lines a very real concern.

Subscriber End

Although the telephone set in use today is based on technology of decades ago, the large number in existence today alone virtually preclude any move to update it to a type which can be interfaced with the latest technology digital switches and subscriber carrier systems more economically. Tradition and the desire for continuous service improvements also dictate that the telephone set be powered off the line itself and that service interruptions be all but eliminated.

Although not a universal requirement, party line service must also be offered. The current method of providing party line service is not conducive to its inexpensive implementation on a subscriber system. High power consumption of the ringers make C.O. powered systems impractical for long distances, and remote power installations are expensive. The question of power systems is discussed further in Appendix D.

4.1.2 Demographies

The varying population densities, land subdivisions, and terrain features require, of necessity, different layouts of outside plant. Along with this, telcos tend to have their own practices, differences in them being particularily visible when crossing international boundaries. Whereas Canada and the U.S. tend to be similar, concepts used in Europe are vastly different. Since the prime markets for this system are in Canada and the U.S., any design effort must be directed towards these countries. Enough flexibility to be able to adapt to requirements outside North America should, however, be provided.

The general rural demographies encountered have been discussed in Section 3. The two relevant types are the clustered and scattered distribution of residences. Existing subscriber carrier systems are designed primarily for the clustered areas with small towns and communities. They become economic only for a relatively large number of lines per remote terminal, and as such are not suitable for the low density scattered areas. Many telcos have therefore expressed a need for a distributed carrier system which will become economic for a much smaller number of lines per terminal.

The technical requirements to implement this type of system differ from those for a purely clustered one in that it must be more general and flexible in its design. For instance it must be able to handle single and multiple channel drops along the carrier line. Carrier line branching, and its associated maintenance and administrational problems, must be solved economically. Various other design issues, such as environmental specifications, system powering, transmission line noise, and lightning (transient) protection, also become more significant in distributed systems, partly because of the isolation of remote terminals, but also because of the larger number of terminals involved, which tends to decrease the overall system reliability when they are operated in a series configuration. It must be stressed, however, that such a general design will be able to handle both scattered and clustered configuration, and should therefore result in more cost effective clustered systems as well.

4.1.3 Timing

The timely introduction of a new carrier system is extremely important in determining future sales. Although no prediction can ever be guaranteed, we can learn from past experiences with other carrier systems which indicate early introduction is necessary for sales to build up to a reasonable level during the product's life time. This impact on the market size has already been addressed in Section 3 and will be further discussed in Section 6. The commercial availability of new technology, however, is also very much dependent on time, and has a direct bearing on the acceptability of any new system.

It is difficult to state with certainty whether today's commercially available technology is sufficient to lower the cost of new systems below that of existing ones, even when considering the introduction of distributed systems. The question of whether to wait for new technology or not then presents the manufacturer with a paradox, since this waiting may well erode the market altogether. Clearly, a compromise must be found, and the design must be flexible enough to accommodate the changing demands and technologies.

4.2 TECHNICAL CONSTRAINTS

As a direct result of the above requirements more specific constraints can be defined. These are largely related to the existing telephone plant and telco practices, and have been derived mainly from discussions with the telcos themselves. The findings are detailed in Appendix E.

4.2.1 Transmission

In choosing transmission types the characteristics of the existing and future plant must be considered as a very basic constraint. The expense of burying new plant simply for the carrier system is clearly unwarranted, and any system must therefore transmit via conventional twisted pair cable. The basic characteristics of this type of cable are the following:

- The twisted pair is balanced with respect to ground
- Signal attenuation increases nonlinearly with frequency

- Characteristic impedance is complex and decreases with frequency.
- Velocity of propagation increases with frequency.
- Crosstalk increases exponentially with frequency.
- Crosstalk increases with increasing wire diameters and lower pair counts.
- DC resistance increases as the wire diameter decreases.
- All cable parameters vary statistically and have a normal distribution about their mean.

These characteristics have a number of significant consequences:

- A composite frequency signal transmitted via the twisted pair will be distorted in both amplitude and phase. This is particularly important for analog transmission in that linearity is important. Digital transmission is more immune to this problem as long as distortion levels are kept below the detection threshold.
- The distance of transmission is limited by the highest frequency in use, which means that a high capacity (wide bandwidth) signal must be repeatered at shorter intervals.

The question of capacity is further discussed below:

- The lower crosstalk losses at higher frequencies result in higher noise levels, reducing the repeater spacings even more. In the case of analog transmission this noise is cumulative over the entire distance of the carrier transmission and therefore severely limits the use of high carrier frequencies for carrier systems. In digital transmission we do not use noise levels to assess performance, but rather the probability of an error in the detection of a bit, expressed as an error rate. And although these error rates are cumulative, they are not dependent on the total distance of transmission, only on the length of cable between repeaters.
- These lower crosstalk losses also limit the number of systems per cable by the frequency of operation. For digital this can be compensated for by appropriately reducing the repeater spacing (see also Appendix A). For analog the total system length is limited since crosstalk (like noise) is cumulative.
- Lightning is a problem for almost all communications systems, particularly for buried cable. There is no question that little can be done to protect against a direct strike, but luckily these are very rare. In buried systems it is the surge of current passing the cable for lightning anywhere in the area which induces surge currents large enough to burn out the entire system if not protected against, and they are not uncommon. Lightning protection is expensive, but must be regarded as an absolute requirement.

- 60 Hz AC voltages are also induced onto the cable from adjacent or overhanging power lines. Although not as severe as lightning, these voltages are present continuously and must be rejected. The balanced wire pairs prevent metallic currents from flowing, but this balance must be preserved at all interfaces.

- Cable variations are inevitable, not only with respect to different types, but also age, condition, and type of installation. In Canada the most common types are screened and unscreened filled polyethylene insulated cables from 2 pair to many hundred pair 19 to 26 gauge. Installations are both buried and aerial design. The larger cables also use paper insulation, but mainly for inter-office trunks. Aircore cables are seldom used in exchange plant in Canada, although common in the U.S.

Standards are also a constraint, though not a physical one. This really means that although original transmission design is possible, acceptability may well be limited if standards are not observed. The use of standard carrier frequencies and levels is therefore preferable in analog systems, and T1 in digital systems. The acceptability at T1 has been proven by its universal use throughout the telecommunications industry. The ready availability of T1 equipment and circuits also serve to reduce the R & D investment for a new system.

4.2.2 Modulation

Modulation serves to transmit the speech via the carrier. Many choices are available for analog systems, such as amplitude modulation, double side band, single side band, frequency or phase modulation and their respective variations. The most common ones are DSB and SSB because of their bandwidth efficiency and relative good noise performance.

In digital systems the choices are equally varied with each coding technique having its own merits in terms of cost, noise performance, distortion, etc. (see Appendix C), however, pulse code modulation is clearly the forerunner because of its almost universal use in telephony. Other schemes are slow in acceptance, in part because of their incompatibility with PCM. Adaptive delta modulation has been successfully employed in a number of subscriber carrier systems and, because of its greater bandwidth efficiency and simplicity, is ideally suited for rural applications. Adaptive differential PCM is possibly better yet, however, it has found even less acceptance. PCM is therefore the most likely choice.

4.2.3 Capacity

The line capacity of a new system should be consistent with the gap identified in Section 3. Current analog systems use from 5 to 8 channels, and even with the addition of concentration, considered too small. A more likely figure is 20 to 40 channels which could be expanded into up to 100 lines and more without seriously degrading the blocking probabilities.

Considering the physical transmission constraints analog systems are hard pressed to yield this number of channels and maintain acceptable performance. A better choice is a digital T1 system which has the potential for being less expensive, and perform better, for the same capacity. PCM on a T1 carrier yields 24 channels, almost at the lower limit of the above stated goal, ADM could yield up to 46.

Related to this issue is the power consumption. A channel implies an active telephone which requires ringing power and a minimum of 23 mA talk battery. In other words a large number of channels requires higher design power capacity to handle that many telephones simultaneously. Traditionally all power to a telephone was supplied from the central office, however, the power supplied through the cable is limited and remote power will be required (see Appendix D).

4.2.4 Interface to Switch Gear

The line circuits of the central office switch are designed to work into a 500 telephone set via a twisted pair cable. It therefore cannot handle a carrier system unless it "looks" like a telephone set. Conversely, the telephone must be connected to a line circuit which is equivalent to that of the switch if it is to function properly.

This imposes some difficulties on the designer, although not insurmountable. The interface to the switch must receive and convert ringing voltages and talk battery, and take the proper actions. In the case of party lines coded, divided, and frequency selected ringing signals must be properly decoded and regenerated at the subscriber end. The power requirements for ringing were discussed previously (see also Appendix D). Hook status information and dial pulsing is to be detected at the subscriber end and regenerated at the interface. At the same time the balance of the wire pairs must be preserved.

Telephone transmission in the loop plant is largely two wire, that is both direction of transmissions are superimposed on each other. Balanced hybrid circuits are used for directional separation, but their balance depends on line impedance. Different line lengths and sizes result in differences in these impedances. Care must be taken to match these line impedances as closely as possible to maximize directional separation and avoid oscillation within the carrier system.

Related to this are the reflections, or echoes, which are introduced at every impedance mismatch. A poorly designed carrier system can contribute significantly to echo problems in the telephone system.

The advent of a fully digital network will make a direct digital interface to it absolutely essential. There is no question that this will happen, although it is difficult to state exactly when. The rate of introduction of digital switches is continuously increasing, and although most installations are currently urban, rural areas are also being converted especially in the U.S. There are, of course, conventional line circuits available for these switches enabling analog interfacing, but the cost and performance penalties to be paid speak strongly in favor of direct interfacing. This brings up the question of code conversion if some other method besides PCM is used in the carrier system. While possible, it is still expensive and undesirable with today's technology. Conversion IC's will be available commercially in the future but exactly when is, again, not known. Most factors still tend to speak in favor of choosing the conservative approach of using PCM for a digital carrier system. Appendices B and C deal further with the questions of direct digital interfacing and code conversion respectively.

4.2.5 VF Performance

Details of performance specifications as required by the telcos are given in Appendix E and are reflected in the design specifications (VOLUME 3 - SYSTEM DOCUMENT). They are generally for toll quality since telcos wish to maintain total system performance at a high level. Pressure for "urban" quality also comes from subscribers who move out of the cities and expect equivalent service in their rural homes. Considering the economics of rural telephone installations, a good case can be made for a reduction of performance in return for lower costs. The final answer to this dilemma will ultimately lie with the manufacturer, and how he perceives the market. It is true, however, that there is not too much room for compromise left as competing systems with relatively good performance will tend to set standards for telco purchasing decisions.

4.2.6 Environmental and Maintenance

Because of the nature of the subscriber carrier installation, environmental consideration have a direct bearing on maintenance costs. The remote terminals and repeaters will be exposed to all types of weather and must not break down as a result, or else maintenance costs will become high and service poor. The effect of this requirement is reflected in the hardware costs which will increase proportionally with the operating range. This is discussed in more detail in Section 5.

Aside from reliability, accessibility and mean time to repair are also important. As such diagnostics to enable remote testing of repeaters, subscriber terminals, and loops are required, especially for large distributed systems. Some telcos require complete backup systems with selectable spare transmission lines.

SECTION 5: PROPOSED SYSTEM

A complete system definition emerged from the study, as a result of continued technical work and marketing research. All of the requirements and problems which came to light as the study progressed had to be addressed and continual adjustments made to the system concept and design. The final design is discussed in this section, both from a technical and economics viewpoint. Technical details are provided in VOLUME 3 - SYSTEM DOCUMENT, and relevant theoretical background information is given in the appendices; they are referenced where applicable.

5.1 BASIC CONCEPT

Early in the study several concepts were examined for their suitability to fill the market requirements. As the study progressed, however, it became clear that in order to define a system which most closely answers to the telco needs, and therefore the market-place itself, the goals for and the concept definition of any new rural subscriber carrier system must be clearly laid out.

5.1.1 Goals

The primary goal, of course, is for the proposed system to be able to economically serve the telecommunications needs of rural dwellers. The key word is economically, since these needs can be served today by various other means, including VF cable and large digital carrier, although rather expensively.

It is expedient, however, to define more specific goals to aim at. This has been done throughout Sections 3 and 4, the results are summarized below:

The proposed subscriber carrier system must:

- fill the market gap between small analog and large digital carrier systems
- be cost effective against the available alternatives in both capital and operating costs
- be compatible with existing and future telephone plant
- be compatible with a wide variety of subscriber densities
- offer all existing voice services (POTS) including party line
- be adaptable to new, especially data, services (PANS)
- meet performance specifications

Only the first three items are sufficiently fundamental to be regarded as absolute requirements, which, if not met, could virtually eliminate any market for the system. Failure to attain all of the last four goals would not be quite as detrimental, but still affect its marketability.

5.1.2 Concept Definition

The concept which is believed to best fulfill most of these requirements and goals has the following attributes:

- digital T1 subscriber carrier system
- optimized for less than 64 subscribers
- distributed configuration
- clustered configuration also possible
- low power consumption
- individual and party line service
- PCM, alternatively ADM
- concentration optionally available as add-on to central office terminal only

The reasons for the above are largely self evident when examining the goals and requirements, however, some warrant further explanation.

With the rapid expansion of digital switching and networks, a digital carrier system will obviously benefit most from the associated advances in technology. Digital also has performance advantages over analog when large distances are covered over noisy lines: it has the potential of remaining virtually noise and echo free over any distance. While analog systems have generally bottomed out in price, digital systems continue to become less and less expensive.

The use of T1 carrier is widespread, line engineering principles are well known and equipment has become relatively inexpensive. The purchase of new test equipment, additional inventory of repeater spares, and the re-training of outside plant personnel is alleviated by the use of T1 carrier. The only hurdle to overcome is its application to small exchange grade cable with sizes ranging from 16 pair down to 2 pair. This difficulty is addressed further in Appendix A.

The combination of distributed and clustered configurations serves the variety in demographies well. It does not present any technical difficulties, since clustered is really a special case of distributed, with only one remote terminal. Thus it gives the freedom of choice to the telco. Three typical configurations are:

1) a fully distributed system as may be applicable to the very low density prairie provinces and states,

2) a clustered system which would serve small communities and resorts, and

3) a combination of both for dwellings and small settlements distributed along roads, river valleys, coast lines, etc.

These are illustrated graphically in Figures 1 to 3 of the EXECUTIVE SUMMARY, which are also appended at the end of this report.

Low power consumption has a direct effect on costs, both capital and operating, since a good portion of them are due to the power supplies and their maintenance. Unfortunately, this is likely the most difficult to achieve, mainly due to the requirement of compatibility with existing telephone plant. The 500 telephone set itself is the worst offender in this regard.

Pulse code modulation (PCM) is suggested as the initial offering, for reasons of compatibility and performance. It is intended, however, that the design be such that all channels are available for other uses, such as data services or different modulation techniques. Adaptive delta modulation (ADM) has many advantages, and could become an alternate offering. From a production point of view only new channel units (line cards) would be required.

Concentration becomes a requirement when larger systems are to be installed. This is particularly true when using PCM which provides for only 24 channels, roughly one third of the desired 64. Since many low density installations require less than 25 lines, concentration should be an option. It is desirable not to have to modify the remote terminals (there could be many in a distributed system) when adding the concentrator into an already installed system, and to simply add the required boards into the central office terminal. The practicability of this concept, however, can only be determined by a more detailed design of the concentrator during the continued R & D activities.

5.2 SYSTEM DESIGN

The detailed design, to the extent that exploratory development has been performed, is described in VOLUME 3 - SYSTEM DOCUMENT. A complete functional description with performance requirements is also provided there. This section presents the philosophy used in deriving the design, and discusses its salient features.

Before discussing the design, it should be mentioned that the requirements of Section 3 and 4 are largely met. The functional goals form the basis of the design, and as such have been achieved. Maintenance features, both in function and specification are very much a function of cost, and as a result tradeoffs must be made. Features with little impact on cost are generally standard offerings, and others are slated to be options, leaving the tradeoff decision to the telco. The same is true for performance specifications, although there is less room for tradeoffs. The majority of the specifications can be met at a reasonable cost, although there are cost advantages in choosing a speech coding technique other than PCM. If this is done, performance may be slightly below the requirements.

5.2.1 Design Philosophy

Any system which is to be cost effective must be inherently simple. It is therefore rather important not to spare any effort to optimize and simplify the design. To this end several rules must be obeyed:

- The design must be modular. A bus structure with a single motherboard is essential in reducing module interconnectivity and complexity.

- The design must be flexible. This requires the optimal distribution of functions into modules, such that individual modules can be changed, rearranged, and updated without affecting system performance. It also requires that the system be easily adaptable to a variety of configurations or options and layout.

- The design must be expandable, in other words, it must allow for the addition of functions without a change to the basic system. An example is the addition of concentration to accommodate subscriber growth.

- The design must be serviceable. The importance of this rule cannot be stressed enough. It means the design must be straightforward and not obscure, it must include test points and sufficient capabilities to locate faults within minutes. This includes fault detection, isolation and possible protection switching for the transmission line, where the majority of faults are likely to occur.

- An optimal balance must be found between minimizing circuit duplication and the amount of common electronics. Consideration must be given to the previous rules when dividing functions between common equipment and per line channel units.

- The number of different modules should be minimized, while maintaining modularity. This reduces production costs by taking advantage of fewer, but larger quantity production runs, simplifies testing and servicing procedures, and reduces inventory requirements.

Aside from these rules, there are other decisions required which have a significant effect on the final design, yet are almost transparent to the user. These include the choice of a logic family (TTL, low power Schottky TTL, or CMOS), the number of available voltages, relay versus semiconductor switching, and others. The answer for those questions lies with the ultimate manufacturer of the system, especially since design practices continually change with advances in technology.

5.2.2 Basic Design

In keeping with the above concept definition and design philosophy, a digital ring design has been chosen. It is schematically illustrated in Figure 5.1. In this configuration data continues around the "ring", i.e. channel information is removed and inserted on the same T1 pair. The returning pair is simply passed through a simplex repeater. The advantages of this design are numerous:

- It handles branching very conveniently for distributed installations. The common electronics are reduced in complexity and duplication of regeneration and multiplexing circuitry is avoided.

- Simplex power feed may be used.

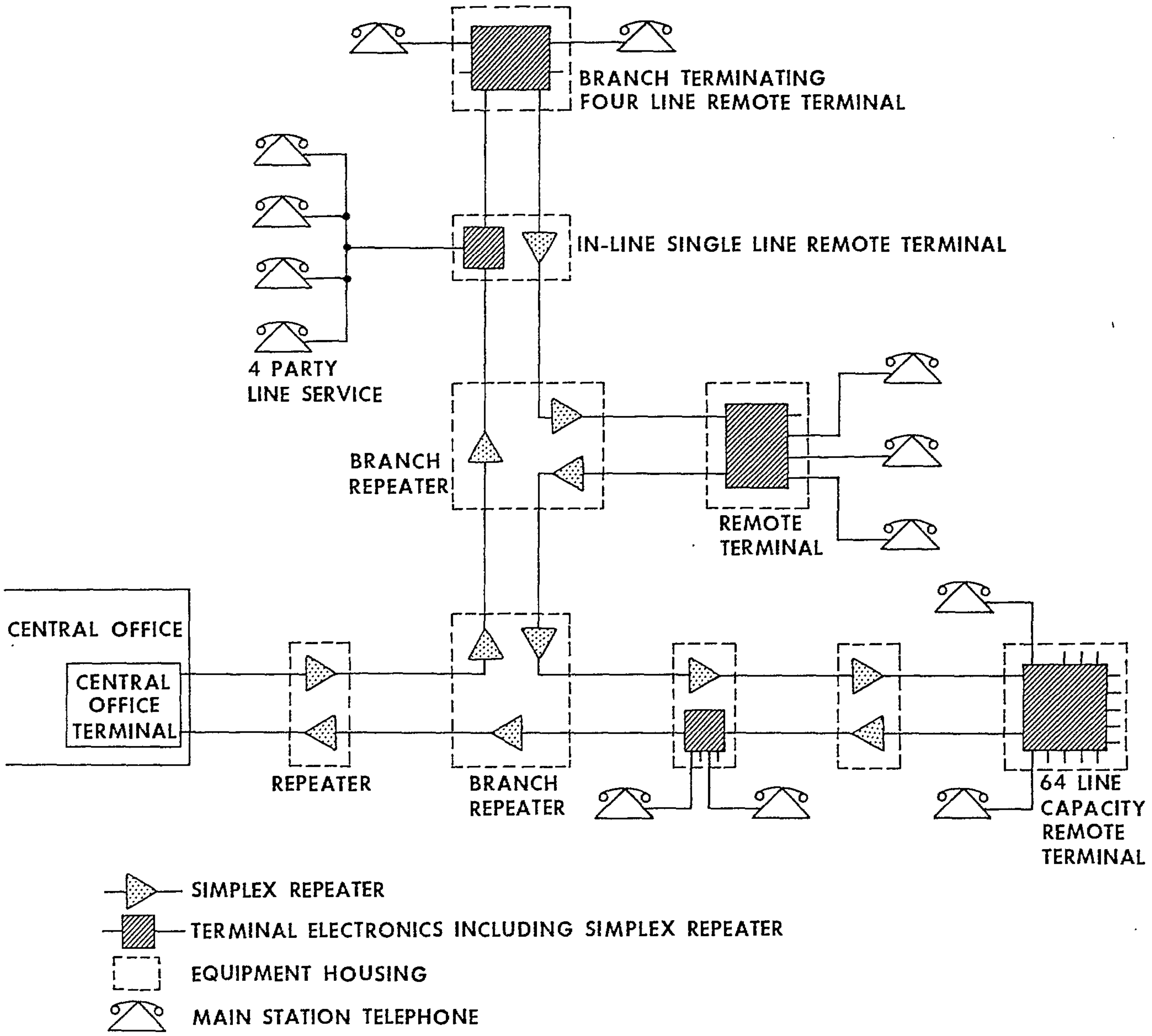

FIGURE 5.1 T1 CARRIER SYSTEM CONCEPT

- Reliability is increased.
- Clustered installations are also possible.

The transmission technique, as mentioned previously, is T1 carrier. Design principles are well known and a number of standard and inexpensive LSI sub-systems are commercially available. These include low power regenerative repeaters and communication controllers (special function microprocessors) which are designed to operate at the T1 rate of 1.544 Mbit/s and above.

A concern with T1 is total number of repeaters allowable per system. Up to 200 simplex or 100 duplex repeaters are generally acceptable due to the cumulative effect of timing jitter induced by them and the line. This may seem like a large number but it is approachable in large distributed installations in very low density areas (a design for Sask Tel's Lloydminster Exchange area shown in Figure H.3, Appendix H, includes 58 remote terminals plus 26 repeaters for a total equivalent of 167 simplex repeaters). Even if fewer repeaters are used timing jitter also reduces noise immunity by contributing to a closure of the "eye" pattern. (An open "eye" pattern at the regenerator is needed to make a reliable decision regarding the presence of a "1" or "0"). For this reason each terminal includes a crystal controlled phase lock loop to achieve clock sychronization, removing the jitter to a large degree. This way considerably more repeaters may be used per system, allowing larger, more cost effective installations.

The channel capacity of T1 carrier depends, of course, on the bit rate of the modulation technique used. To retain as much flexibility as possible, the standard D2/D3 framing pattern is used regardless of channel bit rate. This also avoids the use of intentional bipolar violations (for synchronization purposes), which interfere with established line testing procedures. PCM is suggested as an initial offering, and provides 24 high quality channels. This is less than the 64 line requirement, and concentration must therefore be available. While it is possible to achieve a 48 channel capacity by using two T1 lines, or even a single T1C line, it was felt that the additional complexity, and the requirement for T1C repeaters, were not in the interest of cost.

The use of concentration can be further reduced by using ADM instead of PCM. A bit rate of 32 kbit/s is suggested for its simplicity in implementation with the D2/D3 framing pattern. The T1 carrier can be easily subdivided into 48 channels, two of which would be used for signalling, and 46 for voice. The performance of ADM is somewhat below that of PCM, but its lower overall cost may be an acceptable tradeoff (See 5.3.1). Incidently, the signalling channels have the same bandwidth per channel as those for PCM.

The implementation of this design calls for the extensive use of a bus structure. It reduces design and construction complexities and allows for partial as opposed to only complete redesign for future versions. The interchangeability of modulation techniques and data services requires the use of individual channel codecs, as opposed to the traditional approach, which uses a single codec and analog time division multiplexing. While the channel unit cost and performance specifications are better for the traditional approach, the added flexibility and lower common equipment costs of the individual channel codecs are very attractive, and have caused semiconductor manufacturers to gear towards this new approach (1). Consequently cost and performance are expected to improve with time.

Inherent in the design are extensive maintenance and servicing features. The various protection features include error rate and bit density detection, alarms from the remote terminals, and a two level backup switching system. The latter is suggested as an option, since the extra expense may not be warranted for small installations, and telcos differ in their policies. Standard fault locating and T1 line testing techniques can, of course, also be used.

Individual modules include built in diagnostic capability, test points and test jack. A test jig (in the form of a complete system with selected test modules and equipment) is used for production testing and factory board repairs. Sophisticated diagnostic software is provided with each concentrator module, and some limited form with each alarm and backup switching module.

5.2.3 Concentration

The design also lends itself to concentration, which is to be included as an option. Another module would simply be added to the bus of each remote and the central office. A slightly more advanced (and more expensive) circuit design could eliminate the requirement for remote terminal modifications altogether. Although the production costs per remote would increase somewhat, the benefits are obvious:

- no need for field changes when adding concentration
- reduced inventory
- improved maintenance

While concentration itself has not been looked at in as much detail as the remaining circuitry (it is very expensive to develop), it has remained a consideration throughout.

The implementation suggests the use of a microprocessor, which allocates channels on a demand basis. Both call origination and completion must be handled, and a polling scheme will likely be used to detect off-hook conditions. Two-way control communication to the remote terminals is via one of the 64 kbit/s channels, thus providing a secure and fast data link.

The concentrator must also properly handle blocking. A central office switch does not expect blocking at the subscriber loop and consequently must be "fooled" into assuming that the blocking occurred inside the switch. This is essential to prevent billing on toll calls which were completed through the switch, but not through the carrier system.

A direct digital interface to the new generation digital switches can avoid this difficulty by accepting the carrier's concentration as that of the switch itself; the subscriber carrier system becomes, in effect, a remote line switch. This is possible depending, of course, on the software of the switch itself.

5.2.4 Servicing of the Distributed System

One of the outstanding features of this design is its capability as a distributed system. While many telcos have expressed fear and doubt about the maintenance and administration of distributed systems, they all concurred in the statement that it has applications, especially in the very low density areas, such as the Prairie Provinces, the Pacific North West and Western states of the U.S.

Distribution in itself is not difficult to provide, and the proposed ring design is far from complex. The difficulty arises when attempting to locate system faults, or cable cuts. Providing carrier loopback on the central office side of the fault ensures that the system remains operating. The line propagation delay of a test signal will indicate the total cable distance which has been lost, however, it will not provide information regarding the branch which has been lost. This must be extracted by knowing which remote terminals are still operating. An approximate location can then be calculated. Should two or more faults be present in separate branches, the calculations will only provide several possible locations.

Needless to say, unless accurate and up-to-date maps of the installation are available, the location of faults can be an expensive procedure. The diagnostics of the concentrator (concentrated systems are obviously larger) must therefore provide as much information as possible, including total distance to fault, and addresses of inoperative lines and/or remote terminals. It is possible to build addresses into each repeater, but that would be very costly, and not possible if standard T1 lines are to be used. Standard fault locating techniques also become more difficult to apply. The fault locate pair has to be split at the branches, unless a pair is provided for each branch. While possible, this can get expensive.

There is no simple solution to this problem and certainly not an inexpensive one. Considering the state of the art of microprocessor technology, and the trend towards more and more computing power at very low hardware costs, an automatic fault locate system has the best potential to simplify the maintenance task. While telcos will likely wish to retain their manual system, which is quite independent of the carrier system design itself, the alternative of automation in this area is attractive to them, and should serve to remove a lot of skepticism about distributed system.

In providing automatic fault locate as part of the system diagnostics, the same cost considerations that were used for the concentrator apply. It should therefore be an option, which, when installed, will not require any part of the manual system.

5.2.5 System Performance

The performance specifications for the system, presented in detail in VOLUME 3 - SYSTEM DOCUMENT, were derived by examining existing carrier system specifications and consulting with the various telcos (see also Appendix E). Some of these specifications require special attention since they may be difficult to obtain inexpensively. They are discussed in more detail below. Specific cost versus performance tradeoffs are discussed in Section 5.3.1.

Idle Channel Noise

Experience with another carrier system which SED Systems Inc. is developing shows that the figure of 20 dBrnC is hard to improve upon without special techniques. These techniques include voice switches or injection of a specific idle pattern. Both involved the detection of an idle condition without seriously affecting the transmitted voice. A prerequisite, however, is a well designed codec layout with shielding, and power supply filtering to achieve maximum isolation from the digital switching noise.

In theory, PCM is quieter than ADM, however, any line noise contributing to transmission error rates more seriously affects PCM. In this case, even the aforementioned techniques will not eliminate all of the noise. The theoretical noise floor for D2 PCM coding is 18 dBrnC, and systems using this coding specify 16 dBrnC typical, and 23 dBrnC maximum; they cannot guarantee 20 dBrnC. Even analog systems typically specify 15 to 20 dBrnC.

Delta modulation's high immunity to line noise allows its noise figure to be reduced (using these special techniques) to an almost imperceptible level. The DM32S system has specifications of 10 dBrnC maximum with 3 dBrnC typical, which were confirmed by AGT's tests (see also Section 2.1.2). Although it is not known what method this particular system uses, it shows the versatility of ADM.

Insertion Loss

A requirement brought forth by the telcos is that central office to subscriber telephone voice loss be no greater than 8 dB. In low density rural areas subscriber loops are long and can easily approach this figure by themselves. This implies that the system insertion loss be held low, preferrably 0 dB. The difficulties in doing this are directly related to the fact that 4 to 2 wire conversion is not perfect. It is accomplished using a balanced circuit, traditionally a transformer, although solid state devices are now available. This balance depends on proper termination of the two wire line whose impedance can vary dramatically with different installations, and certainly during on hook conditions. A severe impedance mismatch can result in an imbalance which reduces the transhybrid loss (transmit to receive on the 4 wire side) to virtually 0 dB, thus creating a closed loop in the case of further mismatches on the central office side. If the loop gain is greater than unity oscillation results, not a desirable condition. As a safe guard the end to end gain is held to an amount sufficiently less than unity to compensate for component and production tolerances, as well as subscriber line tolerances. The 8 dB figure of total loss may therefore not be achievable when stipulating that maximum subscriber loop length can be used. Many existing systems cannot handle long loops, and telcos serving low density areas find this undesirable. This difficulty can largely be overcome by installing a distributed system since, by definition, they result in shorter average loop lengths.

Return Losses

Both Echo Return Loss and Singing Return Loss are related to this phenomenon of impedance mismatches. Echo return loss specifies the level at which a talker hears his own echoes which are reflections caused by impedance mismatches. Singing refers to the losses at specific frequencies, namely 250 - 500 Hz and 2500 - 3200 Hz where return loss have been shown to be worst. If the total losses are low enough, "singing" may result. Both echo and singing are already factors in the existing analog network, and it is therefore of paramount importance to keep additional losses high. Unfortunately, it also requires the insertion loss to be greater than 0 dB, most likely 2 to 4 dB.

Distortion

There are many types of distortion affecting any carrier system, and a brief discussion follows of some which are peculiar to digital systems.

One of these is Quantization Distortion, or noise introduced by discrete sampling of the analog signal. Quantization noise for linear PCM is generally a constant value independent of signal amplitude. The signal to noise ratio thus worsens as the signal level drops. To compensate for this companding is used which boosts low signal levels while attenuating large signals before encoding. The reverse happens when decoding and the net effect is that the S/N ratio stays more constant as levels change. The D2 PCM format can achieve 35 to 40 dB for signal levels down to -30 dBm. In delta modulation quantization noise is related to both amplitude, slope and sampling rate. An adaptive stepsize algorithm may be employed to reduce high sampling rate requirements for improved signal to noise (distortion) requirements. The distortion due to sampling alone, assuming the stepsize can follow the signal instantly, would be less than for PCM; however, since the stepsize cannot do this, some degree of distortion is introduced. It usually involves a phase shift, which in itself is not a problem, but it also contributes to quantization noise. To achieve PCM equivalent signal to noise performance, at the 1004 Hz test frequency, a 40 or 48 kbit rate is generally required. Lowering the bit rate brings a performance penalty, however, at 32 kbits very close to telephone standard performance can be still obtained, usually within 2 or 3 dB (30 to 31 dB, compared to 33 dB for the Bell Telephone specifications). Subjective listening tests show this difference to be virtually imperceptible, and future innovations will surely improve these figures.

Foldover distortion, or aliasing, is a direct result of sampling. In essence sampling is modulation, and in the process of demodulation, an input signal (including noise) of a higher frequency than one half the sampling rate will also appear at a lower frequency. For example, in the case of PCM, which is sampled at 8 kHz, a 5 kHz signal will "fold over" around 4 kHz (one half the sampling rate) and also appear at 3 kHz. To prevent this from occurring, line filters are employed. For PCM, the filter has to be very sharp to sufficiently attenuate signals greater than 4 kHz, yet not attenuate voice frequencies below 3.4 kHz. These filters are available, but are more expensive than those required for ADM where aliasing occurs far above the voice band at 16 kHz in the case of a 32 kHz sampling rate.

Environmental

The requirements for the remote terminal regarding environmental protection and temperature operating conditions may well be the single greatest contributor to hardware costs. At T1 data rates TTL electronics are necessary (as opposed to CMOS technology which has inherent wide temperature specifications) and the military versions which can handle these temperatures cost approximately 50% more. Special circuits, such as the codecs, op amps, ROM or logic gate arrays, may have an even higher upcharge. Temperature tolerant capacitors are expensive as are electrolytic power supply capacitors rated for -40° C. Besides extreme cold, all of these components must withstand high temperatures in the summer months.

REA specifications (PE-69, May, 1978) call for rugged, long life equipment housing which has to withstand:

- sand and dust test (at various temperatures)
- driving rain test
- temperature, humidity and thermal shock
- salt fog test
- fungi test
- vibration tests (5-55 Hz @ 1.0G)
- shock tests (40G)
- flame test (exposed to open flame without igniting)
- firearms test (#6 lead shot fired from a 12 gauge shotgun at 12 m. must not cause penetration)
- field exposure test
- lightning surge test

While no specific design for such a housing has been made, availability was examined and its cost included in the cost estimates of Section 5.4.2. Considerations were also given to these tests when calculating overall production costs.

5.3 COST PERFORMANCE TRADEOFFS

Throughout the discussions with the Canadian operating companies it has become apparent that performance and serviceability of the rural subscriber carrier system are of utmost importance to them. Even though cost effectiveness is always a factor, the telcos wish to retain a reputation of providing good reliable service, and appear to be willing to pay a premium for it. Existing systems both meet specifications, and fall short of them, yet they are selling. In many cases telcos have built on this experience, and tightened their specifications, or accept the shortcomings since no or only undesirable alternatives are available.

The telcos indicated their requirements in view of their experience, and were, naturally, reluctant to accept tradeoffs when discussing future systems. What did become clear was that any new system must effectively compete with alternatives which will exist at that time. It is therefore rather difficult to assess the true compromises which can be made. Comparing with advanced information of carrier systems is not very useful, since they usually quote existing subscriber carrier system specifications, such as the ones published by the REA, which are not necessarily indicative of actual performance.

The independent telcos in the U.S. do not appear quite as rigid in their stance toward specifications: economics is the ruling factor. The REA, however, finances only approved equipment, and their position is somewhat similar to that of the Canadian telcos.

The conclusion drawn from these discussions is that little design effort may be spared in an attempt to meet specifications. In other words, even if selected features are supplied as options only to lower the basic system cost, they must still be designed.

Nevertheless, some tradeoffs are still possible if telcos can be convinced that they are in their interests. Further compromises are also possible if a manufacturer is willing to market a lower quality product with the hopes that telcos will purchase it regardless of their recently expressed concerns. Listed below are various tradeoffs with an estimate of their impact on system price and R & D development cost.

5.3.1 V.F. Performance

These compromises relate to the voice circuits only, specifically the channel units or line cards.

Tradeoff	Price per line Saving	R & D Man-hour Saving
Signal to Noise Ratio (full spec: 33 dB min)		
64 kbit/s PCM - full spec	0	0
48 kbit/s ADM - full spec	\$140 @ 32 lines max.	0
40 kbit/s ADM - 1-2 dB below spec	\$120 @ 38 lines max.	0
32 kbit/s ADM - 3-4 dB below spec	\$100 @ 46 lines max.	0
lower tolerance components	\$20	100

These savings essentially indicate the saving of the concentrator, with 32 kbit/s ADM costing less per line for systems up to 46 lines. This is illustrated in Appendix H, Figure H.1. The above savings also include approximately $15 per line in basic component cost of ADM over PCM. With the availability of low cost PCM line filters, this saving is expected to disappear. No saving was estimated for less temperature tolerant components, since it is felt that no tradeoff is possible here.

Tradeoff	Price per line Saving	R & D Man-hour Saving
Idle Channel Noise (full spec: 20 dBrnC max)		
64 kbit/s PCM - 25-30 dBrnC	$10	100
40 kbit/s ADM - 25-30 dBruC	$10	100
32 kbit/s ADM - 29-34 dBrnC	$10	100

Indications are that full spec idle channel noise is possible with both PCM and ADM. Lowering performance results in some component savings, particularily power supply filters and shielding.

Crosstalk Coupling (full spec: 72 dB, 67 dB min)		
65 dB	$10	150
60 dB	$20	250

This is somewhat more difficult to achieve and is a function of physical layout and power supply filtering. It is closely related to idle channel noise which, in part, is digital crosstalk noise.

Longitudinal Balance (full spec: 60 dB min)		
40-50 dB	$30	350

While the saving here looks attractive, it is questionable if this compromise should be made, particularly in rural systems characterized by long loops. Even at 60 dB balance, a 60 Hz hum can be detected if the induced voltage is high enough. 60 Hz voltages and currents also potentially interfere with off-hook and dial pulse detection.

Ringing (full spec: 5 ringers)		
2-3 ringers	$10	50

Aside from the component saving per line card, there is the potential saving of some remote power supplies in a distributed system. The wide variance of configurations makes it virtually impossible to estimate a saving per line. This, of course, does not apply to party line service.

Party Line Service (surcharge)		
2PL	$80/line	200
4PL	$100/line	300

Environmental

This is very hard to estimate since some temperature tolerance is required, as is a housing which can protect the electronics to a certain degree. The environmental specifications contribute approximately one third to one half to the total component costs, including the box, of the remote terminals and repeaters; but these can only be saved if the terminals are placed into air conditioned buildings. If the design will not meet the full REA specifications (which is not recommended) then a new cost estimate must be prepared.

5.3.2 Maintenance and Servicing

Considerably more money can be saved in this area than for V.F. specifications. The list below gives total equipment cost and the design requirements. Some of these are not included in the estimates done in Section 5.4, and must be considered surcharge of the price (as opposed to manufacturing cost).

Feature	Equipment Cost	R & D Man Hours
Automatic backup line switching	\$ 800/C.O. \$ 200/remote + spare line	800
Loop back on C.O. side of fault	\$ 50/remote	300
Manual fault locate	\$ 50/repeater	300
Automatic fault locate	\$1000/C.O. \$ 50/remote \$ 20/repeater	500
Error rate detection	\$ 100/C.O.	150
Alarms	\$ 200/C.O. \$ 50/remote	400
Full Diagnostics	\$ 200/C.O. \$ 50/remote \$ 20/line	1000

In examining these costs, it must be remembered that these are very approximate estimates only, and require a much more detailed design than was performed under this study.

It is obvious that these features are better candidates for lowering the system price, although it may require changes in telco engineering policies and practices for them to be generally acceptable. Providing most of these as options rather than as standard features allows for individual preferences.

5.4 SYSTEM ECONOMICS

Estimates of the various stages of implementation of the system were based on the proposed system design, the exploratory development of parts of the system, relevant manufacturing experience, and experience gained through the development of another, lower capacity system in conjunction with Sask Tel (DLS-7). Detailed breakdowns of costs are provided in Appendix H, and are believed to be accurate to within 10% in 1979 dollars considering availability of today's applicable technology. Unforeseen changes in both availability and cost of various components and/or subsystems may change these estimates considerably.

The first stage deals with the outstanding Research and Development work required to produce a working production model including its field trials. Following that the production costs and pricing policy are discussed, and finally a summary of the installed system costs as seen by the telcos is given.

5.4.1 Research and Development Costs

The work activities required to develop a working production model of the system discussed above are shown in Figure 5.2. It is estimated that a total of 18 months will be needed to complete the design, production engineering, field trials, subsequent evaluation and modifications, and documentation. The manpower requirements and the associated costs are detailed in Tables 5.1 and 5.2.

The tasks and costs are divided into basic system development, concentrator development, and common tasks required for both. This division shows the high proportion (31.5%) of the total cost which is required for the development of the concentrator, which is microprocessor based and therefore predominantly software. It is suggested that concentration therefore be an option and, depending on the pricing policy, the development costs for the concentrator be added to the concentrator price only. The basic unconcentrated system will then be less expensive making it more attractive for smaller installations.

It should be mentioned here that, apart from concentration, the basic system includes the various options suggested previously, such as:

- ILS channel units
- 4PL/MPL channel units
- 4 wire channel units
- spare line capability
- alarms from remote terminals
- full fault locate
- basic diagnostics
- loop back on C.O. side of fault
- full environmental specifications

Not included are:

- direct digital interface to the digital switch
- automatic backup transmission line switching
- data channel units

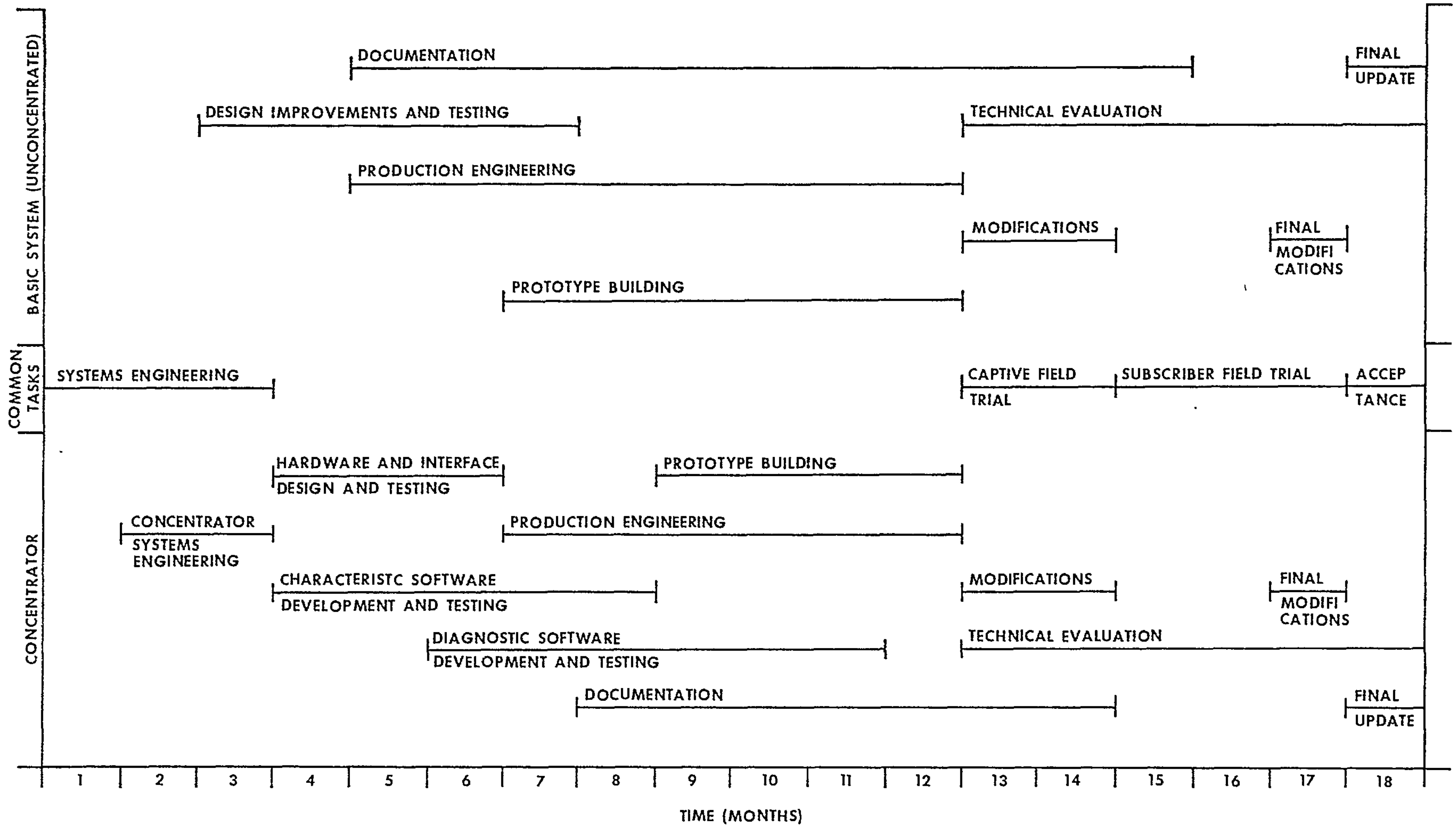

FIGURE 5.2 SUBSCRIBER CARRIER SYSTEM R & D TIMETABLE

TABLE 5.1 MANPOWER REQUIREMENTS

TASK	EN	SW	DR	TE	AS	MA
Project Management	1650					
Systems Engineering	1400					
Captive Field Trial	200	200				
Subscriber Field Trial	300	400				
Common Tasks - Sub Total	3550	600				
Design Improvements	1600			900		
Production Engineering	1300		1800	500		100
Prototype Building	200			300	350	150
Technical Evaluation	200			100		
Modifications	200		100	100		
Documentation	500		200			
Basic System - Sub Total	4000		2100	1900	350	250
Characteristic Software		1000				
Diagnostic Software		800				
Hardware Design	550					
Production Engineering	100		200	100		
Prototype Building	50			50	100	
Technical Evaluation	50	50		50		
Modifications	50	50	50	50		
Documentation	50	50	50			
Concentrator - Sub Total	850	1950	300	250	100	
TOTAL MAN-HOURS	8400	1950	2400	2750	450	250

EN - Engineer
SW - Software
DR - Draftsman
TE - Technician
AS - Assembler
MA - Machinist

TABLE 5.2 R & D COST CALCULATION

Classification	Rate (1979)
EN - Engineer	$36.00
SW - Software	36.00
DR - Draftsman	25.00
TE - Technician	20.00
AS - Assembler	15.00
MA - Machinist	25.00

Basic System	Hours	Cost
Engineering	4000	$144,000
Drafting	2100	52,500
Technician	1900	38,000
Assemblers	350	5,250
Machinists	250	6,250
	Sub-Total	$246,000

Concentrator	Hours	Cost
Engineering	850	$ 30,600
Software	1950	70,200
Technician	300	6,000
Assemblers	250	3,750
Drafting	100	2,500
	Sub-Total	$113,050

Common Tasks	Hours	Cost
Engineering	3550	$127,800
Technician	600	12,000
	Sub-Total	$139,800

ADD:		
Test Jig		$ 40,000
Materials		50,000
10% Contingencies		58,885
	TOTAL	$647,735

For the purposes of cost recovery, this cost can be divided proportionally between:

Basic System (68.5%)	$443,790
Concentrator (31.5%)	$203,945

The digital interface is not included since the problems associated with it have not been resolved and a good estimate for development costs can therefore not be made.

Another assumption made is that all designs are derived only from the work done during this study. Any peripheral experience in subscriber carrier systems will lower this cost to the extent existing designs can be used. The rates used in the calculations may also have to be corrected when cost calculations are done for different manufacturers.

5.4.2 Manufacturing Cost and Price

A budgetary estimate of the potential production costs and subsequent selling price has been made based on the system design as presented in the system document. Not all modules were actually designed, and the accuracy of the estimates consequently varies. A summary of these estimates is given in Table 5.3; details are provided in Appendix H. Areas where price reductions are feasible are also discussed.

Cost and Price Estimates

The manufacturing costs for the system are believed to be relatively accurate for a small independent manufacturer. Quantity purchases and production runs of approximately 200 units over one or two years were assumed. Larger manufacturers, even if the same number of units were produced, would likely be able to secure standard components at lower prices due to their larger quantity purchases. This could well result in lower overall production costs.

The anticipated markup factors may also vary somewhat with the manufacturer, resulting in differences in the estimated selling price. The rate for development could vary considerably depending on cost recovery and the amount of original engineering required. As mentioned previously, experience with subscriber carrier systems and the availability of applicable designs and circuits could contribute to a shorter timetable and lower R & D costs.

Another important consideration in determining the selling price is the manufacturer's pricing policy. It may be expedient to lower prices by reducing the profit margin, or the rate of development cost recovery, to make the system more attractive to the telcos. Another possibility is to spread the R & D costs (and/or manufacturing costs) differently over the various system components. This is shown by a rather high rate of R & D cost recovery for the concentrator. The actual rate would depend on the additional sales such an option would induce. Of course, this depends on many factors, not the least of which is the choice of modulation (by virtue of the different bit rates). Other factors, such as the average size of installations, or a telco's choice between two smaller versus one larger system, are much more difficult to define. In choosing the rates given in Table 5.3 , a basic revenue (less markups, i.e. based on manufacturing costs only) of $3,000,000 was assumed over which the $450,000 R & D costs for the basic system are to be spread, yielding a rate 15%. An additional $1,000,000 in revenues are assumed to be achievable by adding a concentrator, resulting in a total of $600,000 towards recovering the R & D costs of $650,000. The remaining $50,000 must then be added to the price of the concentrators, and if 25 are sold, this means $2,000 each or 200%.

TABLE 5.3 SUMMARY OF COSTS AND SYSTEM PRICING

Markup Factors

Marketing and Advertising	10%
Warranty	2%
Profit	10%
Federal Sales Tax	9%
R & D Cost Recovery - Basic System	15%
R & D Cost Recovery - Concentrator	200%
Combined Markup - Basic System	54.7%
Combined Markup - Concentrator	303.6%

	COST	PRICE
Remote Terminals		
1 to 4 lines (n)	643 + 99n	995 + 153n
Up to 64 lines (n)	1233 + 104n	1907 + 161n
Alarm and Backup Switching Option	129	200
Central Office Terminal		
Basic System	2390 + 103n	3697 + 159n
Concentrator (303.6%)	1000	4036
Alarm and Backup Switching Option	500	774
Remote Terminal Power Pack	650	1006
Repeater	200	309

Note: All costs and prices are in 1979 dollars, F.O.B. factory, assembled, tested, packaged for shipment.

The prices calculated in Table 5.4 are somewhat higher than desired by most telcos but are sufficiently low to make a distributed system viable. When increasing terminal capacity a trend becomes evident in the reduction of the four drop system price to less than one half. A clustered system with a single remote terminal will likely reach a minimum price of $464 per subscriber, fully equipped with 46 channels, unconcentrated. A slight increase will be experienced with lower average loading factors ($595 for 24 channels). For the purpose of comparisons, no repeaters were included.

Cost Reduction

To bring about a price reduction an initial attempt to reduce material costs should be made, since they represent almost 80% of the total manufacturing costs. This is especially true for the common equipment which becomes relatively expensive for a small number of lines. For example, the common equipment cost for a clustered system (less repeaters) is $4273 or 31% of the per line cost for 46 channels, 46% for 24 channels, and 77% for 6 channels. The biggest offenders are the boxes, cabinets, and power supplies, especially those requiring wide operating temperature specifications, and considerable effort should be spent towards cost effective designs in these areas. Cost reduction in the line cards have a dollar for dollar effect on the per line cost of any system configuration. Innovative design can bring this about, although the wide operating temperature requirements make this task much more difficult. Almost one half of the cost of line cards is in the central office equipment. This could be substantially lowered by the use of a direct digital interface to digital switches, where applicable. The technical difficulties are discussed in Appendix B. A detailed estimate of the savings is difficult to make, since a large number of variables have not yet been defined, but a $60 to $80 per line cost reduction should be possible.

Large scale integration (LSI) of various circuits such as the subscriber line interface circuit (SLIC), voice coder and decoder (CODEC) and others contribute to lower costs, but their availability and applicability depends on the activities of the semiconductor manufacturers, and how they view the market requirements. The above mentioned LSI devices exist today, but their performance under harsh outside plant conditions is not proven, and likely won't be for some time. It is doubtful therefore that any major breakthrough will come in time to benefit the first system which may result from this study. Subsequent products, however, will likely be able to use this technology.

Other methods for cost reduction could include the use of lower tolerance components, or even less reliable components. It is debatable whether any direct benefits would be derived from this practice. The resulting worse performance may well bring lower sales, since the telcos have generally indicated high performance requirements. Lower reliability components are certain to raise telco maintenance costs and do nothing to enhance the manufacturer's reputation. Clearly, neither of these two methods is recommended.

To summarize, the areas which contribute most of the cost of the system, and where cost reductions are most effective are:

- components, especially those with wide operating temperature specifications

TABLE 5.4 BASIC SYSTEM COSTS AND PRICES

	COST	PRICE
Distributed with 46 Lines on Single Subscriber Remote Terminals		
1 central office terminal	7128	11011
46 remote terminals	34132	53808
11 remote terminal power packs	7150	11066
TOTAL	48410	74885
per line	1052	1628
Distributed with 46 Lines of Four Subscriber Remote Terminals		
1 central office terminal	7128	11011
12 remote terminals	12270	18978
6 remote terminal power packs	3900	6036
TOTAL	23298	36025
per line	506	783
Clustered with 46 Lines on Single Remote Terminal		
1 central office terminal	7128	11011
1 remote terminal	6017	9313
1 remote terminal power pack	650	1006
TOTAL	13795	21330
per line	300	464
Clustered with 24 Lines on Single Remote Terminal		
1 central office terminal	4862	7513
1 remote terminal	3729	5771
1 remote terminal power pack	650	1006
TOTAL	9241	14290
per line	385	595

Note: All costs and prices are in 1979 dollars, F.O.B. factory, assembled, tested, packaged for shipment.

- boxes and cabinets
- power supplies
- line cards
- direct digital interface to digital switches where applicable

5.4.3 Installed Costs to the Telcos

The estimates presented in the foregoing discussion was used to obtain an indication of the final installed costs to be paid by the telcos. It is these costs which are used for their planning and purchasing decisions. A summary is provided in Table 5.5 and details are given in Appendix H. In general, the selling price of the equipment accounts for approximately 75% of the total cost.

In comparing these figures with those given as target costs in Section 3.3.3, we find that they are comparable, and neither substantially lower or higher. In all cases, however, they are less than those for other existing alternatives: comparisons were made with large digital (DM32S and DMS-1), small analog (S6A and CM-8) and VF cable designs. The net result of this is that the telcos would likely purchase the proposed system, providing of course that performance is at least comparable, or superior to competing carrier systems. On the other hand the prices are not low enough to convince the telcos to accelerate their introduction of carrier systems into rural areas.

A point of interest is the difference between the calculations done by the various telcos. Both NBTel and MTS have submitted calculations which included higher overheads (loadings) than those used by Sask Tel. The reason for this is not apparent, and care must therefore be taken to ensure that comparisons of competing equipment and technologies be made within the serving area boundaries of a particular telco.

TABLE 5.5 SUMMARY OF INSTALLED COSTS PER LINE

	30 lines	64 lines
Sask Tel Standard Case	911	666
NBTel Standard Case	1245	817
Upgrade Communities to ILS	850	650
Upgrade Resort Areas to ILS	820	650
Upgrade Farms to ILS	1500	1500
Upgrade Farms to 4PL		850
Accommodate Growth in 4PL to Farms		3120

SECTION 6: SALES POTENTIAL

Section 3 introduced the market analysis by looking at telephone companies' service requirements and delineating a gap in available products to serve low density rural areas. The product gap led to a list of product requirements for a small digital carrier system, the concept and definition of which were described in Sections 4 and 5. This system was found to be compatible with a wide variety of telco requirements in terms of service offerings, adaptibility to existing plant, performance and maintenance standards and cost effectiveness.

This section provides estimates for the amount of the potential market which the proposed system can reasonably expect to capture. As outlined at the beginning of Section 3, this analysis is in two steps. First, a "potential market" is estimated based on customers' service requirements. Secondly, the portion of this market for which the proposed product is suitable is estimated, based on the product gap left by available technologies and the ability of the proposed system to meet the customers' product requirements.

The results of this quantitative market assessment must be viewed with caution, however. Other factors also enter into the analysis to qualify the results. Such effects as the attitudes of telcos towards standardization and the impact of digital switching on purchases of non-standard plant can only be guessed at this stage from past telco practices and stated intentions. There therefore remains a probabilistic element to the analysis which can be minimized by considering all the evidence, but not removed entirely.

Finally, some estimates of the pattern of sales over time based on the sales experience of other carrier systems are made.

6.1 MARKET POTENTIAL

As discussed in Section 3, the market for small digital carrier systems is in providing new lines in rural areas to meet the demand caused by growth, upgrading to ILS and reducing line loads. The models and estimation procedures used to derive estimates of the number of new rural lines in the period 1980-1989 are described in Appendix G.

A number of assumptions are required in order to develop these estimates. These are:

- long-term historical trends in numbers of total and party-line main stations will continue during the 1980's. This inertia results from factors discussed in Section 3.2 above.
- a fixed fraction of party-line telephones are upgraded each year to ILS
- line-loads on party-lines will remain relatively constant at 3.0
- growth in rural ILS populations (apart from upgrades from party-lines) will be an insignificant part of the market
- in the U.S. a modest (3%) growth in party-lines occurs in advance of upgrading

The last three assumptions tend to make the market estimates conservative. With respect to the first two of these, falling average line-loads translate into a requirement for more lines, and there will inevitably be some growth in rural areas where ILS is the basic service. However, the distortions should not be large. First, an average line-load of 3 is probably low already as an estimate. Further, even if the estimated 930,000 party-line telephones in Canada in 1989 are loaded 2.5 to a line instead of 3.0, the difference requires only 6,000 lines a year over the decade to accommodate. This is an increase of 8% over the estimated market. Second, rural areas already served by ILS will tend to have higher densities than those where small carrier is most cost-effective.

With respect to the last assumption about the growth rate of U.S. party-lines, some arbitrariness is necessary since there is insufficient data to distinguish the separate effects of upgrading and growth, which tend to cancel to produce a net decline in party-line telephones. Since this decline is more rapid in the U.S. than in Canada, one can infer that relatively more effort is being devoted by U.S. telcos to upgrading than to serving growth. A small growth rate of 3% per year is assumed as an intermediate figure between the Canadian rate (estimated to be almost 5.6%), which is probably too high for the U.S., and zero which is undoubtably too conservative.

The resulting estimated potential markets in terms of total and rural lines per year are:

REGION OR TELCO	NEW LINES PER YEAR, 1980-1989	
	Total	Rural
Canada	549,000	76,000
Bell Canada	320,000	43,000
BCTel	76,000	7,700
Participating Telcos	105,000	16,700
Other Canada	48,000	8,600
REA Borrowers	399,000	46,000
U.S. Independents	961,000	186,000

Market potentials outside of North America are discussed in Appendix F.9, and will not be quantified here for lack of detailed information. Two points are of interest, however. The first is that in 1977, the U.S. exported only 3.1% of its carrier equipment production to countries outside of North America. The second is that digital technology is favoured by developing countries who are bypassing several stages of technology through which the telephone industry in North America has evolved. The lower cost, higher reliability and greater imperviousness to environmental factors (e.g. high humidity, fungus and insects) compared with electro-mechanical technology are readily appreciated by telco planners in the third world.

6.2 POTENTIAL FOR THE PROPOSED CARRIER

Once a potential market of rural lines has been estimated, this must be apportioned among available products to determine the market share of a specific technology, here small digital carrier. The contenders are shown on the tree diagram in Figure 6.1. First, all of the new lines will not result in new plant: some may be taken up by spare capacity that will never be replaced. Of the new plant, only a portion of the lines will go on pair-gain systems. Large systems will take up a good proportion of this latter market. Finally, the remaining market for small carrier systems must be subdivided between analog and digital technologies.

Clearly, the percentage alloted to each branch will vary widely according to the existing plant, rural service program, subscriber distribution and telco philosophy. However, some interesting results follow from the structure of the tree itself. The use of small digital carrier can only come about if the right branches are chosen at each of four decision points. For example, if at each of these points one-half of the remaining market goes to the alternate technology, then small digital carrier can expect a sales potential of only $(1/2)^4 = 6\%$ of the total market.

The actual percentages forecast to be suitable for small digital carrier and alternative technologies is derived in what follows.

6.2.1 Spare Capacity

The possibility that spare capacity in existing plant might absorb some of the future demand for new lines arose in discussions with Sask Tel concerning the market segment represented by growth in farm areas served by 4-party service. By definition, spare capacity can only be a factor where new demand is very low, and hence can be assumed to have a negligible impact on the rural market overall. This is confirmed by telcos with more dynamic rural areas. NBTel installs new capacity in advance of actual requirements, but has no permanent spare capacity. Similarly, AGT has no spare capacity left in areas served by 4-party because the growth rates there have used up what spare was designed-in when cable was buried in the 1960's.

6.2.2 VF Cable

The investment in wire and cable by Canadian telephone companies stood at just over $4 billion at the end of 1977, and grew at 12% per year over the period 1973-1977 (Table 6.1). This investment is almost entirely related to exchange rather than toll lines (98% on the basis of wire-miles, 96% on the basis of pole-line plus cable-miles).

If we relate the estimated number of new lines appearing in 1977 (317,000) to the new cable investment ($413,495,000), we obtain an average cable cost per new line of $1300. The comparable figure for U.S. Independents is $786 (Table 6.1).

Using the estimate that 76,000 new lines are needed in rural areas, then a conservative estimate of the annual Canadian market in rural areas is $100 million in 1977 dollars. This is conservative because the $1300 average is low for two reasons: first, cable costs will tend to be higher than average for rural lines,

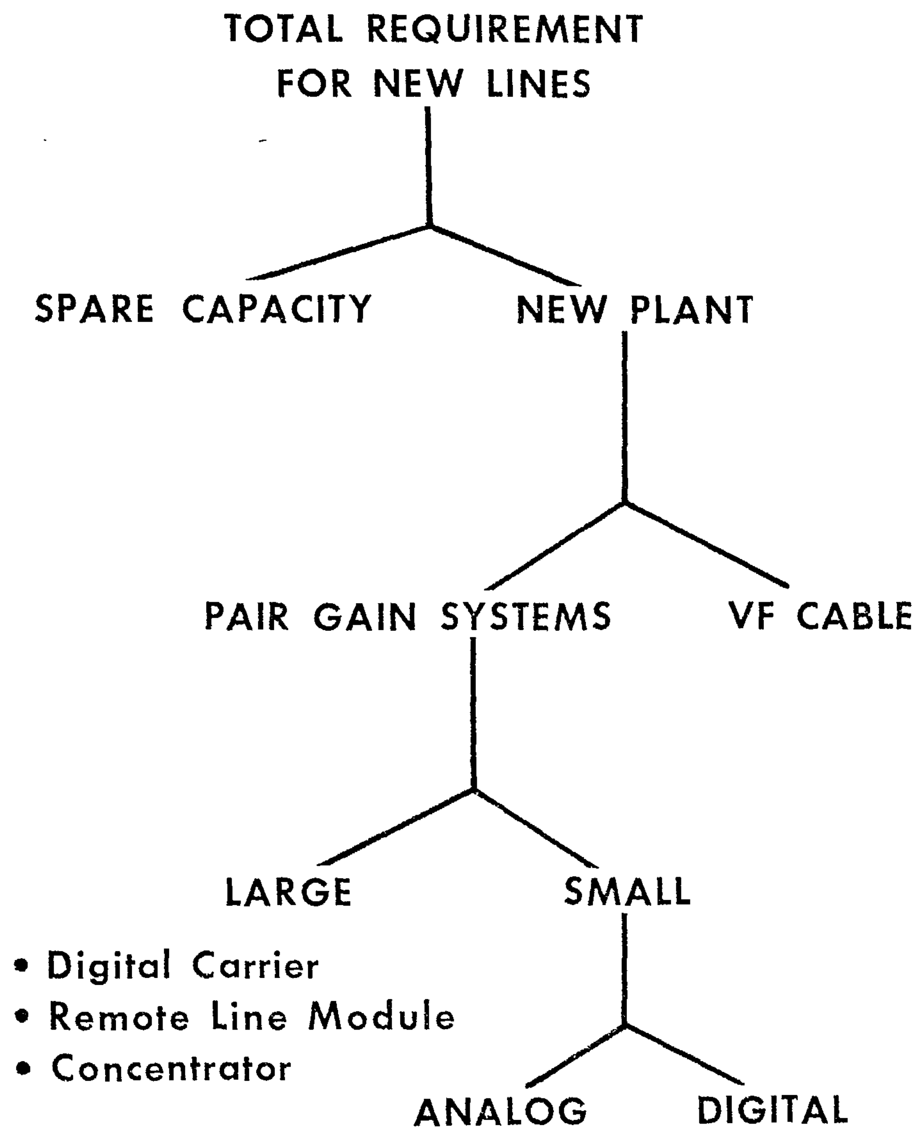

FIGURE 6.1 SALES POTENTIAL AS A FUNCTION OF ALTERNATIVE TECHNOLOGIES

TABLE 6.1 MARKET FOR CABLE PLANT, CANADA AND U.S. INDEPENDENTS 1974-1977

YEAR	CANADA: CABLE AND WIRE (AT COST) TOTAL	CANADA: CABLE AND WIRE (AT COST) INCREASE	CANADA: NEW LINES	CANADA: CABLE & WIRE COST PER NEW LINE	U.S. INDEPENDENTS: POLE LINES, WIRE & CABLE TOTAL	U.S. INDEPENDENTS: POLE LINES, WIRE & CABLE INCREASE	U.S. INDEPENDENTS: LINES	U.S. INDEPENDENTS: CABLE ETC. COST PER NEW LINE
	$'000	$'000		$	$'000	$'000		$
1977	4,184,143	413,495	317,157	1,304	8,084,893	625,935	796,440	786
1976	3,770,648	392,261	342,689	1,145	7,458,958	598,485	844,829	708
1975	3,378,387	380,828	381,192	999	6,860,473	566,314	705,298	803
1974	2,997,559	345,753	384,987	898	6,294,159	643,045	700,348	918
1973	2,651,806	-	-	-	5,651,114	-	-	-

SOURCE: Canada (1)

U.S. Independents (2)

New Lines: estimated in accordance with Appendix G.

and second, some new lines in 1976-77 would have gone on pair-gain systems rather than cable. Nevertheless, this figure is a lower bound on the total investment in new plant in rural areas in the 1980's.

Clearly, however, not all rural lines will go on cable. The actual percentage is estimated in the following discussion of the place of pair-gain systems.

6.2.3 Pair-Gain Systems

At this stage, pair-gain systems refer to carrier systems (large and small, digital and analog), concentrators and remote line units. Further distinctions within this class will be addressed subsequently.

A good feeling for the size of the overall carrier equipment market can be gained from U.S. figures on the value of shipments of carrier line equipment (office and line repeaters and line terminating carrier equipment) and U.S. exports to Canada of telephone carrier equipment and parts. Data for three recent years are given below (3), (4). Unfortunately, no comparable data are collected in Canada.

YEAR	U.S. CARRIER SHIPMENTS ($000)	U.S. CARRIER EXPORTS TO CANADA ($000)
1977	$529,135	$4,845
1976	$373,987	$4,462
1975	$403,679	$5,726

The imports of U.S. carrier equipment to Canada are only a portion of total Canadian consumption. They do not include the Canadian content of equipment manufactured or assembled in Canada. Examples of the latter include Northern Telecom's DMS-1 (although the first installations only took place in 1977), ITT's DM32-S which is manufactured in Guelph, Ontario for sale in both Canada and the U.S. (5), and GTE Lenkurt equipment.

A second source of Canadian data on carrier systems is Statistics Canada's table of figures published annually (7). Statistics Canada notes that the data should be used with caution. However, they are probably reasonably accurate in terms of total systems and channels.

YEAR	CARRIER SYSTEMS ON PHYSICAL CIRCUITS		
	Systems	Channels	New Channels
1978	13,522	260,011	34,895
1977	12,356	255,116	38,475
1976	10,866	186,641	48,730
1975	8,727	137,911	27,390
1974	7,887	110,521	-

This market, however, includes toll with subscriber carrier. Several telcos (e.g. Sask Tel and MTS) do not distinguish the two on their returns to Statistics Canada. However, a consistent time series of data has been obtained for NBTel, Bell Canada, AGT and BCTel with the cooperation of the Statistical Information Services Division, Department of Communications. These four telcos owned 78.2% of the total main stations in Canada in 1978.

Table 6.2 shows the division between subscriber and toll carrier for the four telcos in total. 1977 was a big year for carrier: 1384 new systems and 36,553 additional channels, of which 38% were on toll lines. In 1978, however, fewer new systems were installed: 771, comprising 29,425 channels, and 96% of these were on exchange lines.

Another way to view the market for pair-gain systems is to compare the channels in use* with the total number of lines. This is done in Table 6.3 for the four telcos for which reliable data are available. Since the end of 1974, 9.8% of new lines have been accommodated by pair-gain equipment. Most of these lines are located in subscriber and rural areas, since urban areas as yet see little use of carrier (e.g. Edmonton had 45 channels on 27 small systems in 1978). Thus the percentage of new rural lines on carrier will be somewhat higher.

For the 1980's, the change in the percentage of new lines on carrier is difficult to estimate. First, the prove-in distance for carrier decreases as the price of copper rises relative to electronics. On the other hand, as the cost of switching decreases, with the increasing use of digital switches and remote switching units for example, the cost minimizing trade-off between office size and outside plant will shift towards having smaller wire centres and therefore shorter loops.

However, the cost of installing carrier will drop dramatically when connecting with a digital switch (if a direct interface exists). Commonwealth Tel's experience is that it costs $659 to add a line with large carrier when interfacing with an analog switch, versus $393 with a digital switch. Similarly, a more theoretical treatment (8) suggests that interfacing with a digital switch

*We assume here that carrier channels on exchange lines are equivalent to lines. If concentration was present but not being accounted for in these statistics, then the estimates of the use of carrier are conservative.

TABLE 6.2 CARRIER SYSTEMS AND CHANNELS, 1974-1978
NBTel, BELL CANADA, AGT AND BCTel

YEAR	SYSTEMS			CHANNELS			
	EXCHANGE	TOLL	TOTAL	EXCHANGE	TOLL	TOTAL	PERCENT EXCHANGE
1978	9,031	2,946	11,977	184,606	54,490	239,096	77.2%
1977	8,190	3,016	11,206	156,398	53,273	209,671	74.6
1976	7,283	2,539	9,822	133,648	39,470	173,118	77.2
1975	5,200	1,553	7,753	94,198	33,199	127,397	73.9
1974	4,045	2,580	6,625	72,133	31,147	103,280	69.8

TABLE 6.3 CARRIER SYSTEMS ON EXCHANGE LINES, 1974-1978
NBTel, BELL CANADA, AGT AND BC

YEAR	CARRIER CHANNELS	TELCO LINES	CHANNELS AS PERCENT OF LINES	NEW CHANNELS	NEW LINES	NEW CHANNELS AS PERCENT OF NEW LINES
1978	184,606	6,572,370	2.8%	28,208	278,062	10.1%
1977	156,398	6,294,308	2.5	22,750	252,663	9.0
1976	133,648	6,041,645	2.2	39,450	266,477	14.8
1975	94,198	5,775,168	1.6	22,065	201,922	7.3
1974	72,133	5,473,246	1.3	-	-	--

would reduce the prove-in distance by 27% from 4.4 miles to 3.2 miles. This in turn more than triples the market for carrier: from 8% of subscribers (i.e. those over 4.4 miles from the switch) to 28% of subscribers (those 3.2 miles or more from the office).

From 1974 to 1976 the number of installed carrier channels among the four telcos grew by 36%, and from 1976 to 1978 it grew by 17.5%. Taking the latter figure, this trend implies that the total number of channels will increase from 217,000 in 1979 to 1,091,000 in 1989. Over the same period, the total lines of the four companies should grow from 7,262,000 to 11,934,000. Thus carrier channels will account for 3% and 9% of total lines in 1979 and 1989 respectively.

For the four telcos, carrier will accommodate 18.7% of the requirement for new lines over the decade. In 1979-1980 the percentage of new lines on carrier will be 10.3%, while in 1988-1989 it will be 28.2%.

A second piece of evidence for the market for carrier is provided by NBTel, who have estimated their requirements for both small and large digital carrier systems over the period 1980-1995 (see Section 2.3, Appendix F). NBTel expects to install 155 large systems (Northern Telecom DMS-1's) with a capacity of 39,680 lines, and 106 small package digital systems with 6300 lines. These 45,980 lines on carrier can be compared with an estimated requirement for 279,000 lines altogether over the period. Thus pair-gain systems are believed to be economical for 16.5% of the future market in New Brunswick.

Thus a reasonable estimate for the proportion of new lines going on pair-gain systems in the next decade is 15%. This translates to the following annual markets:

Canada	82,350	lines per year
Bell Canada	48,000	
BCTel	11,400	
Participating Telcos	15,750	
Other Canada	7,200	
REA Borrowers	60,000	
U.S. Independents	144,000	

6.2.4 Small Carrier

It remains to estimate the proportion of lines on pair-gain systems which will go to small carrier systems. The value in use studies (Appendix H) have shown that the proposed system can replace analog carrier in new installations and therefore capture all of the small carrier market (except single-channel systems).

The data on installed carrier systems on exchange lines in New Brunswick, Bell Canada, AGT and British Columbia (Table 6.2) can be pressed to yield information on the size of carrier systems (Table 6.4). The average number of channels per installed carrier system rose from an average of 18 in 1974 to over 20 in 1978 overall, and for new carriers in 1978 the average size was 33.5 channels. This

TABLE 6.4 SIZE OF CARRIER SYSTEMS ON EXCHANGE LINES, 1974-1978
NB, BELL CANADA, AGT AND BC

YEAR	SYSTEMS		CHANNELS		AVG. CHANNELS PER SYSTEM		PERCENT SMALL SYSTEMS*	
	TOTAL	NEW	TOTAL	NEW	TOTAL	NEW	TOTAL	NEW
1978	9,031	841	184,606	28,028	20.4	33.5	30.4	16.3
1977	8,190	907	156,398	22,750	19.1	25.1	33.0	23.7
1976	7,283	2,083	133,648	39,450	18.4	18.9	34.6	33.3
1975	5,200	1,155	94,198	22,065	18.1	19.1	35.1	33.0
1974	4,045	-	72,133	-	17.8	-	35.7	-

*Based on the assumption that the carrier systems are a mix of 7 channel and 128 line systems.

Percent small systems = $\left(\frac{128S - C}{121}\right) \frac{7}{C} \times 100\%$

where S = number of systems
C = number of channels

increase reflects a trend away from the small 1 and 7-channel analog systems in new installations. Moreover, it is evident from the individual data for New Brunswick (published by Statistics Canada) that recent years have also seen smaller installed systems being replaced by larger ones. Between 1976 and 1977, for example, the number of carrier systems reported by New Brunswick fell even though the number of channels available was increasing.

By introducing an additional assumption, one can estimate the percent of the carrier market (in channels) which is going to small systems. The assumption is that the reported carrier systems and channels represent a mix of 7-channel ("small") and 128 - line ("large") systems. Obviously, this is only approximately correct, since there would also be 1-channel, 24-channel and, after 1976, 256 - line systems in use. However, 7 and 128 - line probably represent good averages for small and large systems over the period.

The results of making this additional assumption are given in the last two columns of Table 6.4. These show that the percent of the carrier market, in channels on small systems, fell from 36% to 30% from 1974-78 (reflecting the rise in the number of channels per system over the same period). For new carrier systems, small carriers accounted for 33% of channels in 1975 and only half that percentage in 1978.

The NBTel estimates described above suggest that a small package carrier is suitable for 13.7% of their total carrier requirements. New Brunswick is typical of the whole eastern market in North America which has a higher subscriber density than the west and which therefore is less favourable for small systems. Thus 15% of the carrier market (in lines) is not an unreasonable expectation for small systems in the 1980's. The resulting market estimates are:

REGION OR TELCO	LINES PER YEAR	$000
Canada	12,400	$ 7,192
Bell Canada	7,200	4,176
BCTel	1,700	986
Participating Telcos	2,400	1,392
Other Canada	1,100	638
REA Borrowers	9,000	5,220
U.S. Independents	21,600	12,528

The dollar amounts are derived from the lines per year using the average hardware cost of $580 per line found by Sask Tel for the case of bringing ILS to small communities (Appendix H).

These figures should be regarded as minimum potentials, based on macro-level considerations, because of the conservative assumptions made throughout. More detailed requirements for small carrier were provided by the participating telcos as outlined below.

6.3 REQUIREMENTS OF THE PARTICIPATING TELCOS

This section summarizes the requirements for small digital carrier which emerged from the interviews and cost analyses conducted in the course of this study. The details are reported in Appendix F. These will amplify and serve as a check on the estimates derived above from more general considerations.

6.3.1 The New Brunswick Telephone Company

NBTel is actively canvassing manufacturers for a small package digital carrier. In their outside plant planning, they have identified locations for 106 systems over the period 1980-1989. These would accommodate 3200 lines initially, but would allow for additional growth to a total of 6300 lines.

Twenty percent of the systems are required to upgrade basic service to 4-party, mainly in the period 1980-1984. The rest will be used to accommodate growth in the rural serving area.

6.3.2 Manitoba Telephone System

A small, distributed, digital carrier system is needed in Manitoba to accommodate growth in very small communities, upgrade groups of 15 subscribers to ILS and accommodate requests for premium service. They also anticipate increasing demand for dedicated or multiple channels to the subscriber's premises to accommodate meter-reading, etc.

Small digital carrier is viewed as appropriate for all of the rural market segments except for the larger communities and resorts where large digital systems are more economical. The advantages of small digital carrier are:

- small communities - allows for flexibility for growth including the potential for upgrading to ILS.
- small resort areas - flexibility in areas with scattered growth which has a tendency to be volatile.
- farming areas - potential to minimize distribution cable costs in an environment characterized by low growth, scattered population and long feeder routes.

MTS has also been contacting manufacturers in an attempt to find a suitable system.

6.3.3 Saskatchewan Telecommunications

Sask Tel is planning to use small carrier to upgrade about 150 small communities to ILS during the 1980's. A total of 6100 lines is required, plus another 600 lines in large resort areas. Secondly, the number of telephones in cottages and resorts is expected to at least double during the decade, adding about 2200 lines. Cost analyses (Appendix H) have also proven the proposed system to be comparable in cost to S6A for upgrading farms to ILS. However, the demand for this has not yet materialized.

6.3.4 Alberta Government Telephones

AGT has identified a requirement for digital carrier which is 24 to 48 channels and an effective replacement for analog carrier. The principal uses to which this equipment would be put are accommodating 4-party and ILS growth, and serving new rural subdivisions. Forty systems (say 1,000 lines) is a lower bound to the potential annual market in Alberta.

6.3.5 Summary of Participating Telcos

The four telcos participating in the study have all expressed an interest in the proposed carrier system. All would purchase a field trial model at least. The markets which they foresee within their rural service plans are:

• NBTel	630	lines per year
• MTS	+	no estimate available
• Sask Tel	890	lines per year
• AGT	1,000	lines per year
TOTAL	2,520 +	lines per year

Thus, as expected, the numerical estimates derived in Section 6.2 have a safety factor built in through the use of conservative assumptions throughout.

6.4 REALIZING THE SALES POTENTIAL

To some extent, the sale potentials derived above are based on a generic small digital carrier. The proposed system meets the telcos' requirements, but so might a number of other systems. Part of the market research conducted as part of this study consisted of contacting a number of manufacturers of carrier equipment to try to determine whether or not they are intending to enter the same market.

The second part of this section is devoted to the related question of timing: How quickly will sales of a new system take-off, and is a year lead-time (or lost ground) critical?

6.4.1 Carrier Equipment Manufacturers

The results of discussions with major carrier equipment manufacturers are briefly summarized in what follows.

Northern Telecom and ITT

Both of these manufacturers produce large digital carrier systems and thus are in a position to use their expertise to produce a smaller design. ITT also has produced a 24 channel T1 PCM carrier with a single remote terminal.

When contacted in 1978, both manufacturers felt that the market for a small distributed system was limited and that the development costs were not warranted in view of the small returns. However, the telcos reported persistent rumours that a stripped-down DMS-1 or DM32S was ready to be unveiled.

Wescom

Wescom got its start in PCM manufacturing by taking over a PCM package from General Electric. At the time, a subscriber carrier was included, although Wescom is now in the process of phasing out the original G.E. designs, including the subscriber package. Wescom believes that the subscriber market is less than 10% of the PCM carrier market and their emphasis is, therfore, towards the trunk applications. Nevertheless, their design of channel banks, in which each channel is assigned its own codec, requires only relatively straight-forward changes to allow Wescom to enter the subscriber market.

Lynch Communications System Inc.

Lynch is known to be developing a small distributed digital carrier system. Significantly, the subscriber system utilizes much of their toll carrier equipment design. The subscriber carrier is already on the market in a single remote terminal configuration. The distributed version is expected in mid-1980.

SED Systens Inc.

SED has recently announced their DLS-7 subscriber carrier system, which is based on a lower bit rate than T1 (320 kbit/s) and uses adaptive delta modulation (CVSD). A concentrator is built in to expand the 7 channels into a maximum of 62 subscriber lines. Depending on the size of the installation, it is possible to power the entire system from the central office. First DLS-7 deliveries are expected later in 1980.

6.4.2 Timing

The second aspect in evaluating competition is, how crucial is the timing of product introduction? Does the first design capture most of the market, or does it only break ground for a slightly better system to take-off a year or two later?

One fact that can be stated with certainty is that in the past, carrier sales have climbed slowly at first. This can be attributed to telcos' caution in purchasing new designs, and to the practice of subjecting them to field trials lasting up to a year. In addition, considerable time is required to train the installation, maintenance and engineering personnel.

Some typical examples of carrier system sales are the following:

- Sask Tel installed its first S6A in 1970, but the bulk of orders came in 1974/75.
- DM32S was introduced in 1974. In 1978, ITT announced 70 systems installed and 100 on order (9).

- Design of the SLM (an 80 line, delta-modulated system concentrated on to one 24 channel T-1 line) was begun by Bell Labs in 1967 and field trials took place during 1971 and 1972 (10). The SLM has since been superceded by the SLC-40, but up to the third quarter of 1975, 155 systems had been shipped (10).

- SLC-40 (an unconcentrated delta-modulated carrier offering 40 channels on a T-1 line) was introduced in late 1974, after a full operational field trial in March. Twelve systems were placed initially, and by third quarter of 1975, 47 systems had been shipped. Projections for the following year were for 14,000 channels (350 systems) (10).

- In the east-central division of the Continental Tel System, consisting of 186 exchanges and 153,000 main stations (Dec 31, 1976), the growth, as shown in Figure 6.2, in CM-8 analog carrier took place over six years (12).

Several observations can be made. First, sales of a new system will be slow for two years at least. Thus the second design on the market may not lose out to the leader if it is clearly superior. Second, sales will climb sooner where one telco does field trials for a system of companies. This is the practice in the U.S. for the Bell, GTE and Continental systems, for example, and for the REA borrowers as a group. In Canada, it is more usual for telcos to field test equipment individually. If this pattern can be broken through co-operative field trials, then the lead time to significant sales volumes can be reduced.

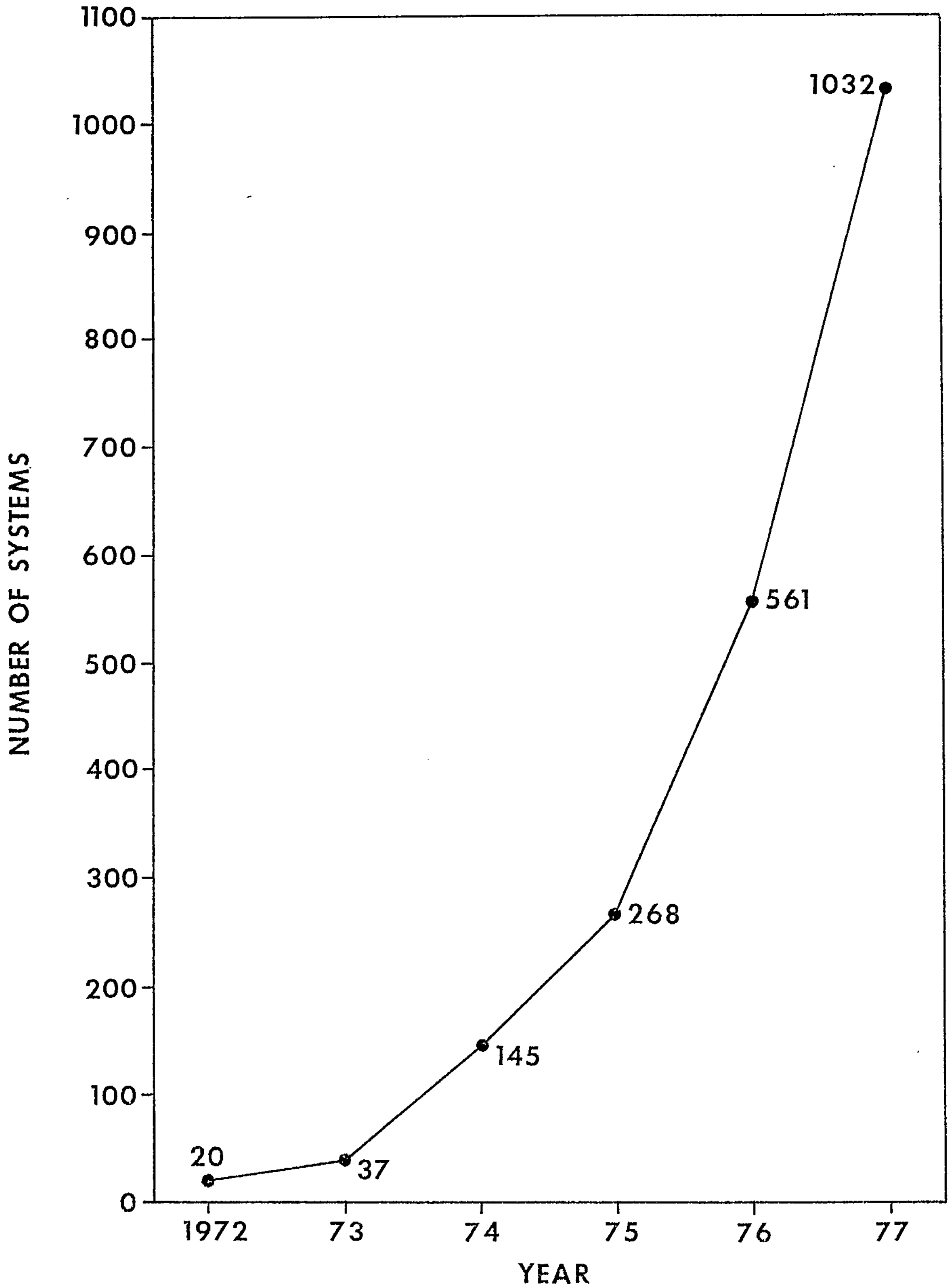

FIGURE 6.2 AN EXAMPLE OF GROWTH IN CM-8 ANALOG CARRIER SALES

6.5 REFERENCES

(1) Telephone Statistics, Statistics Canada, catalogue 56-203 annual. Table 26: Telephone Plant (at cost). Data excludes CN Telecommunications.

(2) Independent Telephone Statistics, U.S. Independent Telephone Association, annual. Composite Telephone Plant of Reporting Companies.

(3) Selected Electronic and Associated Products, incl. Telephone and Telegraph Apparatus, Current Industrial Reports No. MA-36N(77)-1, Bureau of the Census, U.S. Dept. of Commerce, October 1978.

(4) U.S. Exports/Schedule B Commodity by Country, publication FT410, Bureau of the Census, U.S. Dept. of Commerce.

(5) A Study of the Available Products and Systems for Rural Telephone Communications, K. Logan & Associates, Department of Communications, Ottawa, April 1976. pg. 38.

(7) Telephone Statistics, Statistics Canada catalogue 56-203 annual. Table: Carrier Systems on Physical Circuits.

(8) An Integrated Carrier and Local Digital Switching System, John C. McDonald, in Proceedings of the International Symposium of Subscriber Loops and Services, 1978.

(9) TCS-5 Central Office and DM32S Subscriber Carrier Integration, R.V. Anderson, D.J. Rotton and W.K. Wurst, ISSLS-78 pp. 177-181.

(10) Digital Loop Carrier Systems, M.T. Manfred, G.A. Nelson and C.H. Sharpless, The Bell System Technical Journal, Vol. 57, No. 4, April 1978. pp. 1157-1185.

(11) Applying Digital Loop Carrier in an Existing Analog World, W.L. Shafer, Jr. and S.J. Brolin, ISSLS-76.

(12) Operating Experience with Analog Electronic Station Carrier, P.G. Stewart and L.A. Day, ISSLS-78.

SECTION 7: CONCLUSIONS

The primary objective of this study was to identify whether an opportunity exists to develop a low cost, low capacity, subscriber carrier system for low density rural areas. This objective has been met and such an opportunity has been identified.

A subscriber carrier system design which is believed to best meet the requirements has been defined functionally and has the following attributes:

- It is a low capacity T1 carrier system optimized for distributed installations with optional add-on concentration.
- The design is based on a data ring concept which provides a simple solution for cable branching and reduces the circuit complexity.
- The basic channel capacity is 24 and may be increased by using adaptive delta modulation as an alternate coding technique.
- No specific upper limit for the total system line capacity is suggested, except that it be no less than 128 to serve as wide a market as possible.
- The number of remote terminals per installation is virtually unrestricted.
- Compatibility with existing T1 carrier lines is maintained by the use of simplex power feed.
- Power is injected as required with inexpensive remote power packs.
- Maintenance of the system is simplified with the use of a comprehensive diagnostic package including automatic fault location.
- The VF performance of the proposed carrier system is comparable to that of existing equipment, with certain compromises in the interest of lower costs.
- The remote terminal and repeater electronics and housings are designed towards compliance with the REA environmental specifications.

The cost for this system has been found to be very competitive with existing technologies at the desired low capacities. The following estimates are based on the preliminary design and are subject to revision as technologies change. They are given in 1979 dollars:

- Continued R & D costs including initial production engineering are $650,000 over an 18 month period. This figure can be further divided into $450,000 for the development of a basic unconcentrated system, and $200,000 for the concentrator. A manufacturer who has existing designs to draw from will be able to reduce these costs substantially.
- A basic unconcentrated system can be produced for as low as $300 per line in quantities of 200 with 46 lines per remote terminal. The manufacturing costs for an unconcentrated distributed system range from $500 to $1100 per line.

- Equipment selling prices range from $460 per line to $1700 per line for the above configurations based on a 55% markup for full development cost recovery.

There is a definite market for small carrier systems with a capacity up to 50 or 60 lines. This market has been quantified in terms of dollars and lines per year as follows:

Region	Lines per year	$000,000
All of Canada	12,400	7.2
Participating Telcos (NBTel, MTS, Sask Tel, AGT)	2,400	1.4
U.S. Independents	21,600	12.5
REA Borrowers	9,000	5.2
Overseas	limited	

The estimates should be regarded as minimum potentials. They are, however, for small carrier systems in general, not just for the proposed system in specific. The exact extent to which a new distributed system will capture part of this market will depend on its superiority over the competition, the time of its introduction, and technological trends. One notable finding is that a number of telcos have stopped purchasing analog carrier systems in favor of digital, and this trend is expected to continue.

The realizable sales potential also depends on a number of significant technical issues:

- Cost versus performance tradeoffs. A proper compromise, which is influenced by the performance of competing systems and telco service standards, is necessary to avoid unacceptably high costs or, conversely, low performance levels.

- A direct digital interface to the new electronic class 5 central office switches will be a requirement within a few years. (A consensus on the exact time, which will vary with the rate of introduction of digital switches in rural areas, could not be found). Such an interface will have a significant, favourable impact on the cost and performance of the subscriber carrier system.

- The technology required to manufacture a low cost system with the potential to significantly alter telco purchasing patterns is not yet commercially available. The general feeling is that a breakthrough towards a low cost transmission medium is needed before this can take place. Most companies are looking towards fibre optics as the medium of the future. The impact of this type of thinking on the total market is not very clear, except that it tends to restrict the life expectancy of conventional subscriber carrier.

SECTION 8: RECOMMENDATIONS

The final requirement for the study was to recommend a course of action to follow. Considering the stated market size, and that the R & D costs were assumed to be fully recovered with gross sales of $6,000,000 (which is equivalent to approximately one half the total participating telco market over 8 years), it is recommended that the proposed carrier system be developed and manufactured.

It is also recommended that:

- the expensive features such as concentration and full diagnostics be offered as options to allow for individual telco preferences.

- the initial version of the carrier system be based on PCM, and that the use of ADM be reexamined once the system is introduced.

- the system be designed sufficiently flexible to allow its modification for data services and alternate speech coding techniques

- the feasibility of designing the remote terminals such that no field modifications and/or additions are required when adding concentration to an existing installation be examined.

Although a decision of whether or not to follow this course of action is not required immediately from a marketing standpoint, it is recommended that it be made within one year to prevent the gradual erosion of the realizable sales potential through the establishment of competitive systems in the market place and/or the provision of the required services by the telcos with alternate technologies.

Attempts to resolve the various technical problems and issues resulted, in a number of cases, in the identification of areas where additional work is required before the stated sales potential can be fully realized. It is therefore further recommended that:

- standards for the direct digital interfacing of subscriber carrier systems to digital switches be defined, or that, in lieu of the above, manufacturers of digital switches be required to publish interfacing information for use by independent subscriber carrier manufacturers.

- an examination be made of the feasibility of using alternate, bandwidth efficient speech coding techniques for carrier systems.

- the limitations of using T1 on low pair count cable be studied in more detail to obtain a definitive specification.

APPENDIX A: T1 TRANSMISSION ON SMALL CABLE

The T1 carrier system was designed by Bell Laboratories during the early 1960's as a means of transmitting time division multiplexed, digitally encoded voice data. Sufficient literature is available on this subject, and describing the system is outside the scope of this report. A short review of T1 carrier is in order, however, before discussing the difficulties in using small exchange grade cable for its transmission.

A.1 PRINCIPLES OF T1 CARRIER TRANSMISSION

T1 carrier has the lowest data rate of the Bell System T-carrier multiplex hierarchy which consists of T1, T2, T3, and T4. Briefly, T1 consists of 24 64 kbit/s channels (PCM) plus frame synchronization information for a combined data rate of 1.544 Mbit/s. T2 consists of 4 T1 carriers time multiplexed with synchronization information into a 6.312 Mbit/s bit stream. Seven T2 carriers multiplex into a T3 bit stream, six of which form T4.

The carrier of interest here, T1, is generally transmitted via twisted pair cable and is used mainly for low to medium capacity inter-exchange trunks. Total cable size is usually large, up to 900 pair.

The transmission line characteristics vary widely with frequency, and transmitting digital pulses with a spectral content any where from DC to frequencies many times higher than the bit rate causes various problems:

- Low frequency components, especially DC contribute to shifts in the baseline of the pulse thus making regeneration difficult.
- Nonlinear amplitude and phase versus frequency characteristics contribute to intersymbol interference.
- Crosstalk between pairs increases exponentially with frequency.

The choice of bipolar, 50% duty cycle return-to-zero transmission combats most of the above problems in that it concentrates its power at the fundamental frequency (one half the bit rate) with no component at DC and little at higher frequencies). The characteristics of T1 pulses are:

Height	±3V
Width	324 ns
Bit Rate	1.544 Mbit/s
Fundamental Frequency Component	772 kHz

At the frequency of 772 kHz, the characteristics of the transmission line differ substantially from those at voice frequencies. The characteristic impedance is approximately 100Ω resistive, attenuation has increased to 20 dB per mile for 22 gauge cable, crosstalk losses have decreased markedly, and the propagation delay is reduced. Exact values can be found in the literature (7). Most significant are attenuation and crosstalk.

When engineering a T1 line, the signal must be regenerated periodically due to the high attenuation. This is done with a repeater, which equalizes (linearizes) the transmission line amplitude and phase characteristics, compensates for varying line lengths by means of an automatic line build out network (ALBO), extracts a clock signal from the incoming pulses, samples them, and retransmits the regenerated T1 carrier signal. A minimum signal to noise ratio is required for the regenerator to operate error free, and since near end crosstalk (NEXT) from the adjacent repeater for the other direction of transmission is substantial, a lower limit must be placed on the signal level. The exact value of signal attenuation is given by equation (1) (See also reference (4)).

$$L = m - \sigma - 32 - 10 \log n \qquad \dots (1)$$

where L = maximum allowable line section loss in dB
m = mean crosstalk loss of cable
σ = standard deviation of m
n = number of systems

Commercially available repeaters are designed for a maximum line attenuation of 35 dB, which is never used in practice. To allow for statistical variation of cable attenuation, a maximum design spacing of 33.5 dB is generally stipulated.

A.2 CHARACTERISTICS OF SMALL CABLE

Traditionally T1 carrier has been used on trunk cable, which usually contains hundreds of pairs. That does not exclude cable of other sizes, of course, but only recently, with the advent of digital subscriber carrier systems, has T1 carrier been applied to the exchange plant.

The fact that crosstalk losses decrease with lower numbers of pairs is well known (8). This characteristic stems from the construction of the cable itself.

Crosstalk is proportional to the coupling capacitances between pairs, which in turn is proportional to the physical separation of the individual pairs. Care is taken to minimize the distances pairs spent adjacent to each other. Obviously, those distances become larger as the number of available pairs decreases to the point where both pairs of a 2 pair cable are always adjacent. This fact has prompted many telcos to reject small cable as unsuitable for T1 carrier. To put this into perspective, average crosstalk losses at T1 rates for cables of various sizes are as follows (8, 9, 10):

Size (22 gauge)	m	σ	m - σ
50 pairs (nonadjacent units)	92	8	84
50 pair (adjacent units)	77	9	68
25 pair	76	13	63
18 pair			61
12 pair	69	10	59
8 pair	66	9	57

Application of equation (1) shows that using the above figures, even if only one system is used, the repeater spacing drops to 25 dB for 8 pair cable.

Other difficulties with small cable are:

- the size itself. Particularily on the prairies, gophers can get their teeth around the cable and cause sufficient damage to disrupt service.
- lack of choice of pairs. When selecting pairs for a T1 carrier system it is desirable to choose those with the largest crosstalk losses. The probability of finding good pairs is proportional to the number of pairs available.
- lack of spares. This goes further than the above in that spares are needed when pairs carrying existing systems deteriorate.

The crosstalk issue tended to cloud the above, and has almost become a scapegoat to rationalize the rejection of small cable for T1 carrier. As it turns out, where T1 was used on small cable, the offender was rarely crosstalk, if ever, but rather one of the above. (This, of course, applies only to those cases where the problem was a function of the small cable size).

A.3 T1 LINE DESIGN FOR SMALL CABLE

The standard design for T1 lines was derived for use with large trunk type cables. Certain assumptions were made about the nature of near end crosstalk on this type of cable. The question must now be asked: Is this design, with its assumptions, valid for small cable?

Before we can answer this question, we need to examine the design in some detail (4).

The basic equation is (See A.1)*

$$L = m - \sigma - 32 - 10 \log n \qquad \ldots (1)$$

This figure -32 is a lumped constant derived from several factors. If we call this constant K, then

$$K = S + G - A - M\varepsilon - 20 \log y + 14 - 48 - 6 \qquad \ldots (2)$$

Factor	Value	Definition
S	18.6 dBm	Transmitted signal level @ 772 kHz
G	23.7 dB	Preamplifier gain @ 772 kHz
A	12 dB	Required signal to noise ratio at regenerator
$M\varepsilon$	8 dB	Margin at error rate ε, or safety margin to take into account statistical deviations of above factors and to insure repeater will work 99% of the time with a specified error rate ε of 10^{-7}

* To make this equation complete, it must be divided by a temperature correction factor, which has been left out for simplicity.

Factor	Value	Definition cont'd ..
y	5.2	z value for $\varepsilon = 10^{-7}$, or number of standard deviations corresponding to a single tail probability of 10^{-7}
	14 dB 48 dB }	(10 log 25) empirical constants related to noise power transfer in cables
	6 dB	allowance for the fact that not all cables behave as measured

Completing the calculation yields K = -32

Examining these factors further we find a number of interesting facts:

1. S, G, A, and Mε cannot be altered since the empirical constants are calculated using the given values. Since it is the S/N ratio which is the determining factor, changing gain which will change the constant 48 in the same proportion will have no net effect.

2. The 6 dB allowance by definition assumes that the cable on which the T1 system is installed has not been measured for crosstalk losses. Obviously when measured this factor can be discarded, as can be σ. This should add at least 12 to 15 dB to the repeater spacings over using tables giving cable characteristics. Allowance for cable deterioration must then be made separately.

3. The factor y assumes that the amplitude distribution of crosstalk is gaussian to at least y standard deviations. If this is not the case then y would have to take on a different value than 5.2. Lab tests showed that with a single interferer no power was found past 3 standard deviations (Figure A.4), and with three interferers (three systems operating), no significant power was found past 4.5 to 5 standard deviations. The additional spacing which can be obtained this way is:

   for one interferer 20 log 5.2 - 20 log 3 = 4.8 dB

   for three interferers 20 log 5.2 - 20 log 5 = 0.3 dB

For the case of one interferer the result is significant, whereas for three interferers it is not. For 22 gauge cable the result means an extra 1250 feet of spacing, which is usually enough to bring the spacing up to the standards used by most telcos.

The design equation for a single interferer where the cable crosstalk loss is measured, thus reduces to

$$L = m - 21.2 \qquad \ldots (3)$$

where m is the measured crosstalk loss. The full 33.5 dB spacing (not considering future cable deterioration) could therefore be used on cable with crosstalk losses as low as 54.7 dB which definitely includes the average 2 pair, 19 gauge cable*.

*This statement is believed to be valid although no actual reference to the crosstalk loss of 2 pair cable was found. Judging by the rate of decrease in crosstalk loss as the number of pairs decreases (reference (9)), and considering that 8 pair 19 gauge cable has an average loss of 64 dB, 2 pair cable should have no less than 60 dB. Obviously this can only be proven by many measurements, although the few that were actually made tend to substantiate it.

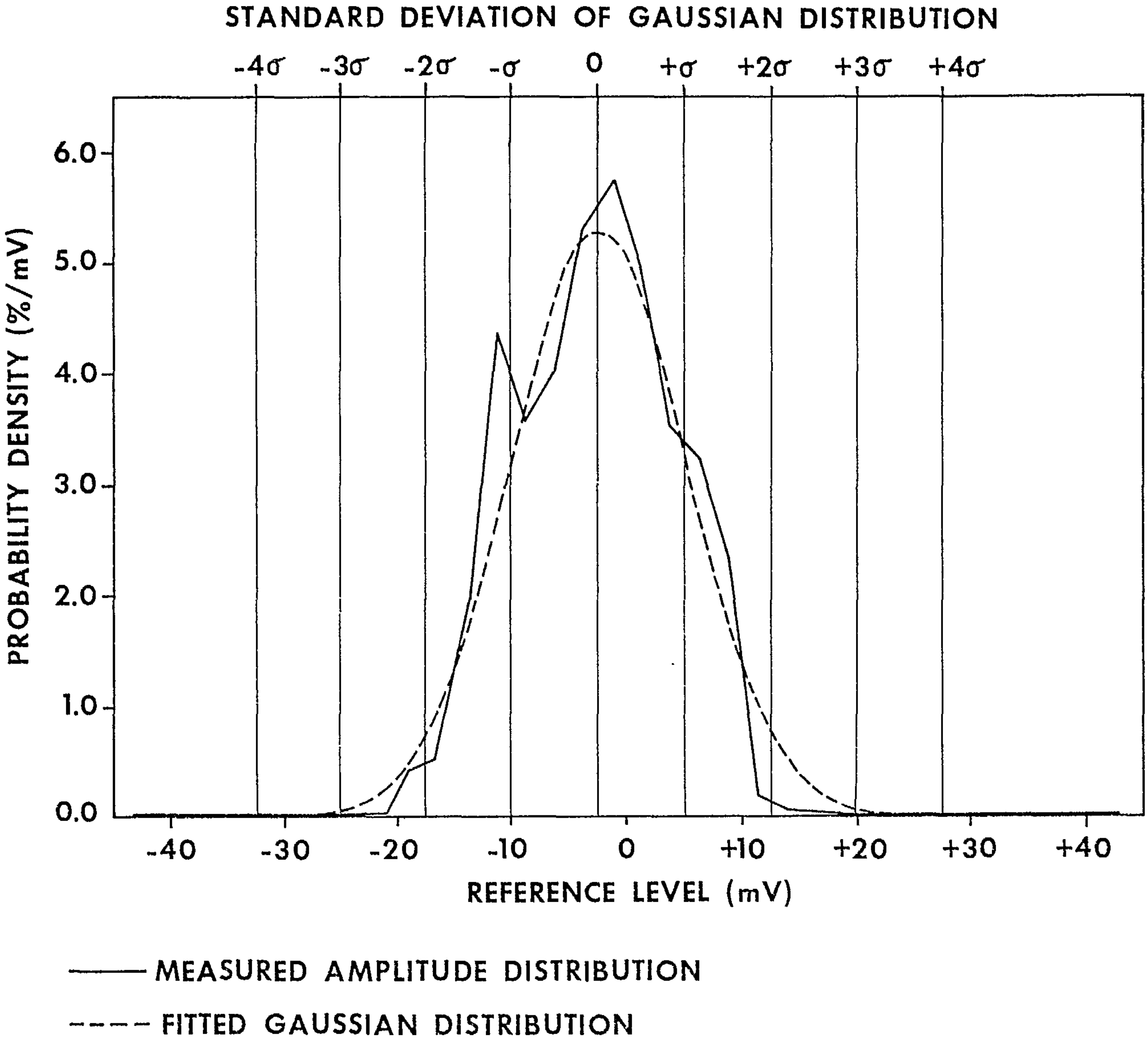

FIGURE A.1 AMPLITUDE DISTRIBUTION OF NEAR-END CROSSTALK ON A T1 LINE FROM A SINGLE INTERFERING SOURCE

These findings, however, are based on laboratory tests which may not be conclusive due to the low number of tests made. The actual figures may be inaccurate, however, the trend shown is real. Further work is required to firm up these values.

Notwithstanding any of the above, even if the unmodified equation (1) is used instead of (3), small cable need not be rejected. In fact, some telcos do use T1 carrier on small cable (See also Appendix E). It is debatable, however, whether the extra 4.8 dB of repeater spacing will induce telcos to increase the use of T1 carrier systems in the exchange plants. While it has been shown here that crosstalk is not the severe problems it is made out to be for small cable, the other difficulties referred to in Section A.2 remain. These issues must now be considered by the telcos. Although they are not unique to carrier systems, they are more visible there due to the larger number of subscribers it serves.

A.4 REFERENCES AND BIBLIOGRAPHY

1) Davis, C.G., An Experimental Pulse Code Modulation System for Short-Haul Trunks, B.S.T.J., 41, January, 1962, p. 1.

2) Mayo, J.S., A Bipolar Repeater for Pulse Code Signals, B.S.T.J., 41, January, 1962, p. 25.

3) Aaron, R.R., PCM Transmission in the Exchange Plant, B.S.T.J., 41, January, 1962, p. 99.

4) Cravis, H., and Crater, T.V., Engineering of T1 Carrier System Repeatered Lincs, B.S.T.J., 42, March, 1963, p. 431.

5) Fultz, K.E., and Penick, D.B., The T1 Carrier System, B.S.T.J., 44 September, 1965, p. 1405.

6) Members of the Technical Staff, Bell Telephone Laboratories, Inc., Transmission Systems for Communications, Fourth Edition, Western Electric Company, Winston-Salem, N.C., 1970.

7) Riley, E.W., and Aarna, V.E., ABC of the Telephone, Volume 7, Lee's abc of the Telephone, Chicago, Ill., 1976.

8) Riley, E.W., and Aarna, V.E., ABC of the Telephone, Volume 8, Lee's abc of the Telephone, Chicago, Ill., 1976.

9) Boxall, F., Pulse Code Modulation in Telephony, VICOM, Mountain View, Cal., 1969.

APPENDIX B: REQUIREMENTS FOR DIRECT DIGITAL INTERFACE

Improvements in performance and cost per line and market can be realized by interfacing the subscriber carrier system direct to digital switches without the intermediate conversion to analog. The advantages are:

- No degradation of signal to noise ratio.
- No four to two wire conversion.
- No additional return losses.
- The potential for low loss transmission.
- The potential for the carrier system to operate as a remote line switch.
- Lower component count, hence lower cost.

Addressing these advantages, we note that the signal to noise ratio is degraded somewhat if a voice code conversion is required. This applies to the use of ADM in the carrier system, which has different performance characteristics. The degradation will be still greater, however, if analog is used as an intermediate step.

The lack of four to two wire conversion is to advantage in several respects, the main one being echo control. Echo is not a problem in four wire transmission since the transmitter is a one way device and does not recognize reflections. Neither does digital transmission generate any echo. In principle this allows low loss transmission, and digital has no inherent loss. This is stated as a potential only, since much depends on the four to two wire convertor at each end. If a severe echo is introduced there, and the probability for this is high due to the variance in subscriber loop impedances, some loss must be introduced to suppress the echo below the objectionable level.

The flexibility of digital switches can be used to advantage by bringing its inherent low concentration ratio out to the subscriber carrier system. In other words, if the carrier system has a certain blocking probability, the switch can provide as little additional blocking as required so that the "system" blocking probability is maintained. The carrier then operates effectively as a remote line switch.

The lower component count is brought about by eliminating individual analog channel units at both the switch and carrier system, and the multiplexing and demultiplexing hardware in some cases. Voice code conversion, for instance, will likely require some form of demultiplexing to allow access to individual channels.

While recognizing the desirability of such an interfacing capability, some mention must be made of the difficulties with it. The major problem currently appears to be the lack of compatibility amongst different makes of switches, and the lack of interfacing information. Direct interfaces are generally available for switches and carrier systems built by the same manufacturers, but they are not compatible with each other. This has led to the formation of "digital islands" around a switch, tying subscriber carrier sales to switch sales.

Formulation of standards is suggested to overcome this difficulty, especially if independent manufacturers are to be competitive in the carrier market, and remain independent.

The following information is required to flow between the digital switch and the carrier system to achieve proper operation.

<u>Unconcentrated Subscriber Carrier System</u>

<u>Call Placement</u>

- Ringing
- Party identification (type of ringing) for party lines.
- Line busy status
- Hook status
- Call termination (hook status)

<u>Call Origination</u>

- Hook status
- Party identification for party lines (ANI)
- Dial tone
- Dial pulses on DTMF dialing
- Channel or trunk busy (reorder tone)
- Ring back tone
- Call completion
- Call termination

The above can easily be handled on a standard D2/D3 format; there may be some incompatibility in the presentation of the signalling information on the A and B bits, especially the party line identification.

<u>Concentrated Subscriber Carrier System</u>

<u>Call Placement</u>

- Channels busy (reorder tone to originating subscriber)
- Subscriber identification, both for individual and party line service
- Line busy (busy tone, release channel)
- Ringing (ringing type for party lines)
- Hook status
- Call termination (release channel)

Call Origination

- Channels busy (internal to carrier system)
- Hook status
- Subscriber identification, both for individual and party line service (ANI)
- Dial tone
- Dial pulses or DTMF dialing
- Channel or trunk busy (reorder tone, release channel)
- Ring back tone
- Call completion
- Call termination (release channel)

For concentrated systems the subscriber identification must be exchanged with every call, and the use of the A and B bits may not be sufficient. Requests for channels must be sent, the actual seizing of them will likely happen within the carrier system, although it need not. In other words, there is a question whether the concentration is performed within the switch, or the carrier system. Another difficulty is the likely use of a dedicated 64 kbit/s channel for concentration control within the carrier system, leaving less channels than may be supplied by the switch.

In the case of carrier systems using more than 24 channels, the simultaneous use of two or more T1 lines, or some other communications link, must be possible. Voice code conversion takes place inside the interface, from whichever modulation technique is used to μ-255 companded PCM. This invariably requires remultiplexing the channels onto more than one T1 carrier.

If V.F. loop testing is to be performed, maintenance information must be inserted at some point. Carrier system alarm and diagnostic information has to be stripped since the switch will likely not recognize it, but it should be notified of any failures which have occurred.

The above list is not exhaustive, since no complete study of the problem was done. It does show, however, that interfacing is not a simple matter of joining the switch to the subscriber carrier system via a T1 link: the protocol must be firmly established before any link can be built. It should also be noted that without standards, there will be as many protocols as there are manufacturers of switches, requiring that number of different interfaces if one is to be compatible with all.

APPENDIX C: CODING TECHNIQUES

The specific speech coding method to be used by the proposed subscriber carrier system has not been established, although the use of PCM for the initial version is suggested, simply because it is widely used and readily accepted. There are many advantages, however, to the use of other more efficient techniques. These will be discussed in rather general terms in this appendix, particularly as they relate to ADPCM and ADM. First, however, a discussion of the principles involved is in order. Comparisons of the various techniques are also provided.

C.1 PULSE CODE MODULATION

PCM was the first technique to be exploited commercially with the introduction of Bell's original T1 carrier system in 1962 (1). Since that time it has been virtually the only coding technique used in commercial telephony. Channel banks, long haul trunks, and digital switches are all based on PCM.

The theory and principles of PCM are given in the literature (2,3,4). Basically, band limited speech is sampled at a rate of 8000 times per second, each sample amplitude is then encoded into a 7 or 8 bit word. Early systems (D1 channel banks) used only 7 bit PCM, resulting in a total channel transmission rate of 56 kbit/s. More recent systems (D2, D3, and D4) use mainly 8 bit coding. The use of only 7 bits every sixth sample allows the transmission of signalling information within the same 64 kbit/s channel.

Companding (a contraction of the words compression and expanding) is used to extend the dynamic range (range of average volumes) to yield the same signal to noise ratio for both high and low amplitude signals. Two types of companding laws are in common usage today: the A-law and the μ-law. The former is generally used in European systems, whereas the latter is used almost exclusively in North America.

C.2 ADAPTIVE DIFFERENTIAL PULSE CODE MODULATION

Where PCM encodes the absolute amplitude per sample for transmission, ADPCM simply encodes the amplitude change from the previous sample (2,4,6). The high correlation between amplitudes of subsequent samples of speech makes this coding technique a very efficient one. The sampling rate of ADPCM may vary, and no standard, such as the one for PCM, exists. To illustrate the principles, however, we can assume the same band limited speech signal is used allowing us to sample at 8000 Hz. All seven bits are obviously not needed, if indeed the successive samples are correlated. Using 5 bit samples reduces the total bit rate to 40 kbit/s. A higher degree of correlation is achieved by faster sampling, allowing the reduction of the sample size even more. The total bit rate, however, would not change much if similar performance is to be maintained.

A further reduction of both sampling rate and sample size is possible with the use of adaptive quantizers (7). These devices alter the stepsize, or the amplitude differential that one bit represents, according to the slope of the waveform. Adaptive predictive coders attempt to predict what the stepsize must be to minimize the sampling error. This is done by exploiting the various characteristics of speech (6). The net result is toll quality coding at one half the bit rate of PCM.

The implementation of ADPCM is relatively simple. The tight band limiting requirements for PCM (3.4 kHz rolloff with a 4 kHz attenuation in the order of 45 dB) can be relaxed by increasing the sampling rate. This reduces the sample size resulting in a simpler A/D convertor. Depending on the algorithm used, the adaptive quantizer can also be implemented rather simply.

ADPCM has not been commonly used, inspite of the fact that it is simpler and more efficient than PCM.

C.3 ADAPTIVE DELTA MODULATION

A special case of ADPCM is its one bit version, or ADM (2,4,6,8). In this coding technique a sample represents only two states: an increase or decrease in amplitude from the previous sample. While it simplifies the coding process immensly, it does have some drawbacks. Stepsize adaption is absolutely necessary if reasonable sampling rates are to be maintained (2, p.41). Much theoretical and practical work has been done on adaption techniques (2,9,10,11) which aim at improving ADM performance at low sampling rates.

The major characteristic of ADM is that it is limited by the slope of the waveform, as opposed to amplitude in PCM systems. This means that fast changes in amplitude cause slope overload distortion. Both increases in amplitude and frequency contribute to steeper slopes, and as a result the delta modulator has a limited dynamic and frequency range. Fortunately voice signals do not have a flat spectrum and tend to have less overall distortion than expected judging solely by single test tone performance curves.

Another characteristic of ADM is granular noise. This stems from the fact that a change in the waveform is always indicated, whether it existed in the input or not. Step size adaption reduces this noise to a large degree.

ADM has been used in some subscriber carrier systems, specifically Bell's SLM and SLC-40 systems, and ITT's DM32S. Because it is such a simple and relatively bandwidth efficient coding technique, it has potential uses outside the telephone industry, and manufacturers are producing inexpensive single chip delta codecs. It appears, however, that telephony will not become the major user of ADM, since PCM is well established and compatibility is a requirement in the interest of both overall system cost and performance.

C.4 OTHER CODING TECHNIQUES

Considerable theoretical work is currently in progress to further improve coding techniques in the areas of cost, bandwidth, and performance (6,12). Different waveform coders have appeared, as well as vocoders (voice coders). In the area of waveform coders, two notable examples are sub-band and pitch-predictive ADPCM coders.

Pitch-predictive ADPCM considers the periodicity of speech by equating the present sample to the value of the signal one or more pitch periods earlier. The performance gain is quite good over straight ADPCM, but coder complexity is also higher. It is apparent that memory of some type is required to retain the delayed speech values.

Sub-band coding divides speech into its spectral components, by bandpass filtering it into several sub-bands. These are then separately encoded using adaptive PCM. In this fashion sub-band sample size can be adjusted according to its importance to the quality of speech perception. Again performance is improved markedly, but four to eight individual coders are usually required.

Vocoders attempt to extract redundancy and periodicity from the voice and only transmit sufficient information to allow a "synthetic" reconstruction of the speech at the decoder. Bandwidth gains are high, although at the expense of substantial complexity. For this reason they are not considered for the subscriber carrier application. The reader is directed to the literature for further information.

C.5 COMPARISON OF CODING TECHNIQUES

Some measure of relative coder performance is needed to allow the selection of the techniques which will best suit the needs of the carrier system. There are many tests which can be made, and it is often difficult to isolate the relevant ones. It must be mentioned at this point that the traditional specifications of SNR values are very limited and can be misleading if used as the sole measure of performance. For the use in telephony systems, there are six basic quality measures which will be addressed here:

- cost and complexity
- SNR performance
- subjective assessments
- performance with transmission errors
- tandem coding
- voice band data transmission

While this list is by no means exhaustive, it is a good sample to allow fair comparison of techniques.

Cost and Complexity

Of the two general types of coders, vocoders are considerably more expensive to implement, owing to their inherent intelligence. As shown in Table C.1, even the simplest vocoders require approximately 50 times the number of logic gates that would be needed for ADM. This introduces such a prohibitive cost factor that, at least at this stage of their development, vocoders cannot be considered for low cost subscriber carrier systems.

The most inexpensive techniques are ADM and ADPCM, with ADM having the advantage of single chip codec availability. Another advantage is the fact that sample word (or byte) alignment is not required: ADM samples are 1 bit only.

While this is not really an important factor for multiplexed systems, which require synchronization regardless, it should be considered when addressing single channel digital loops to the subscriber.

The advances in large scale integration (LSI) technology will inevitably reduce these cost advantages by making single chip codecs and synchronization/multiplexing circuits available at more or less uniform prices. It also increases the dependency of the choices for technology on the semiconductor manufacturers, and their perception of the LSI market.

A few words about standards is in order at this point. It is easy to overlook the costs associated with not only code conversion to make different systems compatible but also with the reformatting of signalling and even multiplexing information. Yet these costs can be substantial. The argument for LSI may be involved here as well, however, it is unlikely that I.C.'s will be produced to handle every conceivable conversion function. Microprocessors may have to be used to control unit costs, but the software costs are again high. In the final analysis, standardization or simply compatibility, may well be the controling factor in choosing a coding technique.

SNR Performance

There are a number of ways to assess signal to noise ratio performance of coding systems. The traditional, and by far the simplest technique is the test tone method. Usually 1004 Hz is used as a standard and SNR values are measured as a function of input level. This yields a value for dynamic range, or the range of input signal levels for which the SNR is above a predetermined value. Figures C.1 and C.2 show the PCM telephone standard which is commonly used to specify carrier system performance. This standard was derived from the D1 channel banks which used 7 bit log PCM. The term toll quality is often used to refer to this performance level.

The required bit rates for various coding techniques such that they will achieve toll quality are shown in Table C.1. D2/D3 PCM, which uses basically 64 kbit/s ("basically" because the bit stealing for signalling purposes reduces the net bit rate somewhat), is well above this performance level, with SNR's up to 40 dB. Single chip PCM codec performance is generally in the 36 - 38 dB range.

Adaptive delta modulation will also reach toll quality at 40 kbit/s. An early development codec for SED Systems' DLS-7 subscriber carrier system, which runs at 40 kbit/s, operated at 31 to 34 dB when C-message weighting was applied. (The standard calls for 33 dB with C-message weighting, although this was not allowed for in Figure C.1). An experimental breadboard model of the proposed carrier system was built using a wire wrapped codec, and the DLS-7 printed circuit board version. The results are plotted in Figures C.1 and C.2. The relatively poor performance can be attributed to:

- use of 32 kbit/s
- high interference levels from adjacent digital circuits
- poor power supply fitering along with poor power supply noise rejection by the codec
- use of low tolerance (10%) components

In light of the above the 29 dB performance by the DLS-7 codec is excellent and

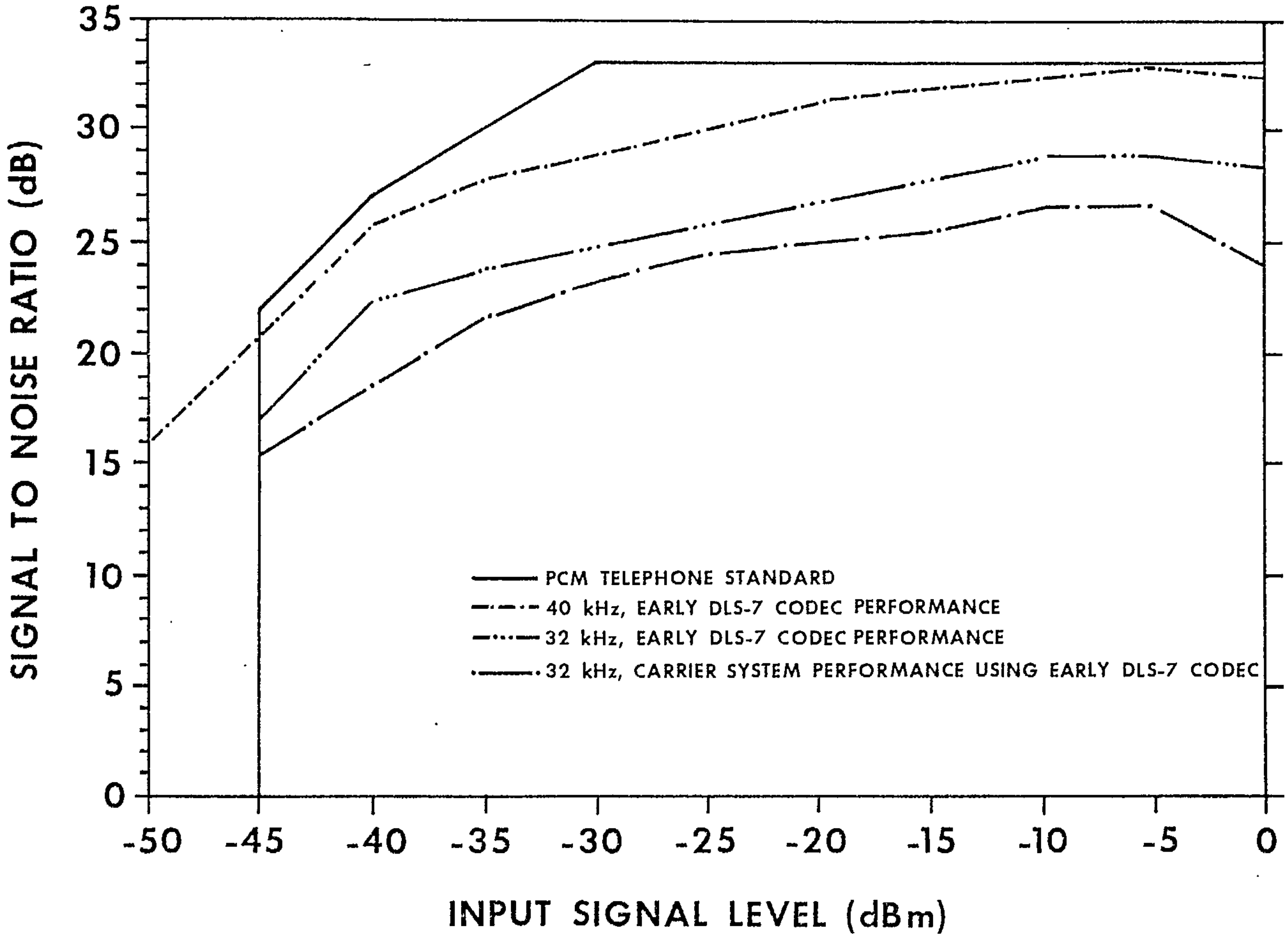

FIGURE C.1 COMPARATIVE ADM CODEC PERFORMANCE USING 1000 Hz TEST TONE, 3 kHz UNWEIGHTED

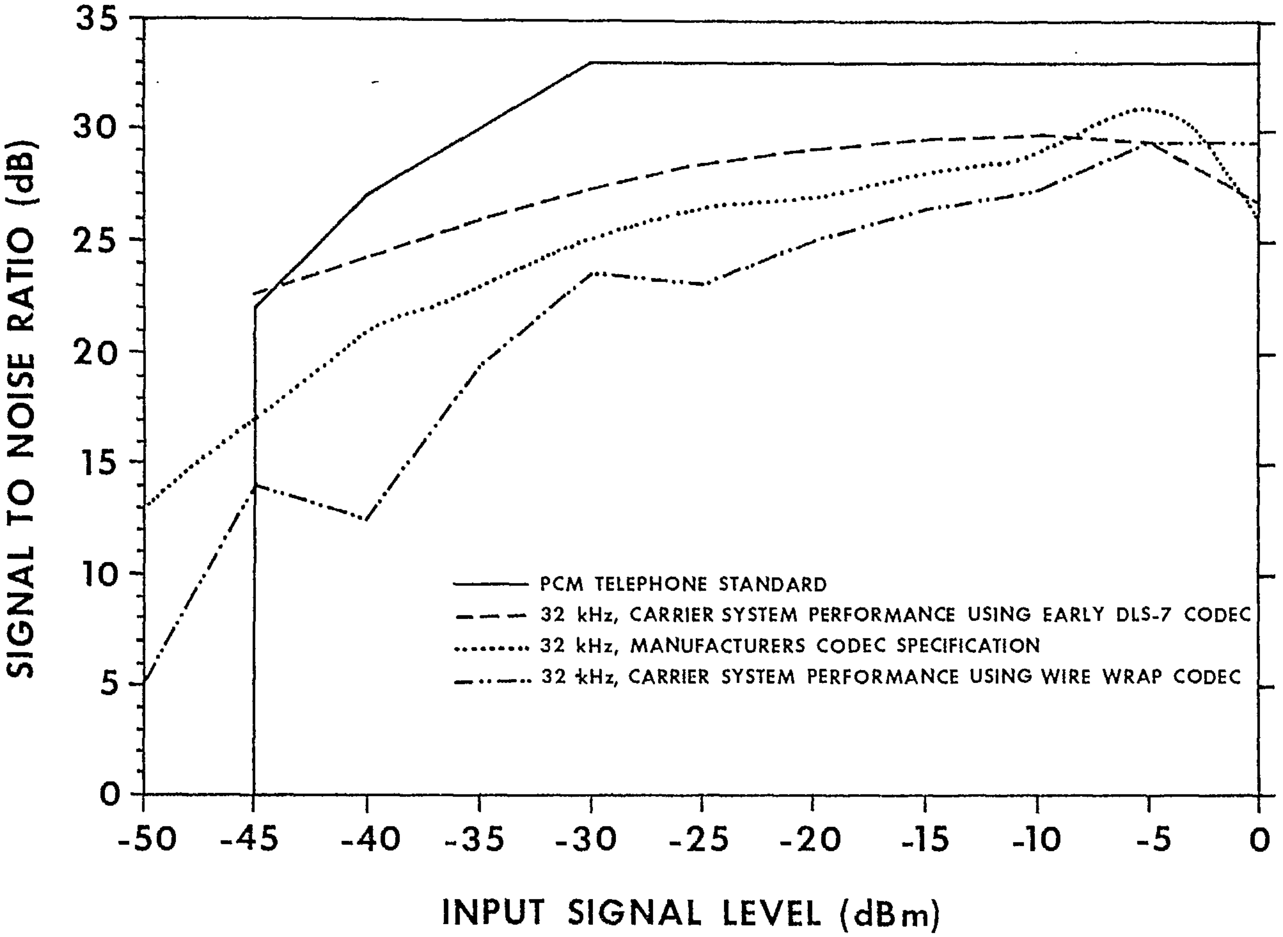

FIGURE C.2 COMPARATIVE ADM CODEC PERFORMANCE USING 1000 Hz TEST TONE, C-MESSAGE WEIGHTED

TABLE C.1: RELATIVE CODER PERFORMANCE
(after Flanagan, J.L., et al., Speech-Coding, see reference 6)

	Complexity relative to ADM	Minimum bit rate for Toll quality
Log PCM	1 - 5	56
ADM	1	40
ADPCM	1	32
SUB-BAND	5	24
Pitch Predictive ADPCM	5	24
Vocoders	50 - 1000	16 (1)

NOTE (1): Some vocoders cannot achieve toll quality.

leads to the conclusion that while the PCM standard may not be achievable with 32 kbit/s ADM, it is possible to come close, and likely sufficiently close for use in the subscriber carrier system.

It is notable that the development of an all digital, exponentially variable slope delta mod (EVSD) codec promises even better performance (11,16), particularily a better dynamic range. Idle noise is reduced substantially (<20 dBrnC) through the elimination of current source or voltage reference matching. This type of codec lends itself well to large scale integration.

ADPCM exhibits still better performance, and allows the use of 32 kbit/s for toll quality. Many of the same arguments used for ADM are applicable, and in addition ADPCM is more flexible in that a choice of sampling rate vs. sampling size can be made to optimize the cost vs. performance tradeoffs. It is generally accepted throughout the literature that ADPCM is preferable to log PCM in virtually all aspects of performance.

Other high performance schemes are sub-band coding and pitch predictive ADPCM. Both give toll quality speech for as low as 24 kbit/s. They are more costly than PCM though, and are relatively little known. Their outstanding feature is good SNR's for speech, but little improvement over conventional methods is expected when single test tone measurements are made.

It is often desirable to know the true SNR performance for speech. By necessity, this is really a statistical measure, but certainly yields results closer to what is perceived by the listener than the single test tone method. There is no simple way to do this, and computers are often used to numerically integrate the noise and signal powers of a specific voice sample. The comparisons of Table C.1 are based on this type of calculation.

The single test tone method discussed above lacks frequency information, and specifying a frequency range only requires the coder gain to remain constant. This way it is very possible to achieve good results for that tone, but not necessarily speech. For example, PCM has a relatively constant SNR over its useful frequency range, whereas ADM and ADPCM do not: their SNR exceeds that of PCM at low frequencies and is well below it at high frequencies. It is important, therefore, that the characteristics of the signal which is to be coded, are considered when comparisons are made.

Subjective Assessment

Any subjective analysis is, again, a statistical procedure, and highly talker dependent. The ear and the listener's perception are highly non linear and very difficult to quantify. A good assessment of this is given by Flanagan et al (6) and others (2,4,7). It is interesting to note that in experiments done with PCM and ADPCM the listener preference was different than what was expected with objective analysis techniques (7). It showed that, in general, ADPCM is preferable to PCM. By inference, this would be the case for ADM also. Informal listening tests done with the EVSD codec (for codec see ref. 11) indicate that perceived toll quality for ADM is achieved by the use of approximately 36 kbit/s or slightly less; 40 kbit/s sounded better than PCM.

These results appear to indicate that the differential coding techniques are better suited for speech transmission, than is absolute amplitude coding such as PCM.

Performance with Transmission Errors

Errors which occur on exchange loops are typically random, and are caused mainly by the presence of gaussian, or white noise. To a first approximation, crosstalk falls into this category (see also Appendix A), as does external noise from power lines, etc. Switching impulse noise originating from the central office is usually more severe. This is usually overcome by using shorter repeater spacings for the first span.

Without error correction techniques being applied, which is generally the case for subscriber carrier systems, noise has a significant effect on the decoded speech signal. Most notable is PCM where an error in the sign bit causes a spike equal in amplitude to twice the actual signal level. This makes them much more annoying than errors in ADPCM systems which are, at worst, equal to the maximum amplitude differential. In the case of ADM, this means a change in the opposite direction only, equivalent to the addition of a step function. This is not nearly as objectionable as noise spikes. The use of leaky integraters in adaptive quantizers also serves to reduce the resulting DC level back to zero over time.

A generally accepted cutoff level for error rates on PCM system is 10^{-4} or 0.01%. A rate of 10^{-3} or 0.1% may still be tolerable (6, p.728), but is not usually accepted by the telcos. ADM, however, is considerably more robust (contingent of course on the adaption technique used): speech intelligibility remains unchanged with error rates up to 4 or 5%, an order of magnitude improvement (2, p.41). It is safe to say that at those rates the probability of loss of sync is sufficiently high to become the overriding factor. When adding robustness to the sync detection algorithm, ADM systems look very attractive where noisy communication lines exist.

Tandem Coding

In view of the fact that until a completely digital network exists world wide there will always be situations where digital is converted to analog and back to digital. A typical case is the use of analog (step by step, crossbar) switches linked with T1 carrier systems. Adding a digital subscriber system compounds this problem and the performance of the various coding techniques when connected in tandem becomes important.

The quantization noise introduced by several PCM codecs adds strictly on a power basis, that is the various noises are not correlated. This is not the case in ADM where correlation is present since the stepsize adapters tend to make the same "mistake". As a result ADM coders in tandem perform not nearly as well as PCM coders. ADPCM would be somewhere in between since it also uses adaptive quantizers. These introduce smaller errors, and slope overload conditions are not nearly as frequent (17).

A related aspect is that of code conversion. In the case of digital switches, it is clearly desirable to avoid the above problem. There is also the benefit of lower component counts and cost in direct digital conversion. Although not yet commercially available, the conversion from ADM to PCM and vice versa is technically quite possible (18,19). In fact, ADM to PCM conversion is relatively simple if the ADM sampling rate is a multiple of 8 kHz. In the case of 32 kHz, it is a matter of linearizing, totalizing, discarding three out of four samples, and compressing to yield the PCM sample. Timing differences are handled conventionally. To generate ADM from PCM, however, requires interpolation to calculate intermediate samples. This requires digital filters which are still very expensive. Code conversion will therefore only become feasible once digital filters are available in LSI form, which is expected to happen within the next few years. By that time the conversion will be an absolute requirement if ADM is to find acceptability in subscriber carrier systems. Much the same is true for ADPCM, although it has found even less acceptability to date than ADM.

SNR performance of code conversions is generally better than that of tandem coding, although some additional quantization noise is introduced. This is particularily true when converting between adaptive and non-adaptive schemes such as ADM to PCM.

Voice Band Data Transmission

With the increasing demand of data transmission, the use of voice band modems will also increase. It is unlikely that digital ports will be universally supplied in the short term, and therefore any coding technique must be able to handle data.

The spectrum of data signals (FSK, PSK, QPSK, etc.) is substantially different from voice to be a concern in coders optimized for speech. It tends to be much more flat than that for voice with most of the energy being confined to the 1200 to 2400 Hz region (13; 2, p.389). PCM has a flat SNR performance and consequently works well for modems. ADM and ADPCM performance is not as good for high speed modems under ideal channel conditions (13,14,15).

Under less than ideal channel conditions the differences become less distinct. Generally speaking, for equivalent bit rates (i.e. 64 kbit/s PCM and ADM), performance is also equivalent and 4800 bps data can be transmitted over up to two tandem links, and 2400 bps over four links. When reducing the ADM bit rate to 32 kbit/s, the maximum data rate is 2400 bps over one or two links (15). In the presence of channel errors, ADM holds its performance better than PCM, which relates back to the discussion on error performance.

One consideration for using delta modulation is that the adaptive algorithm is tailored for speech, and as such is not appropriate for data. Improved performance from the above can be achieved by non- or self-adaptive techniques which consider the fact that data has a relatively constant amplitude and slope (14,15).

C.6 SUMMARY

In the preceding discussion an attempt was made to illustrate the characteristics of various coding techniques, especially log PCM, ADPCM, and ADM. No attempt was made to answer the question of which technique should be used, that is outside the scope of this report. Table C.2 summarizes the categories discussed and the preferred coding techniques. The comparison is based on the type of coding which would be used in the proposed subscriber carrier system, they are D2/D3 PCM (64 kbit/s), 32 kbit ADPCM and ADM. The exact adaption technique is not specified, but will be one of the commercially available ones (3 or 4 bit CVSD algorithm).

It becomes obvious that there is no clearly preferred coder type, although the most important category may well be compatibility, especially since the cost differences are quickly being eliminated with the availability of LSI codecs and filters. For this reason it is suggested that PCM be used for the initial version of the carrier system. ADPCM cannot be recommended since no single chip codecs are available at this time. ADM, for its greater bandwidth efficiency and robustness to transmission errors, is very attractive and will result in lower system costs. It is therefore suggested as an alternative offering.

TABLE C.2: PREFERRED CODING TECHNIQUES BY CATEGORY

Category	Preferred Coding Technique
Cost and Complexity	ADM, ADPCM
Compatibility	PCM
SNR Performance	PCM, ADPCM
Subjective Assessment	ADPCM
Performance with Transmission Errors	ADM
Tandem Coding	PCM
Voice Band Data Transmission - low speed	ADPCM, ADM
Voice Band Data Transmission - high speed	PCM
Bandwidth	ADPCM, ADM

C.7 REFERENCES

1) Boxall, F., Pulse Code Modulation in Telephony, VICOM, 1969.

2) Jayant, N.S., Editor, Waveform Quantization and Coding, IEEE Press, Institute of Electrical and Electronics Engineers, Inc., New York, 1976.

3) Oliver, B.M., Pierce, J.R., and Shannon, C.E., The Philosophy of PCM, Proceedings IRE, Vol. 36, pp. 1324-1331, Nov 1948.

4) Jayant, N.S., Digital Coding of Speech Waveforms: PCM, DPCM, and DM Quantizers, Proceedings IEEE, Vol. 62, pp. 611-632, May 1974.

5) Henning, H.H., and Pan, J.W., D2 Channel bank: System Aspects, BSTJ, Vol. 51, No. 8 (October 1972), pp. 1641-1657.

6) Flanagan, J.L., Schroeder, M.R., Atal, B.S., Crochiere, R.E., Jayant, N.S., Tribolet, J.M., Speech Coding, IEEE Transactions on Communications, Vol. COM-27, April 1979, pp. 710-737.

7) Cummiskey, P., Jayant, N.S., Flanagan, J.L., Adaptive Quantization in Differential PCM Coding of Speech, BSTJ, Vol. 52, No. 7, (September 1973) pp. 1105-1118.

8) Shindler, H.R., Delta Modulation, IEEE Spectrum, Vol. 7, pp. 69-78, October 1970.

9) Cummiskey, P., Single Integration Adaptive Delta Modulation, BSTJ, Vol. 54, No. 8 (October 1975), pp. 1463-1474.

10) Brolin, S.J., and Brown, J.M., Companded Delta Modulation for Telephony, IEEE Transactions on Communication Technology, Vol. COM-16, No. 1, February 1968, pp. 157-162.

11) Dodds, D.E., Adaption Techniques for CVSD Coding, Proceedings of the NTC 1979, IEEE, pp. 4.1.1 to 4.1.5.

12) Bayless, J.W., Campanella, S.J., Goldberg, A.J., Voice Signals: Bit by Bit, IEEE Spectrum, October 1973, pp. 28-34.

13) O'Neal, J.B., Jr., Stroh, R.W., Differential PCM for Speech and Data Signals, IEEE Transactions on Communications, Vol. COM-20, October 1972, pp. 900-912.

14) O'Neal, J.B., Jr., Delta Modulation of Data Signals, IEEE Transactions on Communications, Vol. COM-22, March 1974, pp. 334-339.

15) May, P.J., Zarcone, C.J., and Ozone, K., Voice Band Data Modem Performance over Companded Delta Modulation Channels, Conference Proceedings of the ICC 1975, IEEE, Vol. III, June 16-18, pp. 40-16 to 40-21.

16) Dodds, D.E., Sendyk, A.M., and Wohlberg, D.B., Error Tolerant Adaptive Algorithms for Delta Coding, Proceedings of the ICC 1978, IEEE, pp. 8.3.1 to 8.3.5.

17) Jayant, N.S., and Shipley, K., Multiple Delta Modulation of a Speech Signal, Proceedings IEEE (Letters), Vol. 59, September 1971, p.1382.

18) Dodds, D.E., and Rothery, R.L., Delta Modulation to PCM Conversion, Conference Digest of the IEEC&E 1979, IEEE, October 2-4, pp. 124-125.

19) Goodman, D.J., and Flanagan, J.L., Direct Digital Conversion between Linear and Adaptive Delta Modulation Formats, Conference Record of the ICC 1971, IEEE, June 14-16, pp. 1-33 to 1-36.

APPENDIX D: POWER SYSTEMS

A significant problem with any subscriber carrier system is that of power distribution. In this Appendix the various alternative powering systems are examined for their appropriateness to a distributed subscriber carrier system.

The various components which consume power are:

• remote terminal electronics	7 - 10 W
• repeater	0.7 W
• subscriber telephone set	0.2 W
• subscriber ringer (one only)	0.7 W
• cable (T1, 6000', 22 ga)	1.0 W
• subscriber loop (1300 Ω)	0.7 W

The power consumption figures are approximate and based on single units. The following sample calculations will attempt to put these numbers into perspective.

- For 24 telephones in use simultaneously (average 400 Ω loops)

  24 x (0.2 W + 0.2 W) = 10 W
- For 24 ringers in use simultaneously

  24 x 0.7 W = 17 W
- For a 20 mile long T1 system with 17 repeaters and 1 remote terminal (no telephones)

  17 x (1.0 W + 0.7 W) + 10 W = 39 W
- For the system at Lloydminster (Figure H.3)

  82 x 1.0 W + 58 x 10 W + 26 x 0.7 W + 24 x 1.1 W = 707 W

The following discussions will attempt to arrive at a power system which supplies these levels of consumption.

D.1 CENTRAL OFFICE POWER

This is the traditional method and the one that telcos prefer for obvious reasons. It requires no maintenance of outside power supplies and leaves the subscriber independent of the availability of AC power at his premises. There is, of course, a very practical limit to this. For safety reasons the maximum voltage on a telephone cable is 150 volts to ground (CSA), which results in a usable voltage differential of 300 V. With a 100 mA current limit the central office can supply only 30 watts to any system! Increasing the current is of little advantage since most of the added power is dissipated in the cable itself. To illustrate this the 100 mA current can reach 35 miles on 22 gauge cable, however, 150 mA can only support 23 miles. Adding electronic equipment such as repeaters and remote terminals will significantly reduce these ranges.

It is obvious that the proposed carrier system cannot be totally powered this way, since the minimum design power for 24 telephones is 17 watts* leaving 13 watts for the remote terminal, repeaters and cable.

Low power technology could change this, of course, and electronic telephones with tone ringers are being developed. The use of T1, however, virtually precludes the use of CMOS in the repeaters and remote terminals, since at T1 rates CMOS power consumption is as high as and performance not as good as that of low power Schottky TTL. It is therefore safe to conclude that the type of low power technology which is required to make 100% central office power feasible with T1 systems is not available today.

There are other ways around this problem, though. One is the use of a lower data rate, which of necessity will support a smaller number of simultaneous subscribers. The problem with this solution is its inherent incompatibility with existing systems in that standard repeaters and existing T1 lines cannot be used. It does, however, result in an attractive system for use in areas where this compatibility is not required.

Another solution is to use rechargeable batteries at the remote terminal which supply the extra needed power, and are recharged during off peak hours. Unfortunately, there is no guarantee that system usage will be light enough to ensure that the batteries can be sufficiently recharged to avoid service interruptions.

A third method is to use several cable pairs to provide for more current capability. It is a good solution, but obviously inadequate when insufficient pairs are available.

D.2 REMOTE TERMINAL AC POWER

Although being more costly, supplying power at remote terminals is certainly the most flexible method. It allows for longer distances between remote terminals and has virtually no overall distance limitations.

This concept is used by most of the existing subscriber systems, but is one of the major contributors for their unattractiveness for rural applications since telcos wish to avoid remote power installations. They do, however, accept them as a necessity, and the proposed system also uses them. In fact, it uses a separate remote power pack which can then be added at any point, repeater or remote terminal. By installing it at branches, 30 watts can be distributed into each, thus optimizing the total number of installations.

---

*Based on all telephones ringing, with only one ringer per telephone. If three ringers are to be allowed for the consumption value is 50 watts.

D.3 POWER SUPPLIED BY SUBSCRIBER AC OUTLET

This is possibly the most cost effective solution for a large number of channels, although a politically sensitive one. Telco reaction was generally cool, but they did not reject it.

In this concept all power for the repeaters and remote terminals is supplied by the central office. A distance of 20 to 50 miles can be reached depending on the type of cable used. Subscriber loops carry only voice power and signalling information. Talk battery and ringing signals are injected into the line at the subscriber end. Power is drawn from a small battery which is continuously recharged from the subscriber AC power. The battery can supply talk power for a certain length of time during power outages.

The telco reluctance to accept this method is essentially political in that they feel a subscriber should not have to supply power for basic telephone service. In addition, of course, is the problem of locating the "power box" near an outlet which could mean extra wiring, objections by the subscriber, accidental unplugging of the unit and others.

Comments in favor of this approach, aside from the lower capital cost, is that more and more options require AC power regardless, and the "inconvenience to the customer" is not a 'real' one. The trend towards fibre optics may also dictate subscriber supplied power unless power is supplied via the cable in which case the same power problems still exist. The reason for not choosing this method as a primary offering is the anticipated slow acceptance and resulting small market. The system design, however, can handle it and, should there be a demand after all, a modified channel unit and home adaptor box can be supplied as an option.

It should be remembered that this method also has restrictions on the size of the installation (30 watts for the T1 system only), and remote power supplies may still be required although not as many.

APPENDIX E: TECHNICAL SURVEY

An information package and questionnaire was sent to the participating telcos as well as selected other companies. This questionnaire accompanied the market survey of these companies which is detailed in Appendix F.

The primary objective was to solicit information on telco engineering policies and practices, field experience with other carrier systems, and reactions to the proposed system. A total of three meetings were held with the participating telcos:

- the New Brunswick Telephone Company Ltd.
- the Manitoba Telephone System
- Saskatchewan Telecommunications
- Alberta Government Telephones

The roles of these telcos extended well beyond that of simply responding to the survey, and each time a more refined system concept was presented to them for their reaction and critical comments. Sask Tel in particular contributed substantially in the economic analyses, and in providing some insight into telco "thinking" and behaviour.

Two other Canadian telcos, BCTel and Bell Canada were also contacted, although little technical information was expected. That which was received was not substantially different from answers received from the participating telcos.

One meeting was also held with the Rural Electrification Administration of the U.S. Federal Government, and valuable technical data for the U.S. independent telco market, specifically REA borrowers, was obtained. The REA also provided a contact for the Commonwealth Telephone Company of Pennsylvania, who is one of the larger REA borrowers. The visit to the CTC, a very progressive company, also proved to be very useful: they have a corporate policy to buy only digital carrier systems, and have considerable experience in that field and digital switching.

The answers to the questionnaire are detailed below:

E.1 T1 CARRIER TRANSMISSION

Do you use any T1 based systems on small exchange grade cable?

NBT: Yes, 12 pr, 22 gauge, screened, filled.
MTS: Yes, 16 pr, 22 gauge, unscreened, mostly aircore
ST: Not now, prefer screened
AGT: Yes, 11 pr., even aircore
REA: Yes, recommend 12 pr. screened as minimum
CTC: Yes, as far down as 18 pair unscreened
The majority of the systems are designed on their own merit, although cable testing prior to installation is usually done. In the U.S., T1 was used on as small as six pair cable, most of which is aircore due to the age of the installations. Use of T1 by CTC tends to be restricted to larger cable due to their population density.

If not, would you use these systems if it can be shown that T1 performs satisfactorily on small cables?

Applicable only to Sask Tel who answered 'Yes' to this question.

If you have used it, did you find that there were problems due to crosstalk?

NBT: No, cable is tested
MTS: No, cable is tested
ST: N.A, testing too expensive
AGT: No
REA: Not sure, there are some problems.

Due to the high safety factor built into design equation for T1 lines (See Appendix A), generally no problems were found due to crosstalk as expected. Bad cables are rejected during pre testing.

What other problems, if any, did you find?

NBT: Generally none, impulse noise from C.O.
MTS: None
ST: N/A, mentioned gophers
AGT: None
REA: Water in aircore cable, pulse reflections, jitter, span switches, ALBO opening up, gophers, high attenuation when using bi-metallic gopher shields.

The difference in difficulties between Canadian and U.S. installations can probably be attributed to the average age of the installations, and the fact that aircore cable is widely used in the U.S. Gophers were mentioned both by the REA and Sask Tel as a problem in prairie land especially with small cable around which gophers can get their teeth. The larger diameter cable appears to be more immune to this.

What is your design criterion for T1 repeater spacing?

Most companies use standard industry guidelines, all based on the equation developed by Bell (See Appendix A). Various simplifications are used.

What is your nominal T1 repeater spacing?

NBT: 28.7 dB nominal, 22.3 dB end section
MTS: as per tables
ST: 27 dB, 30 dB max.
AGT: as per Lenkurt design standards
REA: 33.5 dB, as per Bell guidelines
CTC: 30 dB, as per formula, design to be flexible

The range in these figures are indicative of the various additional safety factors telcos wish to build in.

COMMENTS:

Various comments received during the meetings were that telcos wish to use a general rule for their design, but feel this cannot be done easily because of the many factors involved. Lack of spares was cited as the most significant problem with small cable as opposed to crosstalk.

Sask Tel mentioned they have unresolved interference problems on 25 pair cable now used. They stated that "it must be shown conclusively that small cables can be used without a lot of preliminary testing".

CTC tries to put their T1 carrier on existing, unscreened cable, rather than burying new plant, although even that cable tends to be large (100 pair) compared to low density areas. Many of the difficulties with T1 therefore do not apply to them.

E.2 MODULATION TECHNIQUES

Do you currently use Delta Modulation Carrier Systems?

DM32S is used almost without exception. NBTel stated they were the first and are now the heaviest user with 28 systems installed. CTC does not use delta mod systems due to their imcompatibility with digital switches.

What is your perception of its drawbacks and disadvantages over PCM?

Compatability with the digital switch and uniqueness were mentioned by all as the main drawback, but they agreed that this may well be an academic problem. NBTel has cited signal to noise ratios as worse than PCM. AGT stated that they had no real preference.

What is your perception of its advantages over PCM?

Cost and the number of channels per T1 line was the number one advantage pointed out by all companies. AGT and Sask Tel also mentioned results of noise test done by AGT which showed almost unmeasurable noise levels.

Would you use Delta modulation systems if compatibility with PCM can be provided?

Since all companies use DM systems already, this question became largely superfluous. No great resistance was found to Delta mod, but it has to meet performance specs.

Do you feel the 2:1 pair gain over PCM is sufficient reason to use it in small carrier systems when providing individual line service?

NBT: Don't accept 32 kbit/sec delta mod
MTS: Depends on economics
ST: Yes, however, concentration is generally used
AGT: Depends on economics
REA: Mostly not applicable since most U.S. applications are not in low density areas. It will become important though as copper prices rise.

In light of earlier comments, the above are not surprising, and DM is generally acceptable as long as the performance criterion is met and the economics are favourable. Whereas for MTS economics is most important for NBTel no tradeoff in performance is acceptable.

When providing four party line service?

With the exception of Sask Tel, no company distinguished between ILS and 4PL. Sask Tel generally does not use PCM (or DM) for party line service.

COMMENTS:

In providing comments, NBTel again stressed the importance of compatibility. The move "towards an Integrated Digital Network", which would use mainly PCM, caused displacement of DM32S by DMS-1 as the NBTel large subscriber carrier standard. The same reason was cited by CTC who use only those carrier systems which interface with the serving digital switch. They agree that this ties them to a specific manufacturer but it seems to be a "fact of life".

E.3 BLOCKING AND CONCENTRATION

What traffic density figures do you use in rural areas for individual line service?

NBT: 3.0 ccs
MTS: 3.0 ccs (3.5) max. (rule of thumb)
ST: 2.8 ccs (not measured)
AGT: actual measured values
REA: Residence 2.4 ccs, Business 3.6 ccs

Most of these are general rules or estimates. Only AGT uses actual traffic figures for their new systems design.

For four party line service?

NBT: 4 to 5 ccs/line
MTS: 2 ccs/party, average 2.6 parties/line (rule of thumb)
ST: 1.4 ccs/party (not measured)
AGT: as measured, 1.5 to 12 ccs/party
REA: 1.4/party

What is the maximum blocking probability you would consider for a small subscriber carrier system for individual line service?

NBT: P.001-P.005
MTS: P.005
ST: No policy, P.02 suggested
AGT: P.001-P.005
REA: P.01-P.02, depends on switch

In general the aim is to not degrade the total blocking of the switch/carrier system combination; P.01 is the basic blocking for most switches.

For four party line service?

Most companies do not distinguish 4PL from ILS, although Sask Tel pointed out that the 4PL blocking is so great anyway, that carrier blocking does not contribute much. NBTel, however, does not accept this since in 4PL, although blocking is high, a conversation can be broken into in an emergency, something which is impossible if concentrated carrier channels are busy.

Described below are four alternative system configurations. Indicate your preference in each service grade for each of the systems by writing a number in the boxes below.

System A:
PCM unconcentrated (24 channels)

System B:
Delta modulation unconcentrated (48 channels)

System C:
PCM with concentration (up to 64 subscribers on 23 channels)

System D:
Delta modulation with concentration (up to 128 subscribers on 47 channels).

Preference:
For individual line service A ☐ B ☐ C ☐ D ☐

for four party line service A ☐ B ☐ C ☐ D ☐

NBT: System A, B if standards are met
MTS: System D due to economic consideration
ST: Depends on economics
AGT: Depends on economics
REA: System C, unless costs dictate otherwise

Economics was again the dominant factor, except for NBTel who, as indicated before, do not readily accept delta mod unless performance standards and compatibility requirements are met.

COMMENTS:

Comments brought forth in this section varied widely.

NBTel: For ILS the additional blocking <u>must not</u> "significantly degrade the P.01 Network Blocking Standard". Even for 4PL an additional maximum of P.001 to P.005 is specified for "break-in" reasons, and that most systems carry both ILS and 4PL service. Although the Poisson probabilities are apparently not accurate, each installation is checked individually.

MTS: Concentration is generally not a consideration in rural areas, and in urban areas designs are checked by the traffic department before being implemented.

ST: Generally no established policy, and extra blocking for 4PL is not critical.

AGT: No set policy, however, each installation is individually designed according to actual traffic measurements.

E.4 QUALITY OF SERVICE

What is the minimum quality of service you wish to provide in rural areas?

NBT: Noise 20 dBrnC, 8 dB switch to telephone, MPL
MTS: Noise 20 dBrnC, <10 dB switch to telephone, 4PL
ST: Noise 20 dBrnC, 8 dB switch to telephone, eventually 4PL
AGT: Noise 20 dBrnC, 10 dB switch to telephone, 4PL
REA: Noise 20 dBrnC, D3 standard for PCM is adequate

Basic objective is to provide urban grade of service. Analog provides typical noise levels of 15 dBrnC, down to 8 dBrnC, and digital should be competitive.

Does this differ for ILS and MPL?

No, without exception.

Is toll grade voice quality required for rural areas? (Reducing voice quality specifications can result in a considerable cost saving).

Not necessarily toll grade, however, urban quality is definitely required. MTS appeared to be the most flexible: Toll grade (urban quality) is generally perferred but "make us an offer".

In the case of digital carrier, what error rate do you tolerate over the system length?

NBT: 10^{-7} overall, 10^{-8} span, for new design
MTS: 10^{-6} for design
ST: 10^{-6} for design
AGT: No set standard, 10^{-4} is system shutdown spec.
REA: 10^{-6} for design, 10^{-4} is system shutdown or backup switching spec.

Design standards were usually quoted, as opposed to absolute maximums.

In areas where not sufficient cable is present to add a system, would you discontinue service to customers temporarily in order to replace VF circuits with a carrier system?

NBT: Never! Use switchover techniques.
MTS: Yes, for low capacity systems
ST: No, use switchover techniques
AGT: No, use switchover techniques
REA: No, this would indicate poor planning, at least 10% spares are provided in new designs.

This practice appears to be frowned upon, and either spares, or a temporary analog system are used to switch over service. REA felt this would only be a last resort, they don't like cutting a subscriber's "life-line". For MTS though, service outages are a "fact of life", a prewarning is always given and the outages must be one half day or less. Sask Tel would use the pay station line for an S6A carrier, then switch over other lines.

What is the maximum service outage time that you tolerate in the case of equipment or cable failure?

NBT: 4 to 5 hours
MTS: 4 hours, up to 12
ST: 4 hours business, 8 hours residence
AGT: No set standard, as short as possible
REA: 4 hours (½ day)

The average outage time tolerated is 4 hours including travel time.

In the case of providing service improvements?

NBT: No outages are tolerated
MTS: Minimum possible
ST: As above, zero hours preferred
AGT: No outages are tolerated
REA: Minimum, people are called first and informed of intentions

These types of outages are tolerated only if absolutely necessary.

Do you tolerate a total system outage in case of a single repeater or remote terminal failure?

NBT: Yes, if no back up and only one remote terminal
MTS: Not presently, backup usually provided
ST: Yes, but spare lines usually provided
AGT: Yes, backup switching is used if over 50 lines on system
REA: Yes, for small system. No, for over 100 lines on system.

This is generally accepted, although spares and backup are usually provided. MTS: "Isolation is bothersome". There appears to be a trend towards not accepting these types of failures in the future. There is also a qualifying factor involved, which is the size of the system.

Assuming it is technically possible, what are the minimum and typical distances a subscriber system should cover?

NBT: 3 to 40 miles, average 9 miles
MTS: 10 to 30 miles, average 15 miles
ST: 8.5 to 25 miles
AGT: 8 to 35 miles, average 15 miles
REA: 3.5 to 20 miles, with many exceptions

An extremely wide range was encountered, but that was to be expected due to different demographies. Typical distance appears to be 13 miles.

COMMENTS:

Comments received included possible solutions to line noise such as use of digital carrier systems, relaxing the frequency response specification (Bell's D3 specs are too tight) by the REA, a complete set of performance specifications by NBTel, and reliability standards by Sask Tel.

NBT: The Telco has a responsibility to provide the highest grade of service at reasonable cost to its customers. Some of the transmission specifications we consider acceptable are:

- Idle channel noise ≤ 20 dBrnC
- Quantization Distortion:

Input (dBm)	SNR (dB-CMSG)
0 to -30	33
-30 to -40	27
-40 to -45	22

- Harmonic Distortion: -40 dB max.
- Intermodulation Distortion: -35 dB max.
- Foldover Distortion: -22 dBm @ 4 kHz
- Return Loss: ERL - 18 dB min.
  SRL - 15 dB min.
- Crosstalk Coupling: -65 dB max.
- Insertion Loss: ≤ 2 dB @ 1 kHz
- Frequency Response: +1 to -3 dB (relative to the 1 kHz loss) from 300 to 3200 Hz
- Impulse Noise: 100% of the lines experience no more than 100 counts exceeding 50 dBrnC in a 5 minute interval).

ST: Central office reliability:

- no more than 1% of PCB cards to fail within 1st 30 days
- no more than 0.5% of PCB cards to fail in 2nd 30 days
- total office failure no more than 1 hour in 20 years

In general the performances of existing digital carrier systems is good. CTC experienced only minor problems when turning their systems up; they are "excellent" systems, are quieter, and better than analog, but very expensive.

E.5 POWERING CONSIDERATIONS

What is the preferred power system you currently use?

NBT: Central office battery plus remote with 10-12 hour backup
MTS: Remote with 8 hour backup
ST: Central office battery
AGT: Central office battery
REA: Central office battery
CTC: Central office battery

Companies use the central office battery for as much equipment as possible, although remotely installed AC power supplies for long distances are a "fact of life". Customer power is only used for special services (VIDON, EUCS, etc. at AGT, Elie Fibre Optics Trial at MTS). CTC feels that using extra pairs to provide central office power is desirable (their use of larger cables makes this an attractive powering method).

What are your voltage limitations for central office powered systems?

All Canadian telcos specified ±150V (tip to ground, ring to ground) for safety reasons. It also appears to be a CSA standard. NBTel also specified current limiting at 100 mA. The REA indicated that the 300V in total are not an absolute limit, and that higher voltage could possibly be used with current limiting.

What problems do you encounter with remote power installations? Is this acceptable?

NBT: Battery maintenance and cost
MTS: No major problems; theft of automotive type batteries
ST: Cost, power failures if no alarm is provided
AGT: No major problems, cost is minor compared to savings in carrier
REA: No answer provided

Very few problems that are unacceptable are being encountered, although a wide range of experiences were found amongst the various telcos.

Would you use a system whereby subscriber talk battery and ringing power are supplied by the subscriber's AC line? (Note: this simply entails the installation of an interface box between the outside line and the telephone(s)).

NBT: No. Concept is a touchy one
MTS: Yes, other services will also require this
ST: Only if the economic advantages were great enough
AGT: Very reluctantly, basically, no.
REA: No answer provided

There was a definite agreement that this is not desirable, and most telcos would not do it. MTS is most flexible in this regard, since their experiments with fibre optics may require this as well. There was agreement, however, that the main reason is tradition, although problems of extra wiring, CSA approval, accidental unplugging, old houses with ungrounded (2 prong) wiring systems, were also mentioned. Sask Tel noted that they had done this in an urban environment with single channel pair savers, but that the nearest telephone in case of a power outage was much more accessible there than it would be in low density rural areas.

CTC also used this method with the single channel pair savers, but they experienced problems where customers removed the systems, or refused to pay the "telco's" power bill! Units outside the house are definitely preferred.

Would you install remote terminals on subscriber premises to save remote power installations?

NBT: No
MTS: No
ST: Would consider it
AGT: No
REA: No answer was provided

An emphatic NO was received by most telcos, Sask Tel would require corporate approval, and it would have to mean substantial cost savings. Access and reliability are the key issues here.

Would you install unconventional power supplies such as solar power, wind generators etc?

NBT: No plans, technology must be proven for New Brunswick
MTS: No, although wind generators are being tested
ST: If they are economical and reliable
AGT: Yes, if cheap, effective, reliable. Currently looking at solar power.
REA: Depends on regional applications.

Since these types of power source have not universally proven themselves, telcos are reluctant to use them. AGT is considering solar power, especially for remote oil or gas well installations which have no AC power available.

As an alternative, would you consider installing low power electronic telephones on subscriber premises to reduce the overall power consumption?

NBT: No, problems primarily with administration
MTS: No, due to compatibility problem
ST: Yes, however rate problems have to be resolved
AGT: Yes, if standard on a province wide basis
REA: No answer provided

All answers were conditional. Tradition again dominated the reason for reluctance to install them; there is a definite problem of compatibility, inventory, lack of universality, etc. Standardization is extremely important.

COMMENTS:

A comment received by the REA regarding the unit which would power a telephone from the subscriber's AC line, stated that "customers are too pampered to replace dry cells themselves", should this be required. When bringing this to the attention of Canadian telcos, the reaction was that Canadian subscribers would not likely object to doing it themselves.

E.6 PACKAGING AND CONFIGURATIONS

Do you agree that remote units for 1, 4, and the full number of subscribers are the preferred configurations?

All companies agreed with this configuration, although 4 was not always necessary.

Would you like to see other configurations?

No, the above are satisfactory.

The REA commented that there was a need for a single package for the remote terminal complete with pedestal. They also supplied a set of their carrier system (subscriber and trunk) and equipment housing specifications. AGT requires good environmental protection against rain, slush, snow, storms, etc.

CTC commented that a single drop package is attractive to replace analog station carrier, although trouble shooting is a real problem with distributed carrier systems. They have found that remote terminals are moved around by field personnel and subsequently hard to find.

E.7 FEATURES AND OPTIONS

(1 - absolutely required, 2 - required, but may be an option, 3 - option, 4 - not required but could be an option, 5 - not required at all)	NBT	MTS	ST	AGT	REA
Interface to analog switch gear using 2 wire drop	1	1	1	1	1
Interface to analog switch gear using 4 wire drop	3	3	5	3	5
Digital interface to digital switch gear	2	1	3	2	1
Automatic backup transmission line protection switching	2	3	3	3	4
Interface to fibre optics transmission line	4	3	4	4	4
Intra calling if concentration is used	4	2	4	5	3
Bridged ringing	1	1	1	1	1
Ground return ringing	1	3	1	1	5
Frequency selective ringing	4	5	5	5	2
Coded ringing	1	1	1	1	5
Automatic number identification	2	1	3	2	4
Dial pulse compatibility	1	1	1	1	1
DTMF compatibility	1	1	1	1	1
Fault locate	1	3	3	1	1
Loop around on Central office side of fault to provide partial service	1	2	4	3	3
Bipolar violation detection	1	1	5	1	2
Bit density violation detection	1	3	5	4	2
Test for remote unit and repeater status	1	3	1	1	3

Other features mentioned were:

	NBT	MTS	ST	AGT	REA
Revertive ringing on party lines	1				
Software flow chart (for Micro Processor based system)	1				
Software support (for Micro Processor based system)	1				
Must have party line service	1				
Wide operating temperature specifications		2			
Vertical services (data, bit stealing)		2			1
Remote terminal power supply AC alarm			1		
RID compatible (if RID is standardized)				1	
Dedicated channel capability if concentration is used				3	
Transparent voice link when on hook					1

The above indicate that only intra-calling could be eliminated from the design, whereas all others must be included as standard features to satisfy all telcos except:

4 wire interface

digital interface

automatic backup switching

fibre optics interface

loop around on central office side of fault

vertical services

power supply AC alarm

dedicated channel capability

The above must be allowed for, but could be offered options or add-ons.

APPENDIX F: DETAILED TELCO REPORTS

This appendix presents detailed profiles of the rural telephone environment in Canada, the U.S. and overseas. Within these, individual telcos are described where the information was available and useful. These profiles combine insights from analyses of published statistical data and reports, with the results of interviews conducted during the course of the study.

Sections F.1 to F.7 deal with the Canadian market. Section F.1 provides an overview of the long-term trends of the country as a whole. Sections F.2 to F.5 cover the four telcos participating directly in the study: New Brunswick, Manitoba, Saskatchewan and Alberta. Long-term trends and future projections are provided, and both rural service and plant are discussed in detail. Sections F.6 and F.7 discuss the two largest Canadian telcos: Bell Canada and B.C. Telephone.

Section F.8 covers the U.S. market, concentrating on the Independents. The information presented was gained through interviews with the REA and an operating telco, together with published material.

Finally, Section F.9 presents some impressions on the state of rural communications overseas. Interviews were held with two national telephone companies in Europe, and the proceedings of an ITU-sponsored conference were reviewed.

Where information and especially opinions are likely to change over time, reference dates have been included. The schedule of interviews was as follows:

- Participating Telcos
  - June 1978, May 1979 and September 1979
- Bell Canada
  - August 1978
- Rural Electrification Administration
  - July 1978 and April 1979
- Commonwealth Telephone Company
  - October 1979
- British Post Office and Austrian Telephone Authority
  - February 1979

F.1 CANADA

This section provides a brief overview of the long-term trends in rural telephone service in Canada. Sections F.2 to F.7 will deal with the experience of specific telephone companies.

Figure F.1 illustrates over twenty years of data on the distribution of telephone main stations by their grade of service(1). Total subscribers are growing exponentially at 4.5% per year, while party-line telephones are declining slowly at 2.3% per year. At this rate, party-line telephones should drop from 1,222,000 in 1978 to 931,000 in 1989, a loss of 26,000 per year.

Two-party lines are maintained by only three telcos: Quebec Tel, Bell Canada and B.C. Tel. Telephones on two-party service are declining even faster than party-lines overall.

Although some telcos differentiate 4-party and multi-party (i.e. greater than 4-party) lines, the data are not reported consistently by all companies. Thus the degree of completeness of various rural service improvement programs which are standardizing service to 4-party, cannot be seen. However, what is evident is that rural growth has, to date, stymied efforts by the telcos to reduce the total number of telephones on four or more party lines.

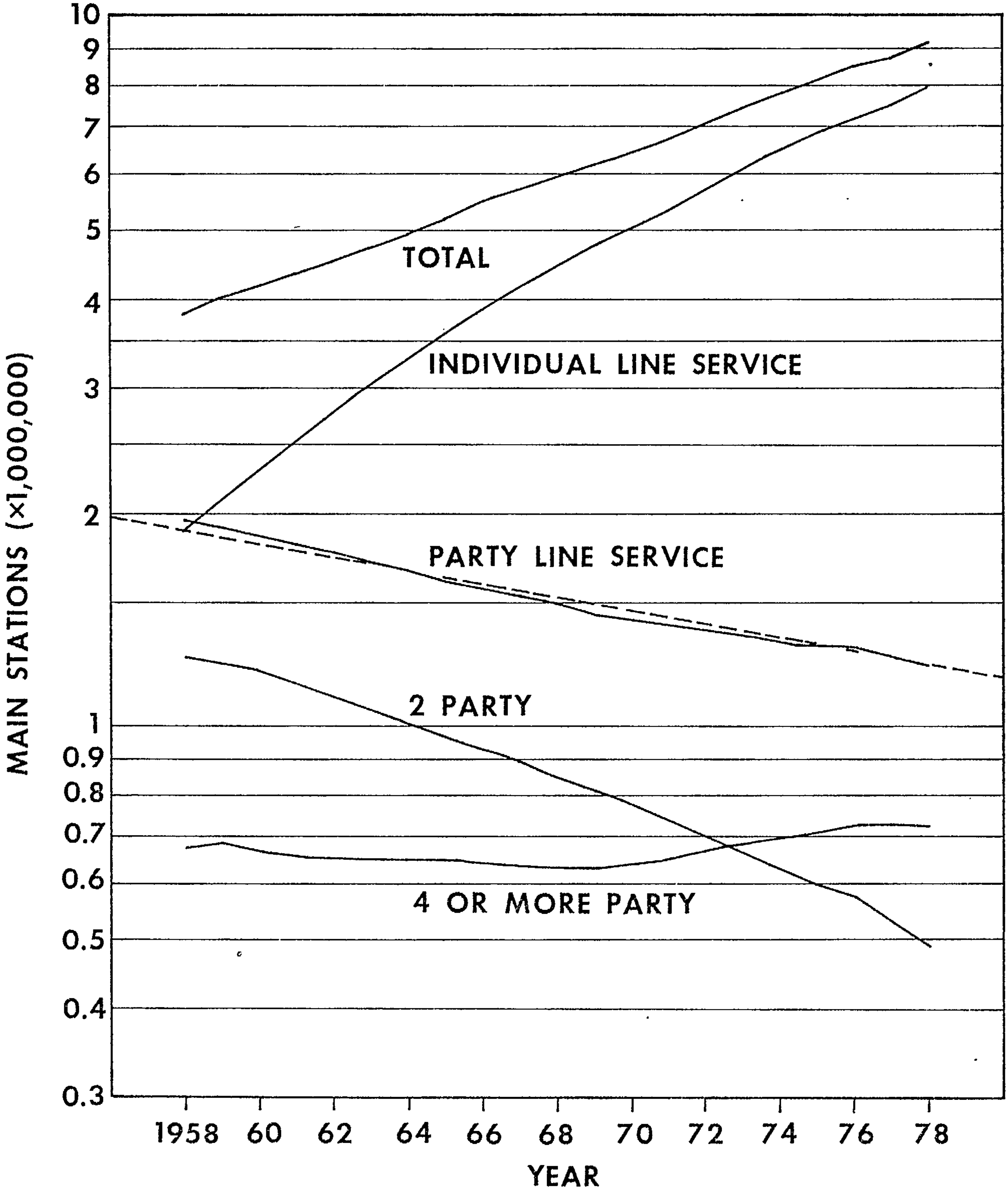

FIGURE F.1 TELEPHONES IN CANADA BY GRADE OF SERVICE, 1958 — 1978

F.2 THE NEW BRUNSWICK TELEPHONE COMPANY

F.2.1 Long-Term Trends

Since 1974, The New Brunswick Telephone Company (NB Tel) has represented all of the telephones in the province. Thus historical data, presented in Figure F.2, are for the whole province. These show a steady growth in total main stations of 4.8% per year and decline in party-line main stations of 1.8% per year.

The company further divides its party-lines into 2-party, 4-party, and rural. The number of phones on 2-party lines have been dropping since 1963 and this decline has accelerated in recent years. Telephones on 4-party lines have been rising since 1971, reflecting upgrades from rural lines. These rural lines have not varied much over the years, due to population increases in the rural areas which offset attempts by the telco to upgrade service. However, a net decline has been in effect since 1973.

F.2.2 Rural Service

Taking the Base Rate Boundary (BRB) within each exchange as the dividing line between urban and rural serving areas, New Brunswick is 28% rural in terms of the total population of telephone main stations. Of the two, the rural area is much faster growing: a 68% increase in the number of customers during the period 1972-1978 inclusive, versus 37% for the urban area. The increase in the number of lines is even more dramatic because of the decreasing line loads. Table F.1 shows an estimated 143% growth in rural lines over the seven year period reflecting an annual increase of 3,200 new lines.

This activity is a result of the Rural Service Improvement Program (RSIP) begun in 1972 and expected to finish by 1983(1). The goals are to upgrade rural plant and service, and to provide all customers with the capability* of 4-party service. By May 1974 the projected total cost of the RSIP was $74 million.

The expected total main stations and distribution by grade of service at the end of the RSIP in 1982 are fairly clear: an estimated total of 44,600 lines are required to accommodate 71,900 rural customers (Table F.2). This could require 1,600 new lines a year over the period 1979-82. After this, two scenarios are projected for 1983-87(2). One would see the present policy continue, including the "grandfather" clause allowing some customers to continue to be on rural lines. The other would have a Rural Interface Device (RID) installed with 4-party service and elimination of the rural lines all together. The main difference believed to result from the RID is the slowing of demand for upgrades to ILS by 4-party customers. NB Tel estimates 10,600 new customers in rural areas in 1983-87. Under the present policy, and expecting the percent on ILS to increase, this demand could be met with 10,500 lines. Utilizing the RID, only 6,900 lines would be required, a decrease of 35%. In either event, it is expected that a program would be underway to eliminate party-line service by 1990.

---

*In accordance with a "grandfather clause", customers currently on rural lines can elect to remain on this grade of service.

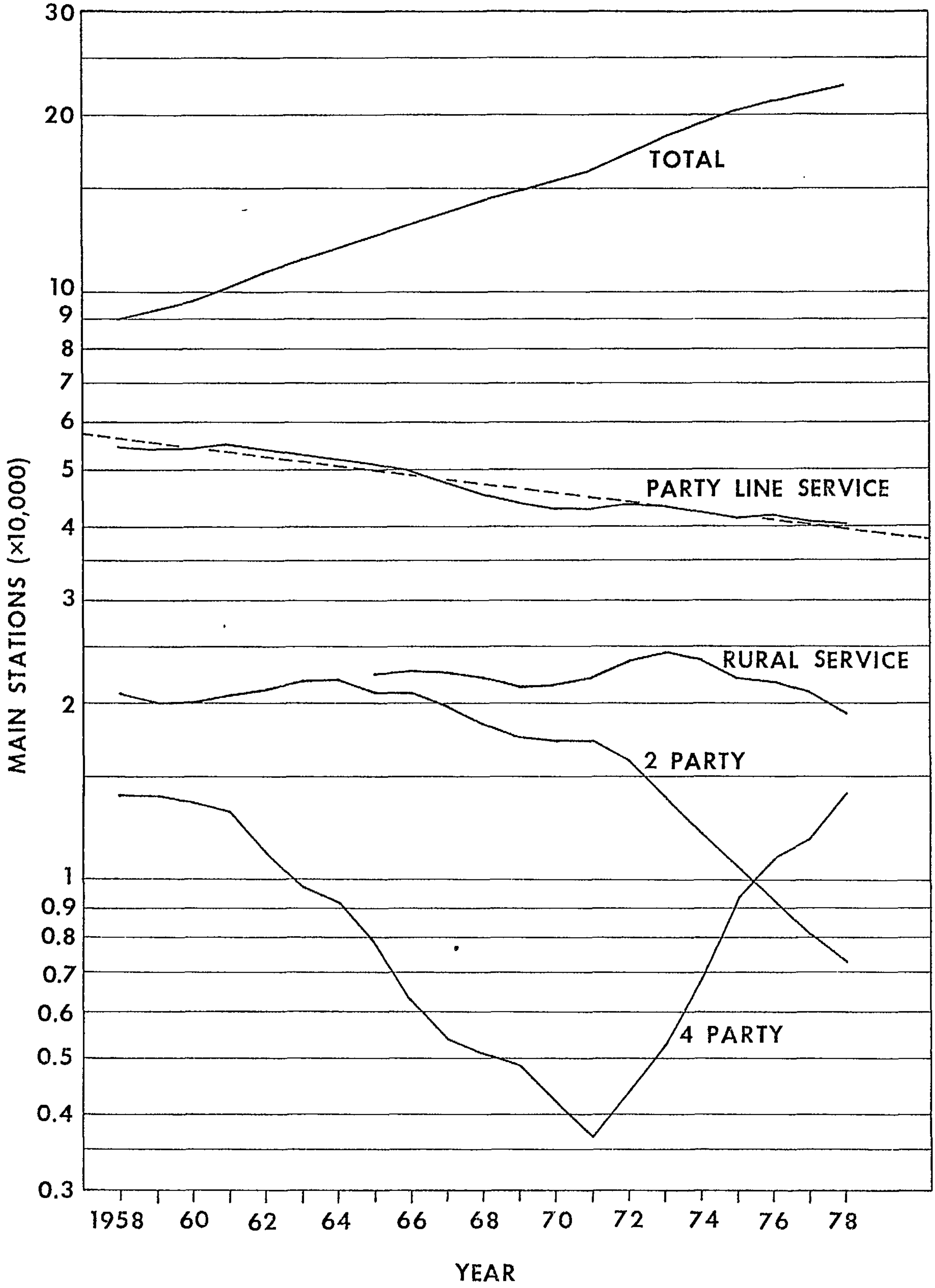

FIGURE F.2 NEW BRUNSWICK MAIN STATIONS, 1958 – 1978

TABLE F.1: ESTIMATED RURAL LINES, NEW BRUNSWICK

DATE	DECEMBER 31, 1971			DECEMBER 31, 1978		
GRADE OF SERVICE	MAIN STATIONS	LINE LOAD*	RURAL LINES	MAIN STATIONS	LINE LOAD*	RURAL LINES
ILS	7,978	1	7,978	28,225	1	28,225
2-party	6,382	1.5	4,255	3,256	1.5	2,171
4-party	1,560	3.0	520	13,039	3.0	4,346
Rural	21,981	7.42	2,962	19,182	5.5	3,488
TOTAL	37,901	-	15,715	63,702	-	38,230

*2- and 4-party line load values are assumed. Rural line loads are calculated by NBTel.

TABLE F.2: PROJECTED DISTRIBUTION OF RURAL SUBSCRIBERS AND LINES IN NEW BRUNSWICK 1982 - 1987.

GRADE OF SERVICE	END OF YEAR DISTRIBUTION OF SUBSCRIBERS			
	SCENARIO I		SCENARIO II	
	1982	1987	1982	1987
ILS	33,400	42,000	32,000	35,300
2-party	3,100	3,000	3,100	3,000
4-party	20,600	30,900	27,800	44,200
Rural	14,000	6,600	9,000	0
TOTAL	71,900	82,500	71,900	82,500
Estimated Lines	44,600	55,100	44,600	51,500

Notes:

1) Scenario I assumes continuation of current policy regarding rural lines.

2) Scenario II assumes making 4-party plus RID the standard offering.

3) Lines estimated assuming the following party line loads:

2-party	1.5
4-party	3.0
rural	5.0

4) Projections of subscriber distributions were made by the NBTel Planning Department.

A survey of rural line subscribers in February 1978 identified a large market for RID(3). Almost 70% of respondants identified one or more major problems with their present service. Of these problems, the most frequent was the lack of privacy on a conventional party-line. Altogether, lack of privacy or hearing the ringing of other parties was the major problem for 43% of those identifying problems. Of these people, 63% indicated that they would be satisfied with the present service if these two problems were eliminated, i.e. if a RID were installed. A second measure of a desire for a RID was that 37% of the customers believed that ordinary 4-party service was of "no advantage" over rural lines. Presumably, some of these would be satisfied, at least for a number of years, with 4-party plus RID.

No rural demand for wide band services is foreseen by NB Tel before the 1990's with the exception of some industrial establishments. This can be blamed on the low level of economic activity in the rural areas of New Brunswick.

F.2.3 Plant

While cable will continue to supply the majority of new lines in the province, the advantages of carrier for rural applications are well recognized by NB Tel. The flexibility of carrier to expand or contract or be removed to another location altogether is an advantage. A good example of the need for flexibility is in servicing the population living in mobile homes. These homes are constantly being moved necessitating new hook-ups even where the net change in subscribers company-wide is zero.

The Exchange Lines Planning group have undertaken studies of large and small carrier applications in NB Tel which yield interesting data for this study. These are reported in what follows.

F.2.3.1 Cable

Cable pairs are expected to be used to provide two-thirds of the yearly growth in installed line capacity in the 1980's(4). Aerial cable is the most common because of the difficult and rocky terrain.

F.2.3.2 Large Carrier and RLM

NB Tel pioneered in the use of digital carrier by participating in field trials of DM32S with ITT. In 1978 when ITT reported 70 units installed in North America(5), 28 of these were placed with NB Tel(6). Significantly, the company has decided not to install any more DM32S. Instead, it is standardizing on the Northern Telecom DMS family of carrier, digital switches and remote line modules. The principal advantages of DMS-1 over the delta-modulated system are its compatibility with other digital equipment, lower cost and improved diagnostics.

NB Tel is also an early user of DMS-1 carrier. Projections call for 60 systems in use in 1982 and 180 in 1995(6). Some of these may be configured as Remote Line Modules (RLMs) operating from digital switches. Current plans call for 9 RLMs in use in subscriber carrier-type applications by the end of 1983(4).

F.2.3.3 Small Carrier

NB Tel is currently using a number of small analog carrier systems of 1, 6, and 8 channel capacities, plus some concentrators. The single channel carrier is used in urban areas, 6 and 8 channel carrier is used to provide temporary relief in low growth (i.e. 1 or 2 lines per year) rural areas, while ES-1 concentrators are used for medium growth (5 to 10 lines per year) urban and rural areas. In general, analog carrier is thought to be too expensive to find wide use.

The telco is also allowing for small digital carrier in its exchange lines planning. A document has been prepared showing the location of prospective systems, number of lines per system, system use and timing(7). No suitable system is yet on the market, and NB Tel believes that the proposed system would be suitable for these applications.

Figure F.3 shows the timing of small digital carrier systems required by use. From a steady rate of four systems per year in 1980 and 1981, the demand peaks to 17 systems in 1983 and 21 in 1986. In the early years of the decade the principal use of the systems is to complete the RSIP program of upgrading basic service. Subsequently, carrier is used to accommodate growth in already provisioned areas.

The distribution of the size of carrier systems in lines is also of interest (Figure F.4) in tailoring a carrier package for the New Brunswick market. Two distributions are shown: the lines per system as initially installed, and the lines per system after allowing for ten years' growth to occur. The average lines per system is 30 initially but this doubles to 60 after ten years. A carrier system offering up to 45 lines would meet 88% of the requirement for the systems (75% of the requirements in terms of lines) initially, but only 65% of the requirement for systems (41% of the requirements for lines) after allowing for ten years' growth.

Of the total of 106 systems, most (74) would find application in areas of scattered subscriber distribution, i.e. in a distributed configuration.

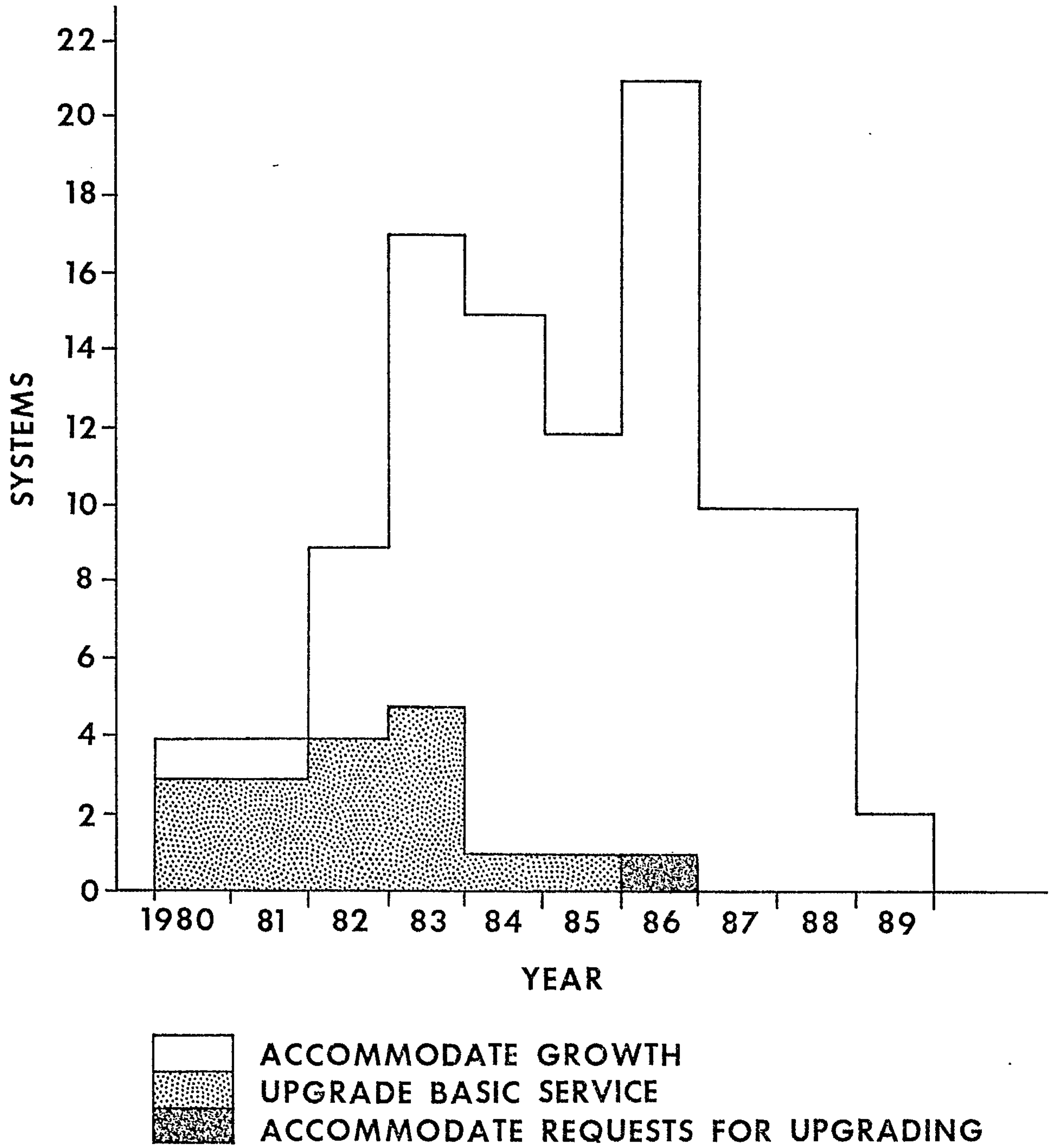

FIGURE F.3 TIMING OF CARRIER SYSTEMS REQUIRED, BY USE FOR NB TEL 1980 - 89

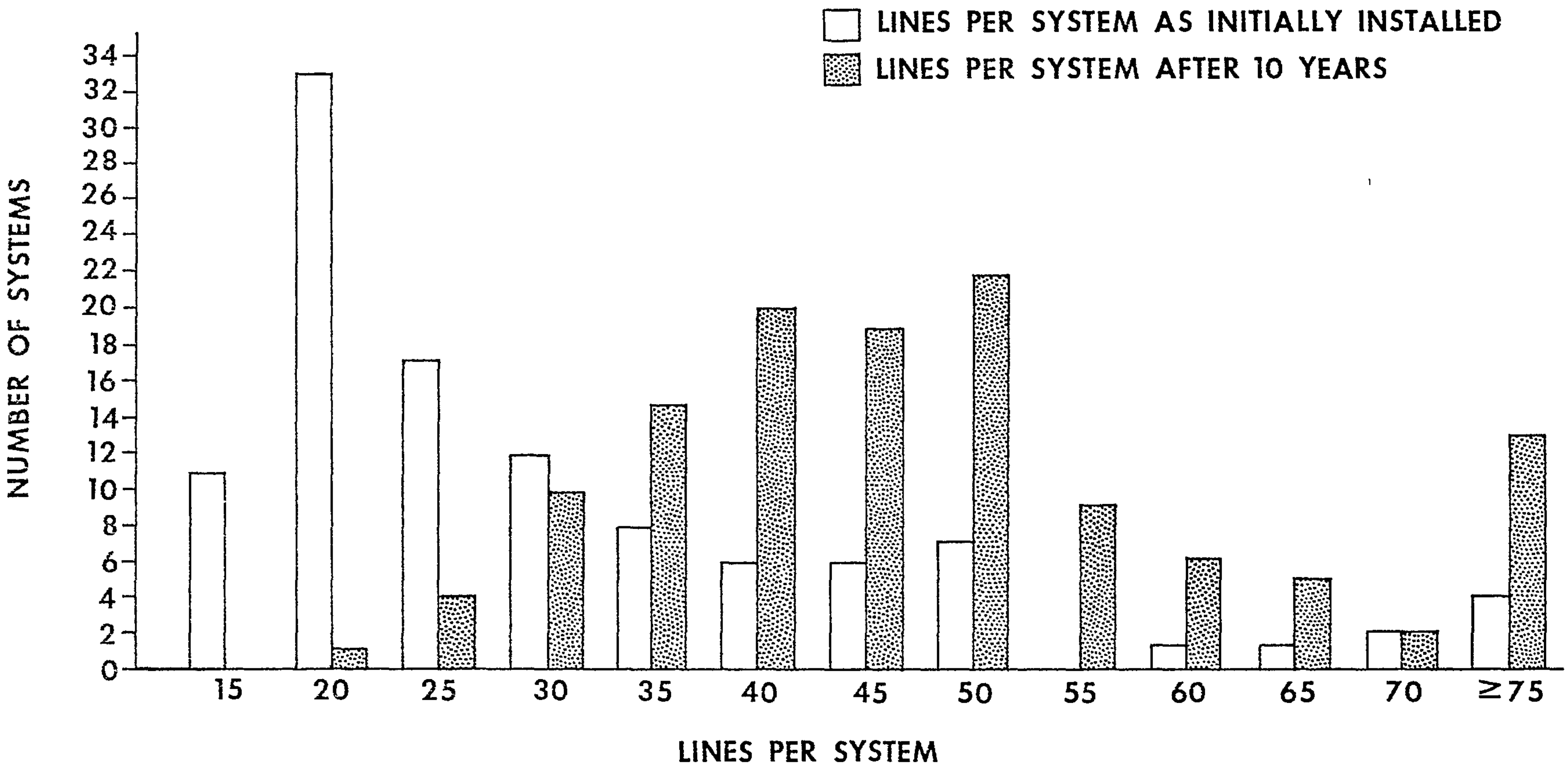

FIGURE F.4 DISTRIBUTION OF SIZE OF CARRIER SYSTEMS (IN LINES) FOR NB TEL, 1980 - 89

F.3 MANITOBA TELEPHONE SYSTEM

F.3.1 Long-Term Trends

Figure F.5 illustrates over twenty years of telephone data for the province of Manitoba, all of which is now served by the Manitoba Telephone System (MTS). The total main stations are growing at 3.4% per year, while the total number of telephones on party-lines has, despite some reversals, seen a 3.5% decline on average. This rate of decrease is expected by MTS to continue into the 1980's, perhaps levelling off at around 40,000 party-line subscribers. There is only a small amount of 2-party (not illustrated) which is rapidly being phased out. Unfortunately, the published statistics do not allow one to differentiate between 4-party and multi-party service.

F.3.2 Rural Service

MTS is well advanced in its efforts to improve the grade of rural service. The rural service improvement program has two aspects: first, to upgrade all lines to a minimum of 4-party by 1980/81 and second, to provide ILS service to all communities of 15 or more subscribers. The 4-party service is actually being implemented with an average line load of 2.8, so that demand for true ILS is expected to be low until at least the late 1980's. The cost of universal ILS has been estimated at $100 million for the province(1).

In recent years the demand for upgrades to ILS outside the Winnipeg region has been as low as 10 per year. However, it is believed that this is changing, and the company is encouraging premium service by having a relatively attractive structure of construction and mileage charges for ILS customers. Another policy area which is changing is that of serving resort areas. Many qualify for ILS service under the "15 subscribers or less" guideline, but up to now providing this service has not been a telco priority. It is believed, however, that this will soon change. About 25% of cottages currently subscribe to telephone service.

Household growth in rural areas of Manitoba is virtually nonexistent with the exception of the fringes of Winnipeg. However, subscriber distributions may slowly change. A succession of provincial governments has affirmed a land use policy which would see new houses being located only in existing communities and sub-divisions. The principles behind this are the rationalization of community services and the preservation of the integrity of farmland. This policy will make it easier for MTS to predict the locations of requirements for new phones and will lead to more use of clustered rather than distributed plant.

At the same time, the government is encouraging people to stay in the rural areas. One aspect of this is to make urban grades of service available to rural residents, whether in the field of health care or telecommunications. This has helped push MTS into the forefront of experimenting with delivering special services to rural subscribers.

MTS has taken two major initiatives in anticipation of demands in the 1980's for data links to computers, interactive video to assist educational and social services, and cable television. The first involves some unique design and development work for long-haul video transmission over coaxial cable. A network linking 29 cities and towns to provide cable television and other broadband services is under construction. The second project is the rural fibre optics trial at Elie, Manitoba.

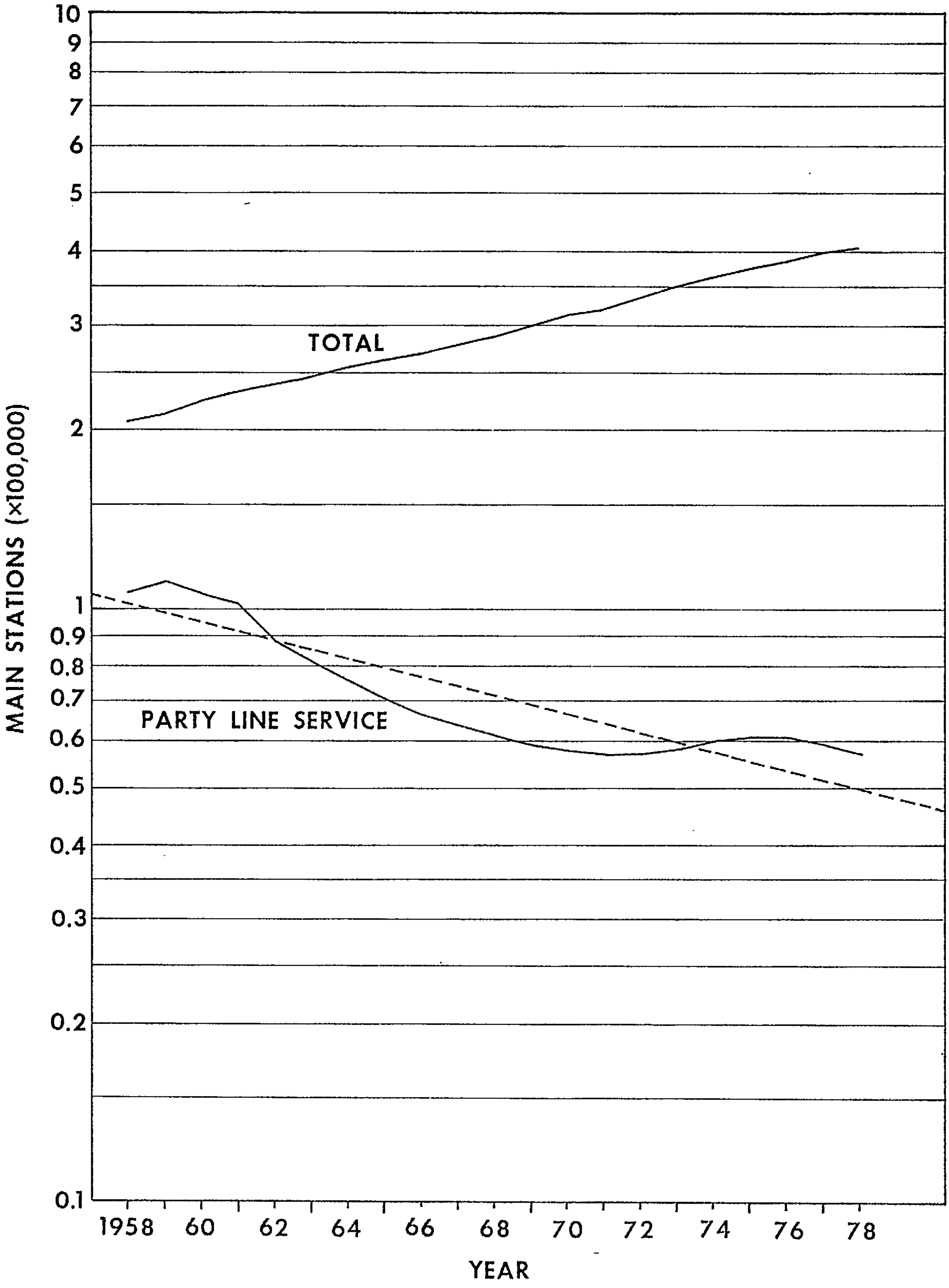

FIGURE F.5 MANITOBA MAIN STATIONS, 1958 – 1978

During the trial, ILS, at least five television channels, FM radio and some two-way interactive computer links will be delivered to 150 households and businesses. The trial will probably last from 1980-83 and will have several important spin-offs. First, it may stimulate demand for more than one channel to be provided to each subscriber. Secondly, the concept of using subscriber-supplied AC power will be tested and may lead to its consideration for other remote applications.

F.3.3 Plant

F.3.3.1 Cable

For the purposes of the rural service improvement program, cable was generally found to be preferable to carrier, presumably because of the relatively low cost of burying cable in southern Manitoba. Additional circuits have usually required only short cable sections for each route rather than complete cable overlays. However, it is felt that the basic cable network is now in place, and there is great reluctance to plough in more cable, e.g. to provide ILS. This is partly due to the low line-fills which should provide spare pairs to meet many of the future requirements without using pair-gain, and also partly in anticipation of the use of fibre optics for the next generation of outside plant.

Little study has been put into a Rural Interface Device, but it is believed that its use will be limited. The low line-fills have really reduced complaints about party service.

F.3.3.2 Carrier

In 1978, MTS reported using five CM8 analog carrier systems, one CM8X on field trial, seven DM32S and one DMS-1. In addition single-channel "add a line" equipment is used for temporary relief. This low use of carrier reflects its unattractiveness economically for the RSIP program. For example, DMS-1 was found to prove in for 50 subscribers only at 40 kilofeet. Generally, a smaller, distributed system would be more useful than DMS-1.

With the RSIP virtually completed, and the cable network in place, it is now company policy to use pair-grain systems to meet new requirements. Digital carrier is preferred to analog to the extent that a 10-15% cost penalty for the digital system would be endured. New markets for a small digital carrier are foreseen in providing premium ILS on demand and additional channels into a subscriber's premises.

F.4 SASKATCHEWAN TELECOMMUNICATIONS

F.4.1 Rural Service

Historical data for the telephones in the province of Saskatchewan are shown on Figure F.6. Total main stations are growing at 3.1% per year. The recent jump in the numbers of party-line phones is explicable with reference to the extensive rural service improvement programs underway.

Saskatchewan is unique in Canada in having hundreds of rural cooperative telephone companies. At the end of 1978 there were 175, but as recently as 1974 there were 796. These are being absorbed by Saskatchewan Telecommunications (Sask Tel) in a seven-year program to be completed in 1983. First, however, it was necessary to provide initial service to 10,000 farms not served by any telco. This explains the rise in party-line main-stations during the 1970's on Figure F.6.

Subscribers of the rural telcos are loaded anywhere from 2 to 14 to a line. At the time of absorption, Sask Tel upgrades the lines to 4-party. This policy is projected to cost $100 million. Over the period 1980-83 it is forecast that 24,360 subscribers will be left to upgrade to 4-party service.

Another aspect of Sask Tel's rural service program is to provide ILS to smaller and smaller communities. The following schedule for the 1980's indicates the projected market:

COMMUNITY SIZE	DATES	COMMUNITIES	SUBSCRIBERS
More than 50 subscribers	1980-83	33	2055
35 - 49 subscribers	1984-86	60	2453
25 - 34 subscribers	1987-89	53	1564
Less than 25 subscribers	1990+	241	3119
TOTAL	-	387	9191

Service to resort areas is a third aspect of Sask Tel's rural service. At the moment there are 2200 subscribers, but the total is growing both through new cottage-building and increased penetration of telephone service. It is believed that there are 10,000 cottages in the province and that this will double in the next ten years. Penetration is at about 20% and will grow by 1% per year.

Demographic changes in Saskatchewan's rural areas are similar to those in Manitoba. Farms are growing in size, and those who are bought out typically move to the small communities. The effects of this differ between the two provinces, however, since Sask Tel is far less advanced than MTS in providing ILS to these communities. This growth will continue to present a challenge to the telco and a market for pair-gain systems. On the other hand, the attrition in the farming areas means that line-loads are slowly dropping and with this, the pressure for ILS in those areas.

Demand for a business phone and extra channels for special services from the larger farms is recognized as a possibility by Sask Tel.

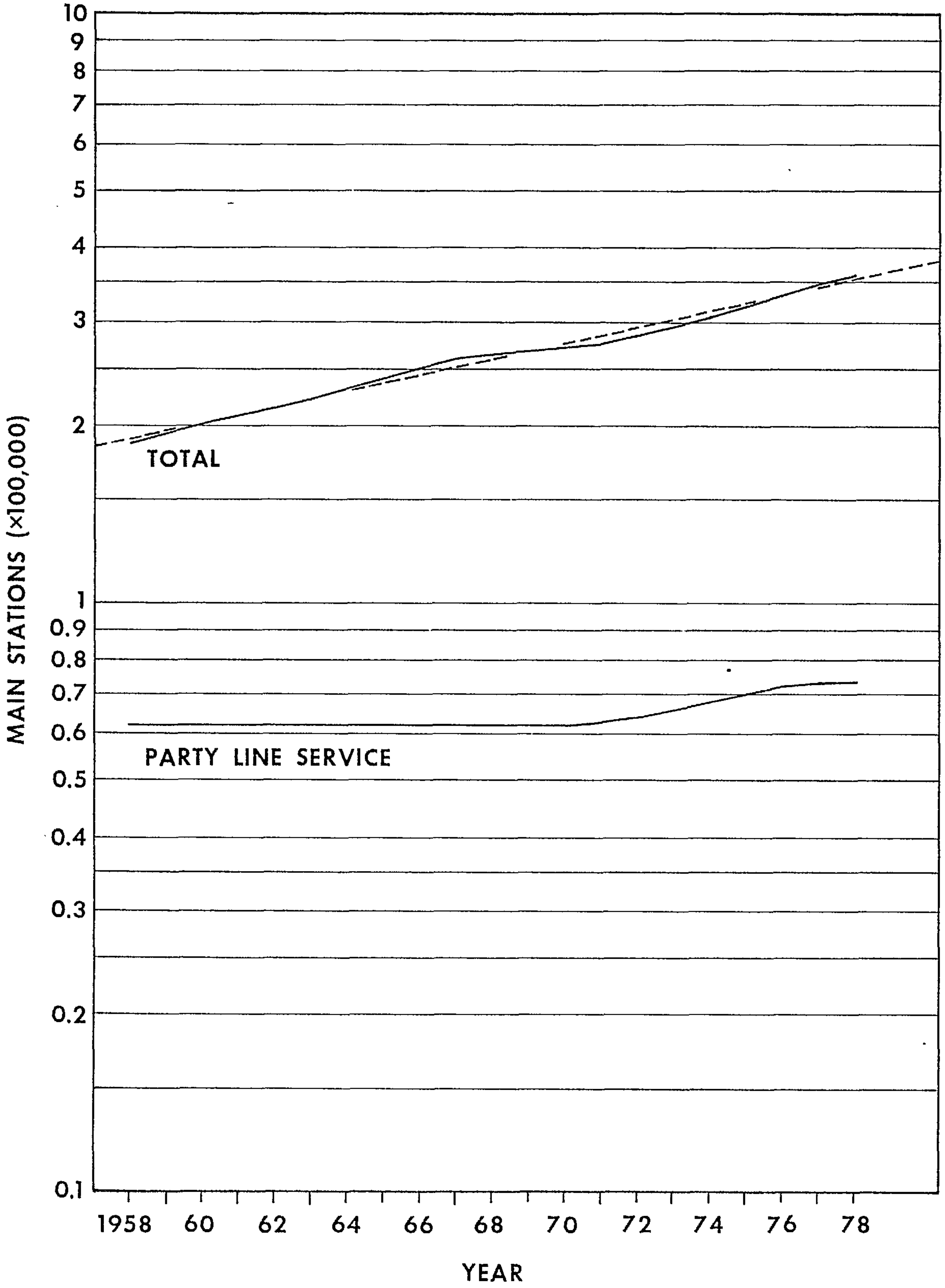

FIGURE F.6 SASKATCHEWAN MAIN STATIONS, 1958 — 1978

F.4.2 Plant

F.4.2.1 Cable

Wherever possible, open wire and old overhead cable lines are being replaced by buried cable and wire as part of the RSIP. Although Sask-Tel has had an active program for buried cable, there still remain 15,700 miles (in 1977) of pole line facilities which must be maintained or replaced.

Much of the cable that is in place is small. While the average in rural areas is 31 pair, the largest amount is 4 and 6 pair. There is also about 21,000 miles of buried wire (1 or 2 pair 19 gauge). About 5% of the lines are longer than 25 miles. With increasing use of digital concentrators in place of Community Dial Offices, this percentage is expected to increase.

Like Manitoba, Saskatchewan has recently (May 1979) announced plans for a 3400 kilometer "electronic highway" which is a trunk system linking all major centres in the province. This network can be expected to spur demand for new services.

The outside plant planning with a 2 or 3 year time horizen is still based on VF (e.g. long loop) designs.

F.4.2.2 Carrier

Sask Tel has made extensive use of analog carrier. In 1978 about 200 systems of 6 and 7 channel analog carrier were in place serving about 3600 party-line subscribers. Other carrier systems in use included two DM32S, four DMS-1 and six unconcentrated PCM systems.

Analog carrier is acknowledged to provide good transmission quality but is expensive. At the beginning of the study it was felt that analog carrier would continue to hold its own in the market because its small capacity matched the low densities and slow growth of Sask Tel's farming areas. This feeling is changing however, in favour of digital technologies because analog carrier has suffered from poor maintenance.

For the most part, the large carrier systems which are likely to prove in are already in place, primarily in urban fringe areas. Sask Tel has taken the initiative in sponsoring the development of small distributed digital carrier partly because they realize that analog is not going to get cheaper, but also because their rural routes tend to be long, thin and continuous.

The belief with respect to digital switching is that the introduction of digital switches is fueled by growth, which is not a characteristic of the rural areas overall. These will continue to be served by analog switches, probably equipment salvaged from the larger centres when digital switches are introduced there. This should be contrasted with the situation in rural New Brunswick, where the higher densities and continuing rural growth mean that digital switching will impact rural areas (in the form of Remote Line Modules) very early.

Centres over 5,000 population (say 2,000 lines) are expected to go digital within a few years. It will take 10 to 15 years before smaller centres down to 1,000 lines are digital. In general, carrier systems installed in rural areas in the early 1980's will likely have lived out their usefulness before the analog switches to which they are connected are retired.

F.4.2.3 Rural Interface Device

Sask Tel expects to make a lot of use of a Rural Interface Device. The difference in attitude from Manitoba can be attributed to the fact that Sask Tel still has a considerable number of larger MPL communities and to the higher line loads in low density areas. For these reasons RID is attractive as a relatively inexpensive means of providing upgraded service while slowing demand for ILS.

It is possible to paint several scenarios of the likely effect of RID on markets for small carrier. Obviously, as a stopgap in the provision of ILS it will delay the need for new lines and hence for pair-gain systems in general. On the other hand, if RID is made a standard offering for rural subscribers, the program of bringing ILS to small communities may be speeded up to keep them ahead in terms of the grade of service received. Another possibility is that as RID goes in, the calling rate will increase. Thus rural subscribers will find access to the line a greater problem than it is today and the demand for true ILS may pick up.

On balance it would seem that the use of RID will lessen the demand for carrier for several years. However, a system that is well positioned in the market in the mid 1980's should find a rapidly growing market despite the RID due to the inevitable pressure for true ILS.

F.5 ALBERTA GOVERNMENT TELEPHONES

F.5.1 Long Term Trends

There are three telephone companies in Alberta: Alberta Government Telephones (AGT), Edmonton Telephones and a tiny co-operative. Edmonton Telephones is entirely ILS, so AGT has all of the rural market.

Figure F.7 gives the trends in total main stations in Alberta. These are growing at 5.8% per annum. The sustained growth in party-line telephones is startling, and unique among the telcos studied. The rate is 6.0% annually which, AGT confirms, is likely to continue in the 1980's. The reasons for this are both economic and technological, and are explored in what follows.

F.5.2 Rural Service

Alberta's equivalent to a rural service improvement program was essentially completed in 1973, well ahead of other provinces. From 1964-1973 an $80 million program provided 4-party service throughout the rural areas by burying 60,000 miles of wire and cable. Initial service was brought to the half of rural households which did not have telephones and over 1,000 mutual companies were absorbed(1).

This program was ahead of its time in 1973 but is causing headaches today. Although the average line fill was 2.6, there was no expectation for rural growth when the program was developed. The economic boom the province is experiencing has put a lot of pressure on the existing facilities and necessitated extensive use of pair-gain systems. Typical examples of rural growth are resort areas being converted into year-round residences and small subdivisions appearing eight miles from a central office.

There is no policy or plan to provide universal ILS. Upgrading to ILS on a premium basis is discouraged by high construction charges, which explains the continuing rise in party-line telephones in Figure F.7. This policy is expected to continue for another decade until a cable replacement program becomes necessary.

However, pressure for improved service is evident. A recent survey of party-line subscribers showed 79% to be dissatisfied with party service. The lack of privacy was cited by 46% while 23% complained of the lack of access (1). This concern for privacy and the reluctance to provide ILS at this time, has spurred AGT to sponsor development of a Rural Interface Device.

AGT is already experiencing demand for teletype and data services (up to 4800 baud) in rural areas. This demand comes primarily from oil companies, but farmers have need of business communications as well.

F.5.3 Plant

F.5.3.1 Cable

As already mentioned, cabling of the province is essentially completed. Company policy is to consider carrier ahead of cable for new requirements. Furthermore, no major upgrades are expected based on paired plant. Such a program, when

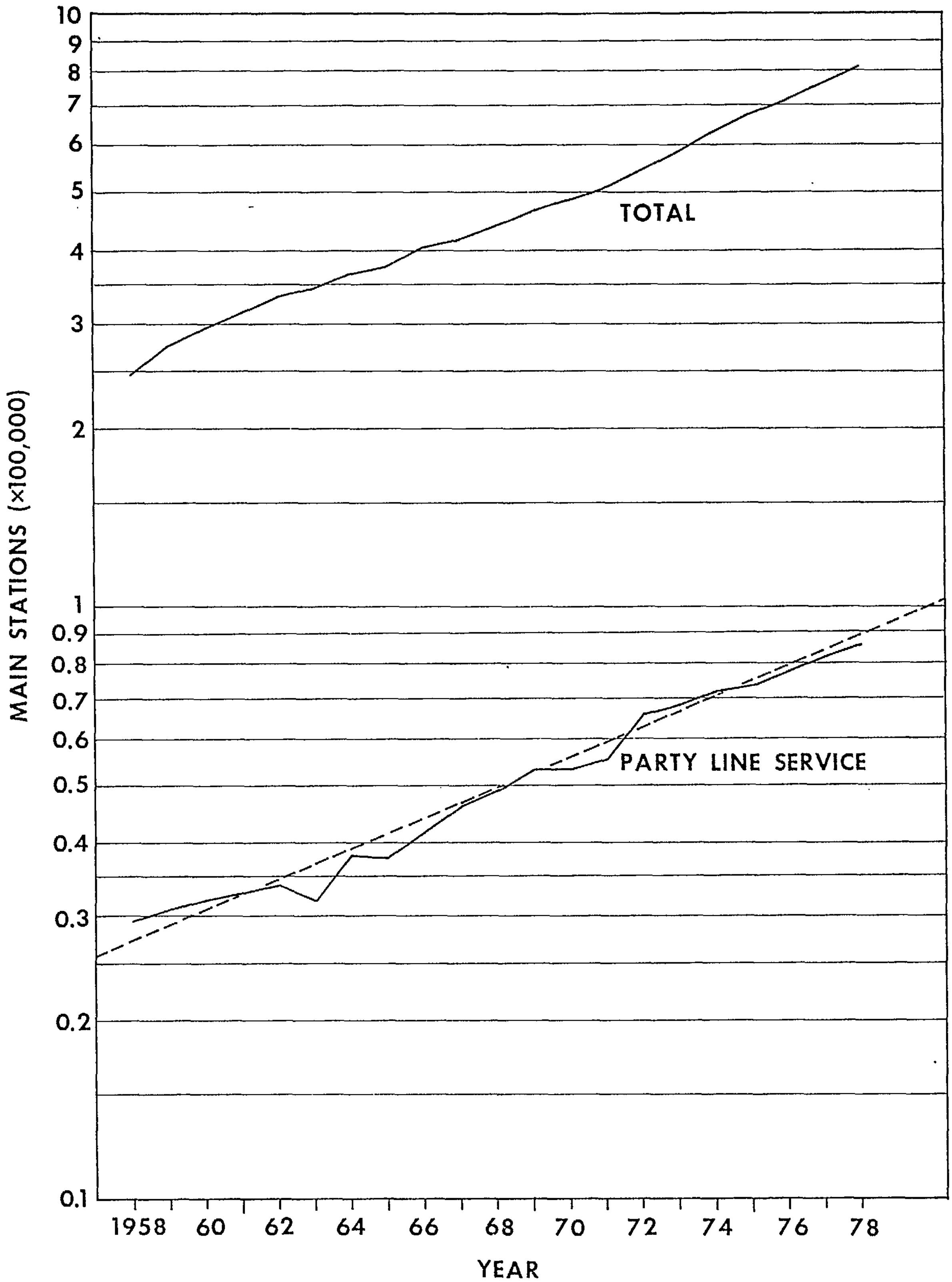

FIGURE F.7 ALBERTA MAIN STATIONS, 1958 — 1978 initiated, would likely make use of optical fibre rather than copper. AGT is already experimenting with a toll fibre application extending 60 kilometers out of Calgary into rural areas. The cable buried in the mid-1960's will be approaching the end of its useful life in the mid to late 1980's. This time frame makes the use of fibre for this replacement program seem likely.

F.5.3.2 Rural Interface Device

AGT is sponsoring development of a Rural Interface Device with DOC. The strategy is to use RID to stave off demand for universal ILS until the mid 1980's when re-cabling the rural areas with fibre optics can begin. Both ILS and wide-band facilities will be a requirement by the late 1980's, so that by holding off on ILS now, major savings can be realized by providing both at once.

F.5.3.3 Carrier

Analog

By reason of the pressure of demand on cable facilities, AGT is already a heavy user of carrier systems. It was reported that there were 250 analog systems in use in 1977 and 235 more forecast for 1978.

Some concentrators are used with analog carrier, but these are mostly suitable only for areas with ILS and low calling rates. Otherwise, too much blocking is introduced.

Some problems are being experienced with analog which is limiting the outlook for future purchases. There are problems of incompatibility with older models, and the feeling that the systems are now over-developed. A search for a digital alternative is actively underway.

Large Digital

As of 1978, the company had several DM32S systems in use and a DMS-1 on field trial. Some problems were encountered with DM32S because of the high calling rates found in suburban fringes. The system is concentrated, and with the low blocking rate allowed by the traffic department, the number of subscribers per system was too low to be economical.

The use of digital switches to consolidate offices is planned. Basically, there are 10 locations where digital switches are being considered. However, with remote wire centres, a reduction in offices from 300 to 80 is perceived as being possible. Several DMS-10's were already on order in 1978.

Small Digital

AGT has identified a requirement for a small unconcentrated digital carrier. They find themselves putting as many as 8 analog systems on one route but being unable to prove in DMS-1. An intermediate sized system would be very attractive. Single drop-offs are a requirement as is the ability to handle ILS, 4-party and data. The fact that analog carrier continues to be purchased merely reflects the lack of a digital alternative. Forty or fifty systems a year is an estimate of the potential demand.

F.6 BELL CANADA

Although Bell Canada was not a formal participant in the study it was felt expedient, because of its size, to learn as much as possible about its rural programs. To this end, submissions to the CRTC were studied, Mr. Emil Gratton, General Supervisor, Customer and Facilities Service Technology Development, was interviewed, and some responses to our questionnaire were obtained. Mr. Gratton was a participant in the ITU seminar on Rural Telecommunications held in New Delhi, India, in September 1978. The results of these investigations are compiled below.

F.6.1 Rural Service and Trends

At the end of 1978, Bell Canada was exactly half-way through a four-year Non-Urban Service Improvement (NUSI) program. NUSI, projected to cost $600 million, will reduce the standard rural offering from 8 to 4-party service by 1981 and bring initial service to a number of remote locations.

Figure F.8 shows the progress to date and puts it into a larger historical context. From this it is evident that no significant shift in the downward trends in total party lines or two-party lines has occurred. Total main stations are growing at 4.1% per year, total party line telephones are declining at 3.5% while two-party is being eliminated at a rate of 5.7% per year. Unfortunately, published data do not distinguish four- and more-than-four-party lines.

The long-term decline of 2-party service is consistent with the company's position that "many customer service complaints support the Company's view that two-party service is considered to be a poor substitute to ILS".(1).

Figure F.9 gives a forecast distribution of main stations in non-urban areas. As a check on the accuracy of the estimates, the actual number of four-party and multi-party stations in 1978 was 252,000 versus the 247,000 predicted. The 494,000 main telephones in 1978 represents 9.4% of Bell's system.

F.6.2 Technology

Analog carrier equipment has been used for "add a main line" in urban areas where installation of additional buried cable would be too expensive. The Anaconda S6A carrier and the Gfeller (Swiss) concentrator are also in use, but there are no plans to buy more. These are said to be not often economical, and so are unfamiliar to outside plant personnel.

Bell has made use of ITT's DM32S carrier but predictably, it has since standardized on Northern Telecom's DMS-1 for rural applications. The advantages cited are its flexibility, improved signal to noise ratio for 4-party service and lower cost. No other carrier is being used or contemplated for the NUSI program. In terms of upgrading communities to ILS and accommodating growth, 15% of the new pairs are cable and 85% are DMS-1.

The Rural Interface Device is under consideration, but the belief is that it will have limited application. RID may quickly be made obsolete by the increasing telecommunications needs of subscribers, who will require true ILS to have them satisfied.

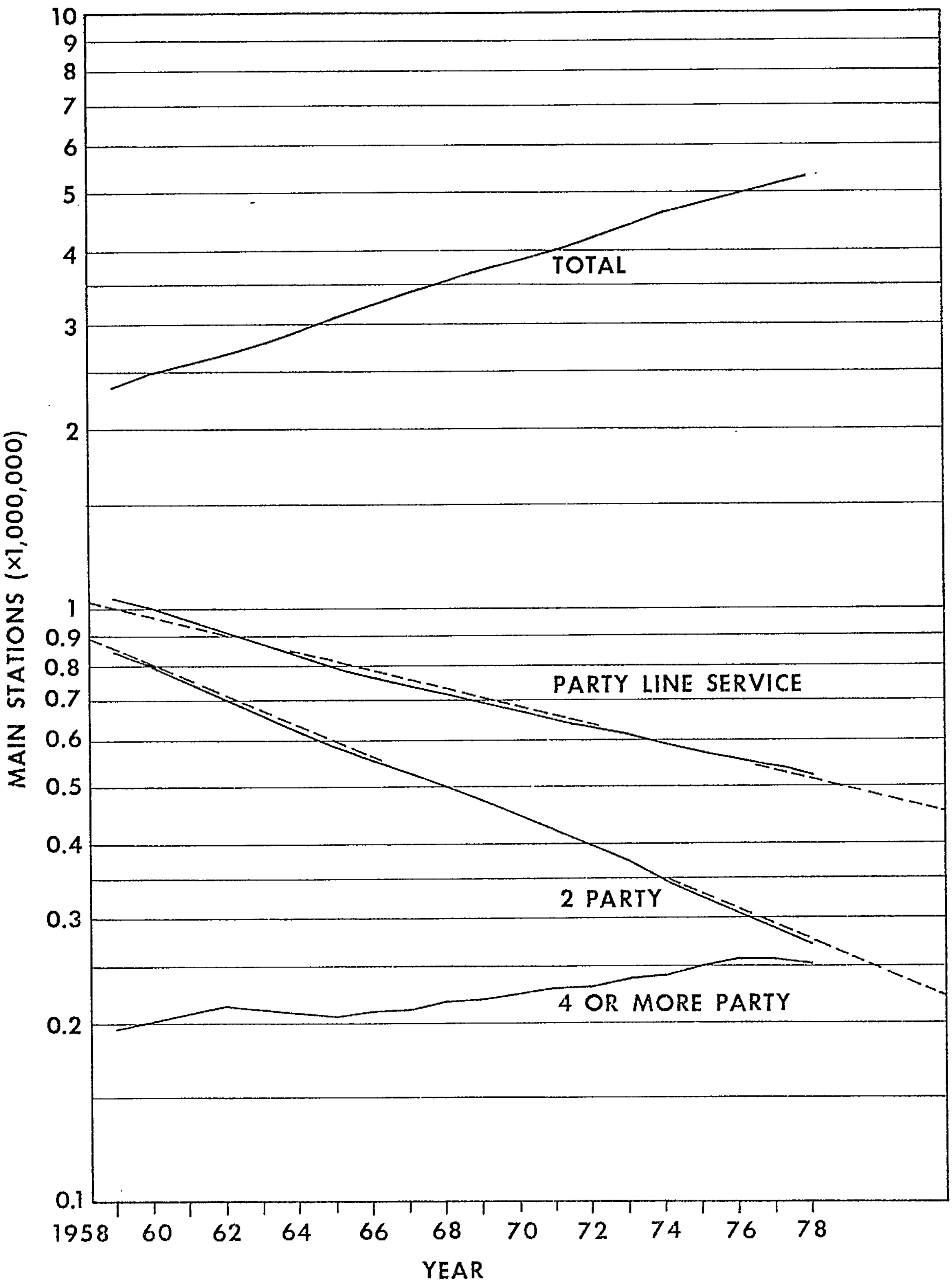

FIGURE F.8 BELL CANADA MAIN STATIONS, 1958 — 1978

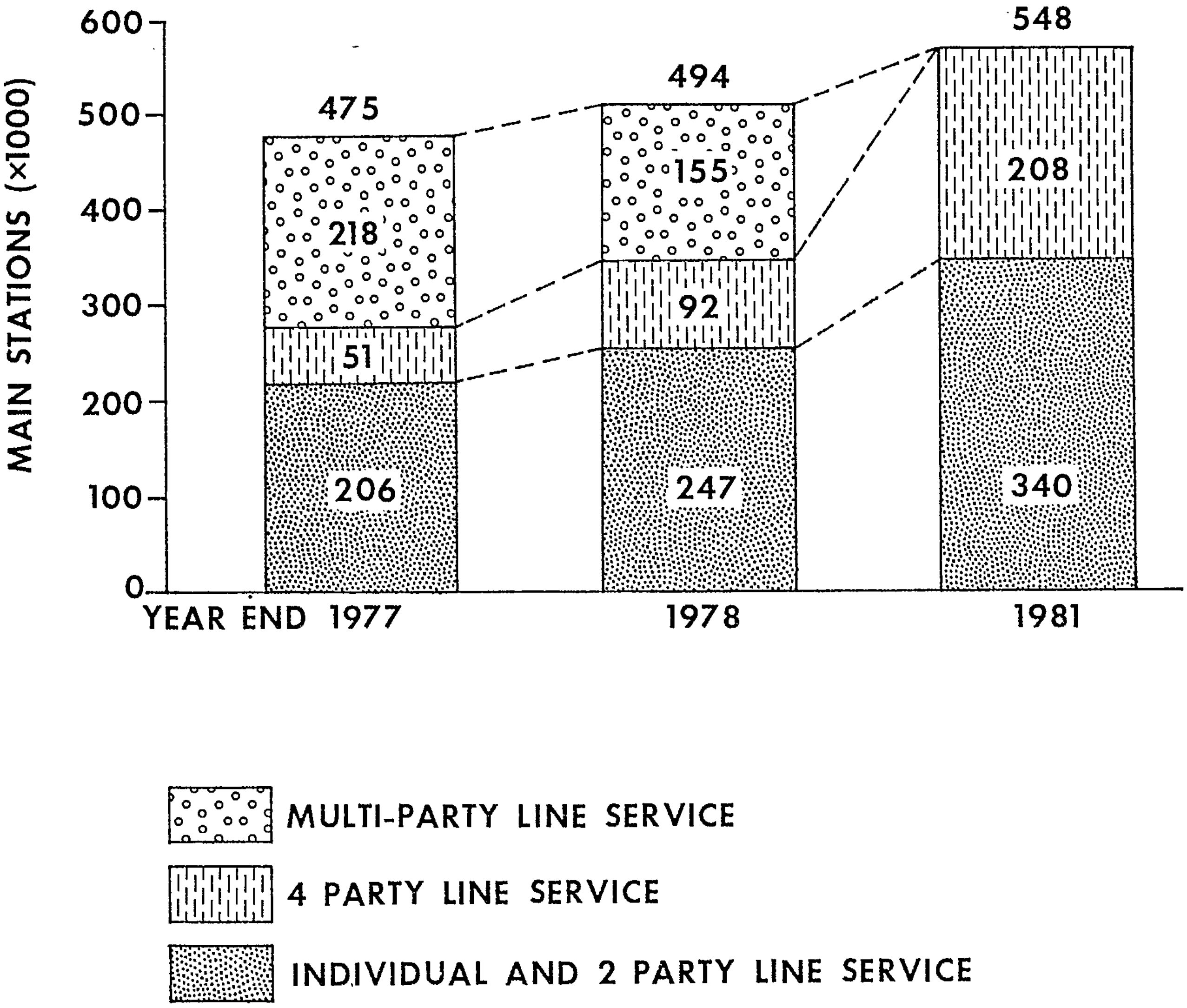

FIGURE F.9 FORECAST OF MAIN STATIONS IN NON-URBAN AREAS - BELL CANADA

Cost studies have been done to try to justify a small digital system of 24 channels, for example one obtained by stripping down a DM32S or DMS-1. A small T1 system was not found to be economical because of the quality of the line required on which it could operate. The technological breakthrough needed to make such a system attractive would have to come on the transmission side more than in the cost of hardware itself.

F.7 BRITISH COLUMBIA TELEPHONE COMPANY

The British Columbia Telephone Company (BCTel) declined to participate in this study. However, in view of its size it seemed expedient to get some idea of its rural programs based on published data.

The province's telephones are owned by three companies: BCTel, a municipal system in Prince Rupert and CN-Telecommunications, which operates in the northern part of the province. BCTel merged with Okanogan Telephone Co. in December 1978 with which it was corporately linked. BCTel has also moved towards vertical integration by purchasing GTE Automatic Electric (Canada) and with it, GTE Lenkurt Electric (Canada) in September 1979.

Figure F.10 shows the trends in main stations by grade of service for the province. Total main stations are increasing at 5.2% per year. Party-line phones exceeded ILS stations until 1967, later than any other Canadian province studied. Figure F.11 shows that the percentage of total subscribers on party-lines is declining at a predictable rate.

This rate is faster than the Canadian average as BC catches up. The percent of main stations on party-lines in BC should be equal to the Canadian average by 1987 at which time the figure will be 5.7% (versus 21.2% at the end of 1977). BC is also one of the areas (with Bell Canada and Quebec Tel) which maintains a 2-party offering.

According to published figures, BC is a heavy user of subscriber carrier: 1,306 systems comprising 29,000 channels in 1977. It is believed that the carrier is largely Lenkurt and Vidar equipment.

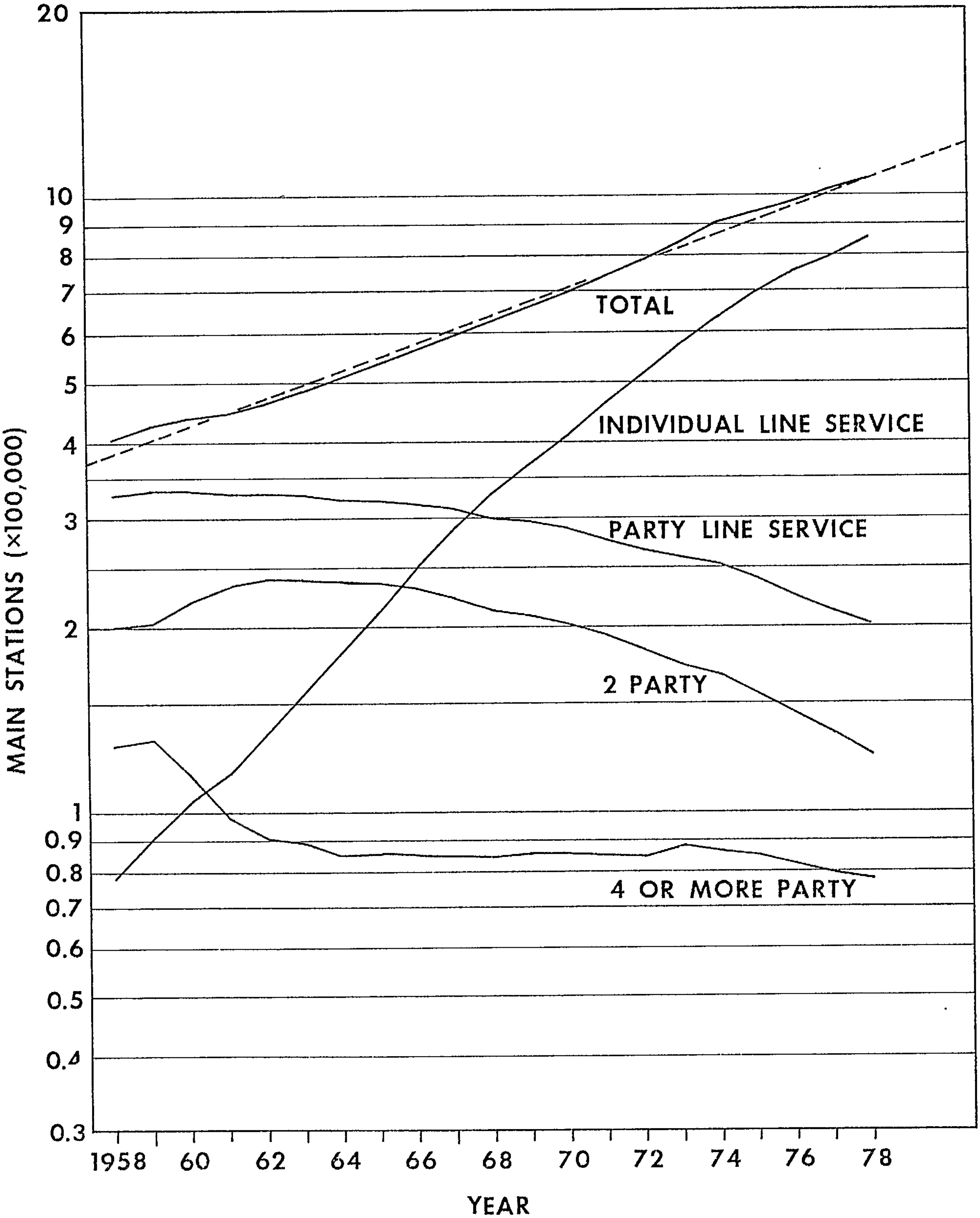

FIGURE F.10 BRITISH COLUMBIA MAIN STATIONS, 1958 – 1978

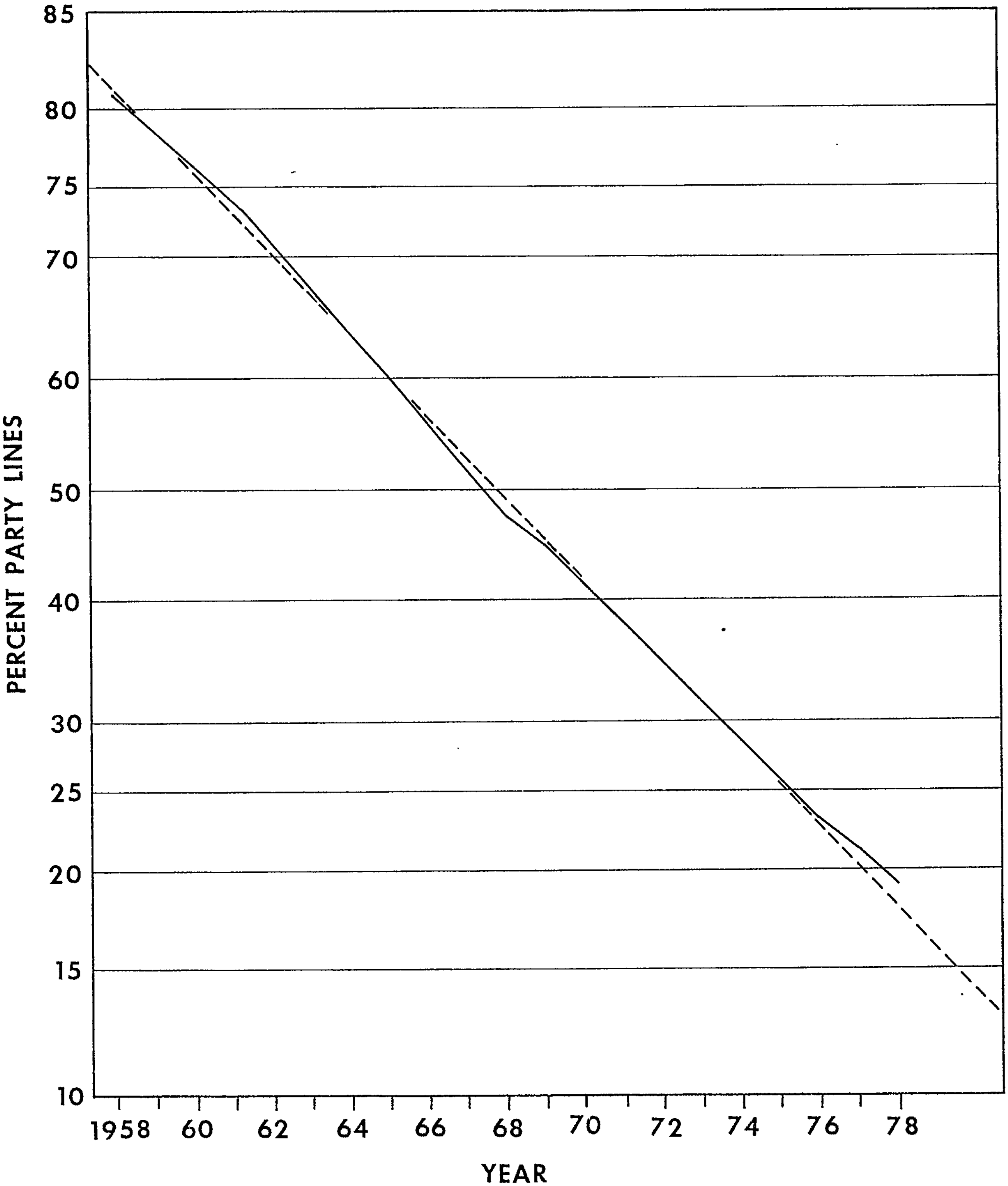

FIGURE F.11 SUBSTITUTION OF INDIVIDUAL LINE SERVICE FOR PARTY LINES, BC 1958 — 1978

F.8 UNITED STATES

Several initiatives were undertaken to learn about rural serving areas in the United States. Published statistics of the U.S. Independent Telephone Association (USITA) were examined, two visits were made to the Rural Electrification Administration (REA) in Washington, and interviews were held with senior people in the Commonwealth Telephone Company, Pennsylvania.

USITA represents the 18% of the U.S. market which lies outside of the Bell System. The REA makes loans to many of these Independents (895 telcos out of 1556 Independents in 1977, representing 12% of the telephones), to upgrade their rural plant and service. It maintains a competent engineering capability to review loan applications and sets technical and service standards for its borrowers. Commonwealth is of interest for two reasons: although small by Canadian standards (two-thirds the size of NBTel) it is one of the largest Independents which is not tied to a holding company such as GTE, Continental or United. Second, it is an innovative user of PCM(1) and fibre optics technology. For example, the second DMS-1 ever installed was by Commonwealth(2). In addition, they are co-operating with the REA on a field trial of a fibre optics trunk line between exchanges.

The general impression is that the U.S. market is similar in broad outline to the Canadian, but is farther ahead in eliminating party-line service and implementing digital technology. The basic regional differences - the higher density East, favouring large carrier and remote line modules, and the lower density West with more application for small distributed systems - hold.

F.8.1 Trends in Rural Service

Comprehensive statistics on U.S. telephones by grade of service are not available as they are in Canada. Five years of data for most of the Independents are shown in Table F.3

In terms of the total market, the number of party-line main stations among REA borrowers was only 84% of the Canadian total at the end of 1977, while the larger Independents represented a market 3.18 times Canada's. The percent of total subscribers on party-lines was 30% and 24% respectively, versus 14% for Canada.

More significantly, however, the rate of decrease in party-line telephones is much more rapid in the U.S. than in Canada. Extrapolating the recent trends (shown in Table F.3) to 1989 gives the following results.

PARTY-LINES TELEPHONES, U.S. INDEPENDENT TELCOS

	YEAR END 1979	YEAR END 1989	AVG. ANNUAL DECREASE
REA Borrowers	970,000	651,000	32,000
All Independents	3,587,000	2,100,000	149,000

In comparison with the equivalent Canadian figure, the above are 28% larger in the case of REA borrowers and six times larger in the case of the larger Independents.

TABLE F.3: SUMMARY OF U.S. INDEPENDENT TELEPHONE STATISTICS, 1973-1978

YEAR[1]	PARTY LINE TELEPHONES		SINGLE LINE TELEPHONES	
	REA BORROWERS[2]	ALL INDEPENDENTS[3]	REA BORROWERS	ALL INDEPENDENTS
1973	1,232,609	4,945,784	1,441,049	9,235,181
1974	1,199,719	4,750,800	1,662,655	10,000,524
1975	1,134,713	4,475,457	1,850,879	10,797,603
1976	1,075,736	4,220,459	2,140,318	11,727,431
1977	1,050,705	3,992,485	2,471,325	12,599,862
Avg. Annual Percentage Change	-3.9%	-5.2%	+14.44%	+8.08%

NOTES:

1) Figures are as of December 31 each year.

2) Number of borrowers was 831 (1973), 848 (1974, 858 (1975), 876 (1976), 895 (1977).

3) Figures are for the companies with annual operating revenues of $50,000 or more. In 1977 this meant 757 companies comprising 96% of the telephones in the total Independent telephone market.

4) Sources: (3) and (4).

In the Bell system, 3.5 million rural lines were added from 1969 to 1977. Thirty-one percent of these were treated electronically: 850,000 with VF electronics (range extension) and 250,000 with pair-gain. The percentage of new lines with pair-gain is rising rapidly(5).

Demand for new services - automatic meter reading and eventually broadband is expected to develop rapidly.

F.8.2 Rural Plant

F.8.2.1 Cable

The REA stopped financing buried air-core cable in 1975. Buried filled cable has become the dominant new facility since its general introduction into REA in 1972(6). By 1990, the REA predicts that 20% of its distribution cable will be coaxial or fiber optic. Commonwealth Tel and REA are experimenting with a fibre trunk between exchanges 13 miles apart. The system was installed in June 1979; 6 carrier systems are operating on the trunk now and ultimately 20 will be.

F.8.2.2 Digital Technology

Some delta-mod systems have found acceptance in the past (Bell's SLC-40 and ITT's DM32S), but new purchases favour the PCM "standard". The ability to interface directly with a digital switch is a primary consideration.

The long-range plan for REA systems is an end to end digital transmission network. Digital switches will predominate in a host and remote switch configuration. The over 5,000 central offices of today will be replaced by not more than 3,000 host switches with the remaining switch points becoming remote units. Over 90% of new switches today are digital.

Commonwealth Tel is rapidly implementing the remote switching unit (RSU) concept using Northern Telecom DMS and Vidar equipment. Of 74 offices, 25 are digital now and 50 will be by 1985. The remaining offices will be consolidated with RSU's.

Commonwealth is servicing growth and upgrades to ILS in its rural areas. Nevertheless the use of new cable is falling dramatically: from 3 million feet annually in the early 1970's, to 1.5 million feet today, down to 500 thousand feet annually in the 1980's. The basic reason for this is that RSU's free up large amounts of cable between the remote and the central office, and reduce the amount of distribution cable required. Basically, the savings generated by putting in RSUs have enabled the outside plant budget to remain constant and are paying for the conversion to digital offices.

The cost of adding new lines is much less with digital than electromechanical switches. The installed costs, including line conditioning, of 128 lines from an RSU is $393 using a digital office versus $669 using an analog one. Up to the end of 1978, 3,378 lines were on digital RSUs. By the end of 1988, the total will be 51,215.

Commonwealth has halted the purchase of new analog carrier equipment. The existing systems function well, and they are moved around in advance of putting in digital RSUs, but no new requirements are foreseen.

Within the Bell system, a mix of VF, analog and digital technologies is predicted for rural areas in the first half of the 1980's. Cost studies suggest that (5):

- Long Route Design is applicable at distances 10 to 15 km from the switching machine, when the switching machine employs space division and is either not capable of CREG or serves substantially less than 400 lines beyond 5 km.

- CREG (Concentrated Range Extension with Gain) will be applicable at distances 5 to 20 km from a space division switch capable of CREG, when serving 400 or more customers beyond 5 km.

- Subscriber Concentrators will have essentially no applications unless unforeseen cost breakthroughs occur.

- Analog Subscriber Carrier will have applications limited to small clusters of customers beyond 24 km on routes without digital subscriber carrier (it is not compatible with digital subscriber carrier in the same cable sheath).

- Digital Subscriber Carrier (or remote switch unit) will have application to clusters of customers beyond 10 km of a time division switching machine or beyond 20 km of a space division switch.

F.8.2.3 Distributed Systems

Commonwealth does not see a market with its own system for a distributed carrier. Subscribers are relatively clustered and rural loops are not extremely long (30-40 kft average; 90 kft maximum). For these reasons, RSUs serve the need ideally. A measure of the lack of interest in distributed remote terminals in the fact that of the 40 or so DMS-1's in use, all but one are configured as a single remote. This situation is believed to be general of the north-eastern U.S., as far west as Michigan.

In addition to the fact that a distributed carrier would not prove-in over DMS-1, there is a great resistance to distributed systems for administrative and maintenance reasons. This experience was gained through the use of small analog carrier. It is believed that distributed remotes are difficult to trouble-shoot. More important, the fact that the remotes are easily relocated means that field personnel move them as required. In the process, however, they become "lost" to the central office, making it difficult to follow-up subscriber's complaints when problems develop.

Despite the lack of applicability within their own network, Commonwealth personnel agree that the proposed system has merit. It is believed to be applicable to the Pacific north-west and the west (North Dakota to Texas) where densities are very low and the plant is mostly buried. This accords with the general verdict of the REA, who have been prodding manufacturers to come up with a similar design. They see the system fitting in well with the Serving Area Concept for distribution facilities.

F.9 OVERSEAS

A preliminary impression of overseas requirements for subscriber carrier was gained in two ways. It was possible to arrange interviews with the British Post Office and the Austrian Telephone Authority. Second, the procedings of the ITU seminar on rural telecommunications held in New Delhi, India in September 1978 were examined.

In general, Europe is not seen as an important market for small carrier systems. Subscriber densities are high and loops are short, so that cable handles most requirements satisfactorily. The BPO is saving distribution costs by converting from copper to aluminum plant (1) rather than through use of pair-gain systems. In any event, it is very difficult for North Americans to compete with European suppliers in their own theatre.

Some developed countries such as Australia do not seem to make use of subscriber carrier at all in their rural plant (2). Most developing countries have concentrated in the past on developing urban networks, inter-urban links and international services. India, for example, has only two million telephones, and half of these are concentrated in a dozen large cities (3). A telephone is available in only 9,000 of 576,000 villages (populations up to 5,000 or more). Plant is of 1930's vintage by North American standards - open wire, manual switching of toll calls and magneto power - but carrier systems are used to get the most out of the meagre facilities. There is no need for these countries to repeat all of the steps in the evolution of telephone plant experienced in North America, so digital technology, including extensive use of remote line modules, is foreseen as the next step (4). One major advantage of digital over electro-mechanical equipment is seen as its imperviousness to high humidity, fungus and insect damage (5).

Finally, one measure of the world-wide markets is the figures for U.S. exports of carrier equipment and parts (Table F.4). Exports totalled $21,315,000 out of a total domestic production of $529 million in 1977. Of this, Canada was the largest buyer, leaving $16,470,000 for "overseas" markets. This is only 3.1% of domestic shipments. All purchasers over $1 million are listed in the table. Two are in Latin America, one in Africa, and three in the Far East.

TABLE F.4: U.S. EXPORTS OF TELEPHONE CARRIER EQUIPMENT AND PARTS

1977

DESTINATION	VALUE
Canada	$ 4,844,654
Singapore	3,112,274
Mexico	1,822,301
Nigeria	1,391,523
Taiwan	1,340,780
Brazil	1,261,384
Philippine Rep.	1,025,576
Other*	6,616,725
TOTAL	$21,315,217

*Individually each less than $1,000,000

Source: (6)

F.10 REFERENCES

Note: "Proceedings" refers to the Proceedings of the ITU Seminar on Rural Telecommunications, New Delhi, India. September 1978.

CANADA

1) Telephone Statistics, Statistics Canada catalogue 56-203 annual. 1978 and preceding years.

THE NEW BRUNSWICK TELEPHONE COMPANY

1) A Report on Telephone Service in the Non-Urban Areas of New Brunswick, The New Brunswick Telephone Company Limited, October 15, 1976.

2) Planning Department Corporate Forecast, April 27, 1979.

3) Rural Line Customer Survey, Summary Report. T.A. Fraser, NBTel May 24, 1978.

4) Estimate by John A. MacDonald, Exchange Lines Planning, October 11, 1979.

5) TCS-5 Central Office and DM32S Subscriber Carrier Integration, R.V. Anderson, R.J. Rottan and W.J. Wurst. Procedings of the International Symposium on Subscriber Loops and Services, 1978.

6) Digital Subscriber Carrier Planning Summary, Exchange Lines Planning, NBTel, April 12, 1978.

7) Potential Applications of Small Package Carrier, Exchange Lines Planning, NBTel, May 17, 1978.

Figure F.3: NBTel, Potential Applications for Small Package Carrier, May 17, 1979.

Figure F.4: NBTel, Potential Applications for Small Package Carrier, May 17, 1979.

MANITOBA TELEPHONE SYSTEM

1) Technologies for Rural Communication, J.D. Adam in ICC'78 Conference Record, pp. 41.3.1 - 41.3.3.

ALBERTA GOVERNMENT TELEPHONES

1) Canada's Rural Telecommunications Networks, Past, Present and Future, R.J. Taylor, Alberta Government Telephones. Proceedings.

BELL CANADA

1) CRTC Bell Rate Hearings, Document B-78-519; Part I, Section C, Page 3.

Figure F.9: CRTC Bell Rate Hearings, Document P(0) 23 December 76 - 905 Revised.

UNITED STATES

1) An Operating Telco Looks at Digital, D. Mike Maxwell, in Telephone Engineer and Management, Vol. 81, No. 5, March 1, 1977 pp. 47-50.

2) Telesis, Bell Northern Research, August 1977, page 125.

3) 1977 Annual Statistical Report, Rural Telephone Borrowers, REA Bulletin 300-4, U.S. Department of Agriculture, Washington, D.C. Table 7.

4) Independent Telephone Statistics, Volume 1, 1978 Edition. U.S. Independent Telephone Association, Washington, D.C., July 1978, pg. 24.

5) Impact of Loop Electronics on the Local Exchange Network, R.E. Mosher. Proceedings.

6) Evaluation of the REA, Gerald Schrage. Proceedings.

OVERSEAS

1) Aluminum Cables: Economic Considerations Leading to their Use by the U.K. Post Office, Herbert J.C. Spencer. Proceedings.

2) Present Rural Telecommunication Scene in Australia, V. Tkocz and A.B. Cazelot. Proceedings.

3) The World's Telephones, AT&T Long Lines. Data as of March 31, 1977.

4) India's Rural Telecommunication Network, S. Sankara, Rowan and K.D. Sangul, and Miss Shanta Pai. Proceedings.

5) Rural Telecommunication Service Expectations, Including Environmental and Maintenance Considerations, A. Curran. Proceedings.

6) U.S. Exports by Commodity and Destination, U.S. Department of Commerce FT410, 1977. Schedule "B" Classifications, commodity 7249130: Telephone Carrier Equipments Parts, NEC.

APPENDIX G: MARKET TREND ANALYSIS

This appendix outlines the assumptions and models used to arrive at estimates of the potential market for small digital carrier over the period 1980-1989. As outlined in Chapter 3 of this report, this potential market is equivalent to the number of new lines required in the rural serving areas of the telcos.

Estimates are provided for Canada and the U.S. Independent telcos and are further broken down by the telcos discussed in Appendix F - The New Brunswick Telephone Company (NBTel), the Manitoba Telephone System (MTS), Saskatchewan Telecommunications (Sask Tel), Alberta Government Telephones (AGT), Bell Canada, the British Columbia Telephone Company (BCTel) and the REA borrowers in the U.S.

Section G.1 presents the models used to arrive at the market estimates. Section G.2 describes the statistical procedures required to estimate the parameters of the models. Finally, Section G.3 presents the results of the statistical analysis in terms of predictions of growth rates and numbers of lines.

G.1 MODEL

As suggested in the introduction, the potential market for a small digital carrier system depends on the number of new lines in rural areas. This section introduces the terminology and elements of a model for estimating this number. First, the growth in total lines is discussed, followed by methods for separating out the rural from the urban lines.

G.1.1 Terminology

Figure G.1 gives a framework for discussing the relationship between telephones and lines. In successive years, t, we observe a population of ILS and party main stations, ILS_t and PTY_t. The year-to-year change in these is ΔILS_t and ΔPTY_t. This annual change is equal to a yearly growth, G_t, which is split between growth in ILS (GI_t) and party (GP_t) phones.

$$\text{i.e.} \quad \Delta ILS_t + \Delta PTY_t = G_t = GI_t + GP_t$$

As well, however, there is a transfer of telephones from party to ILS status, U_t, which does not affect the total growth. Thus,

$$\Delta ILS_t = GI_t + U_t$$
$$\Delta PTY_t = GP_t - U_t$$

There is a one-to-one correspondence between ILS main stations and lines but the relationship in the case of party-lines depends on the line fill, LF, where

$$LF = PTY_t \text{ divided by the number of party lines}$$

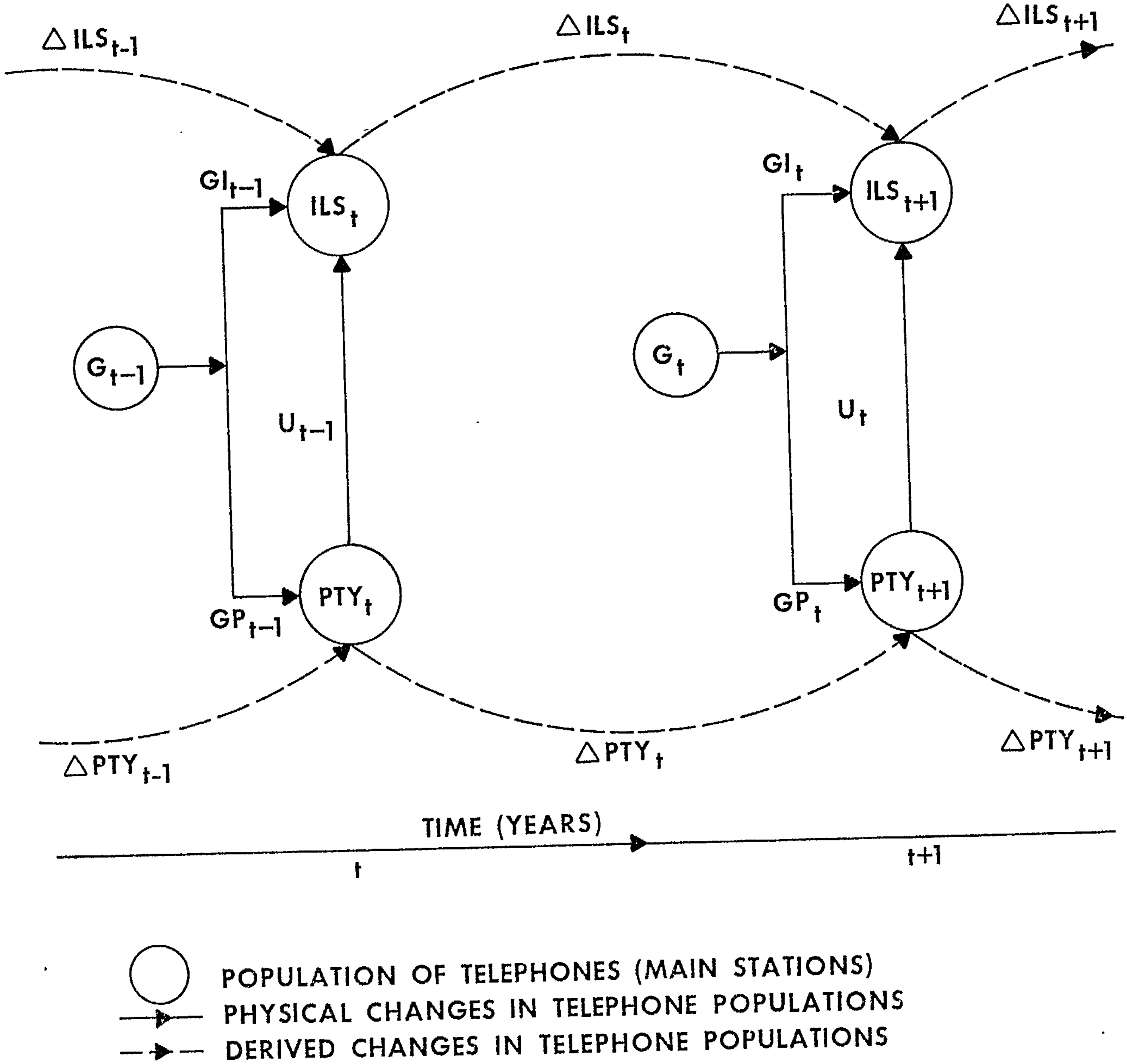

FIGURE G.1 MODEL OF GROWTH IN TELEPHONES

G.1.2 Growth in Total Lines

The growth in lines arises from four sources. These are:

- Growth in ILS subscribers
- Growth in party subscribers
- Upgrades from party-line service to ILS
- Decrease in line loads on party lines

In order to assign numbers to all but the first source, we must know something (or make assumptions about) line loads. It is reasonable to assume that party-line loads are not increasing in North America. Thus, a conservative estimate of new lines assumes that line-fills remain constant at some level. The estimate is conservative since a decreasing line-fill requires additional lines.

Assuming a constant line-fill, LF, one can describe in symbols the number of new lines from each source as follows:

- Growth in ILS Subscribers: GI_t
- Growth in party subscribers: $\frac{1}{LF}\ GP_t$
- Upgrades from party-line service to ILS: $(\frac{LF-1}{LF})\ U_t$
- Decrease in line-loads: zero

Thus, if L_t is the number of new lines in year t, then:

$$L_t = GI_t + (\frac{LF-1}{LF})\ U_t + \frac{1}{LF}\ GP_t$$

$$= \Delta ILS_t + \frac{1}{LF}\ \Delta PTY_t \qquad \ldots (1)$$

G.1.3 Growth in Rural Lines

We first make the assumption that all party-line subscribers are in rural areas. Then the growth in rural lines consists of:

- Growth in rural ILS subscribers
- Growth in party subscribers
- Upgrades from party-line service to ILS
- Decrease in line-loads

A difficulty arises because there is no way to separate rural from urban ILS subscribers in published statistics, nor to assign a growth rate to them. A conservative estimate for rural lines would be to omit the growth in rural ILS subscribers. This may not be a serious underestimate for two reasons: first, growth in rural populations tends to be slow and secondly, growth in rural ILS subscribers is not as likely to be accommodated by small carrier as by VF or large carrier and remote units.

Thus, if RL_t is the number of new rural lines in year t, then:

$$RL_t = (\frac{LF-1}{LF}) U_t + \frac{1}{LF} GP_t$$

$$= U_t + \frac{1}{LF} \Delta PTY_t$$

The means to estimate the required quantities: ΔILS_t, ΔPTY_t, and U_t, are given in the next section.

G.2 ESTIMATION PROCEDURE

The previous section identified three quantities whose values must be estimated in order to determine a potential market for small digital carrier. This section describes the models and statistical techniques used to obtain estimates for these quantities.

G.2.1 Estimation of ΔILS_t

It turns out to be easier to avoid estimating ΔILS_t directly. If we define the total main stations in year t as:

$$TOTAL_t = ILS_t + PTY_t$$

and the annual change in total main stations as:

$$\Delta TOTAL_t = G_t = \Delta ILS_t + \Delta PTY_t$$

then, equation (1) above for L_t can be re-written as:

$$L_t = \Delta ILS_t + \frac{1}{LF} \Delta PTY_t$$

$$= \Delta TOTAL_t - (\frac{LF-1}{LF}) \Delta PTY_t$$

It is evident from Figure F.1 in Appendix F that $TOTAL_t$ for Canada is extremely well behaved. This also holds for the total main stations for most provinces (Figures F.2, 5, 6, 7, 8, and 10, Appendix F). These figures are all plotted on semi-logarithmic scales. A straight line on these scales implies that $TOTAL_t$ grows exponentially, i.e. by a fixed rate each year.

We shall assume that this exponential rate of growth will continue throughout the 1980's. While followers of the "Limits to Growth" controversy will realize that exponential growth cannot continue indefinitely, the exponential growth in telephone main stations in the medium-term future can be defended on several grounds. First, main station telephones are closely tied to the number of households and small businesses. Statistics Canada predicts that the number of households in Canada will increase at a steady rate of 2.54% per year from 1971 to 1991 (1). This compares with the actual rate of 2.86% from 1961 to 1971 and 3.45% per year from 1971 to 1976. Secondly, although surveys of household facilities show that Canadian households almost all have a telephone (96.4% in May, 1978, ref. (2)), the penetration of cottages and resorts is still quite low. As well, the growth in households with two listed numbers, special channels for meter-reading, and so on, will all contribute to a continuing growth in new lines.

Assuming that the exponential growth in telephone main stations is a reasonable model and will continue throughout the period of interest to this study (i.e. from 1980 to 1990), the growth rate can be estimated rising linear regression as:

$$\ln(TOTAL_t) = a_1 + b_1 t$$

$$\Delta TOTAL_t = e^{b1} \cdot TOTAL_{t-1}$$

where "ln" is the logarithim to the natural base, e.

G.2.2 Estimation of ΔPTY_t

Examination of Figures F.1 etc., Appendix F, will show that a downward-sloping exponential model for PTY_t is reasonable for Canada as a whole, and for most provinces or large telcos. Estimates for the number of party-line subscribers and rate of decline are obtained by linear regression from the relations:

$$\ln(PTY_t) = a_2 + b_2 t$$

$$\Delta PTY_t = e^{b2} \cdot PTY_{t-1}$$

This result can be justified by the following argument. The replacement of party service by ILS is an example of technological substitution. Several models have been proposed for this process (3) of which one of the most widely applied is the Fisher and Pry model. This model can be shown to be the theoretically correct one if the following conditions are fulfilled:

- the substitution process is competitive
- the substitution will progress to a complete takeover of the market
- the rate of fractional substitution (f) is proportional to the extent of additional substitution possible (1-f)

This last condition means that f/(1-f) is exponential, or equivalently, that f describes the familiar S-curve of technological substitution. Figure F.11 illustrates the exponential nature of f/(1-f) (where f is the percent of telephones on party-line service) for the case of BCTel.

It can be shown that the upper and lower tails of the S-curve are close to being exponential. Thus in cases where the substitution of ILS for party line service is well advanced, PTY_t should approximate an exponential.

G.2.3 Estimation of U_t

There is no way to measure U_t, GI_t, or GP_t directly. Thus additional assumptions must be introduced before proceeding further.

We can hypothesize the following relationships between the observable quantities (ILS_t and PTY_t) and the quantities of interest (U_t and GI_t):

$$GI_t = \alpha \; ILS_{t-1}$$

$$U_t = \beta \; PTY_{t-1}$$

In words, these relations suppose that the ILS population grows at a fixed rate each year, and that the upgrades to ILS constitute a constant fraction of the population of party-line telephones in the previous year.

U_t can be estimated once β is known. This is possible through linear regression of the relationship.

$$\begin{aligned}\Delta ILS_t &= GI_t + U_t \\ &= \alpha \; ILS_{t-1} + \beta \; PTY_{t-1}\end{aligned}$$

Digression on the Meaning of U_t

It is assumed by the modelling just described that U_t measures the number of telephones upgraded in a year from party-line service to individual line service. In fact, however, what it measures is the disappearance of a party line telephone and the simultaneous appearance of one on individual line service. While this includes the case of an upgrade, it also includes the situation of a dwelling with a party telephone being abandoned and the household purchasing ILS elsewhere, say in a city. Thus does U_t contain elements of rural to urban migration which are assumed by the model to be upgrades?

There are good grounds for believing that the answer is that the migration effect is small in relation to the number of true upgrades. The key is the fact that the party-line telephone must go out of service - if the dwelling is re-occupied by a household having a telephone, then the net effect is no change in the number of party-line telephones and a growth of one in ILS (which is handled by the model). Thus the question is: what is the net loss in rural households, and how many of these are likely to have had telephone prior to leaving the rural area? Data on household facilities published by Statistics Canada (4) show that in the last decade, the net loss in rural households (if any) is small compared with the number of rural households without a telephone.

The conclusion to be drawn is that the abandonment of occupied dwellings in rural areas is not of itself likely to affect the number of party-line telephones. This is so first because the net loss in rural households is not large. This "loss" includes, for example, households whose definition changes to urban over time because they are situated near a large centre. Second, for dwellings which truly are abandoned, it is reasonable on economic grounds to argue that they were not likely to have had a telephone in the first place.

YEAR	RURAL HOUSEHOLDS	AVERAGE ANNUAL CHANGE	PERCENT OF RURAL HH WITH A PHONE	NUMBER WITHOUT A TELEPHONE
1968	1,089,000	-	81.0%	207,000
1972	1,183,000	+23,000	88.2	139,600
1974	1,174,000	- 2,000	91.1	104,500
1976	1,149,000	- 6,000	93.2	78,100

G.3 ESTIMATION RESULTS

This section gives the results of estimating the total lines and total rural lines using linear regression techniques. Where possible, results are presented for Canada and the U.S., broken down by region and/or telco.

G.3.1 Estimates of Total Lines

The estimates for total lines are obtained in two steps; first the equations are regressed:

$$\ln(TOTAL_t) = a_1 + b_1 t \qquad (2)$$

$$\ln(PTY_t) = a_2 + b_2 t \qquad (3)$$

and then the results are used to obtain:

$$L_t = \Delta TOTAL_t - \frac{(LF-1)}{LF} \Delta PTY_t$$

Table G.1 shows the goodness of fit obtained with the equations (2) and (3) for Canada and the various telcos or provinces. The data used are those plotted in respective figures in Appendix F. The R^2 statistic basically measures the percentage of the variation in the raw numbers which is explained by the above equations.

The market of total lines is expressed as a 10-year average number of lines per year over the period 1980-1989 inclusive. This is equal to:

$$\bar{L} = \frac{1}{10}\{(TOTAL_{1989} - TOTAL_{1979}) - (\frac{LF-1}{LF})(PTY_{1989} - PTY_{1979})\}$$

The results are given in Table G.2 by region and/or telco. Line fill is assumed to be equal to 3.0 throughout for the purposes of the above calculation.

TABLE G.1: GOODNESS OF FIT FOR $TOTAL_t$ AND PTY_t MODELS

REGION OR TELCO	PERCENTAGE OF VARIATION EXPLAINED (R^2)	
	$TOTAL_t$	PTY_t
Canada	99.95%	98.61%
NBTel	99.79	93.14
MTS	99.75	76.94
Sask Tel	98.92	66.54
AGT	99.54	98.00
Bell Canada	99.85	99.16
BCTel	99.40	88.17
REA Borrowers	98.48	98.14
US Independents	99.90	99.61

TABLE G.2: ESTIMATED TOTAL, PARTY AND NEW LINES PER YEAR, 1980-1989

REGION OR TELCO	TOTAL AS OF YEAR END		PTY AS OF YEAR END		AVG. NEW LINES PER YEAR
	1979	1989	1979	1989	
Canada	9,627,000	14,951,000	1,176,000	931,000	549,000
NBTel	241,000	387,000	38,800	32,500	15,000
MTS	411,000	600,000	48,000	34,000	20,000
Sask Tel	366,000	499,000	70,500	76,000	13,000
AGT	826,000	1,439,000	95,300	164,000	57,000
Bell Canada	5,652,000	8,750,000	495,000	348,000	320,000
BCTel	1,110,000	1,836,000	220,000	173,000	76,000
REA Borrowers	3,968,000	7,737,000	958,000	624,000	399,000
US Independents	17,928,000	26,535,000	3,587,000	2,077,000	961,000

G.3.2 Estimates of Rural Lines

As with the estimates for total lines, a two step procedure is required. First, β is estimated from regression analysis of the equation

$$\Delta ILS_t = \alpha ILS_{t-1} + \beta PTY_{t-1}$$

Second, a ten year average of rural lines $(\overline{RL})$ is obtained as follows:

$$\overline{RL} = \frac{1}{10} \sum_{t=1980}^{1989} (U_t + \frac{1}{LF} \Delta PTY_t)$$

$$= \frac{1}{10} \sum_{t=1980}^{1989} (\beta PTY_{t-1} + \frac{(e^{b2}-1)}{LF} \; PTY_{t-1})$$

$$= \frac{1}{10} (\beta + \frac{(e^{b2}-1)}{LF}) \sum_{1980}^{1989} PTY_{t-1}$$

$$= \frac{1}{10} (\beta + \frac{e^{b2}-1}{LF}) \; PTY_{1979} (1 + e^{b2} + \ldots . + e^{9b2})$$

$$= \frac{1}{10} (\beta + \frac{e^{b2-1}}{LF}) \; PTY_{1979} (\frac{1 - e^{10b2}}{1 - e^{b2}})$$

$$= (\frac{\beta}{1-e^{b2}} - \frac{1}{LF}) \; \frac{PTY_{1979} - PTY_{1989}}{10}$$

Of course, $\frac{PTY_{1979} - PTY_{1989}}{10}$ is the average loss of party-lines over the decade, and $\frac{\beta}{1-e^{b2}}$ is the ratio of the rate of upgrading to the total decline in party-line telephones.

The estimation of β presents some difficulties, and therefore care is required in interpreting the results. Figure G.2 shows that for data for the whole of Canada, ΔILS_t is a fairly erratic series of numbers to try to approximate by a smooth curve. The estimated value of β has a relatively high degree of uncertainty associated with it. Table G.3 gives the estimated value of β and a 90% confidence interval for this value, for each of the regions and telcos discussed.

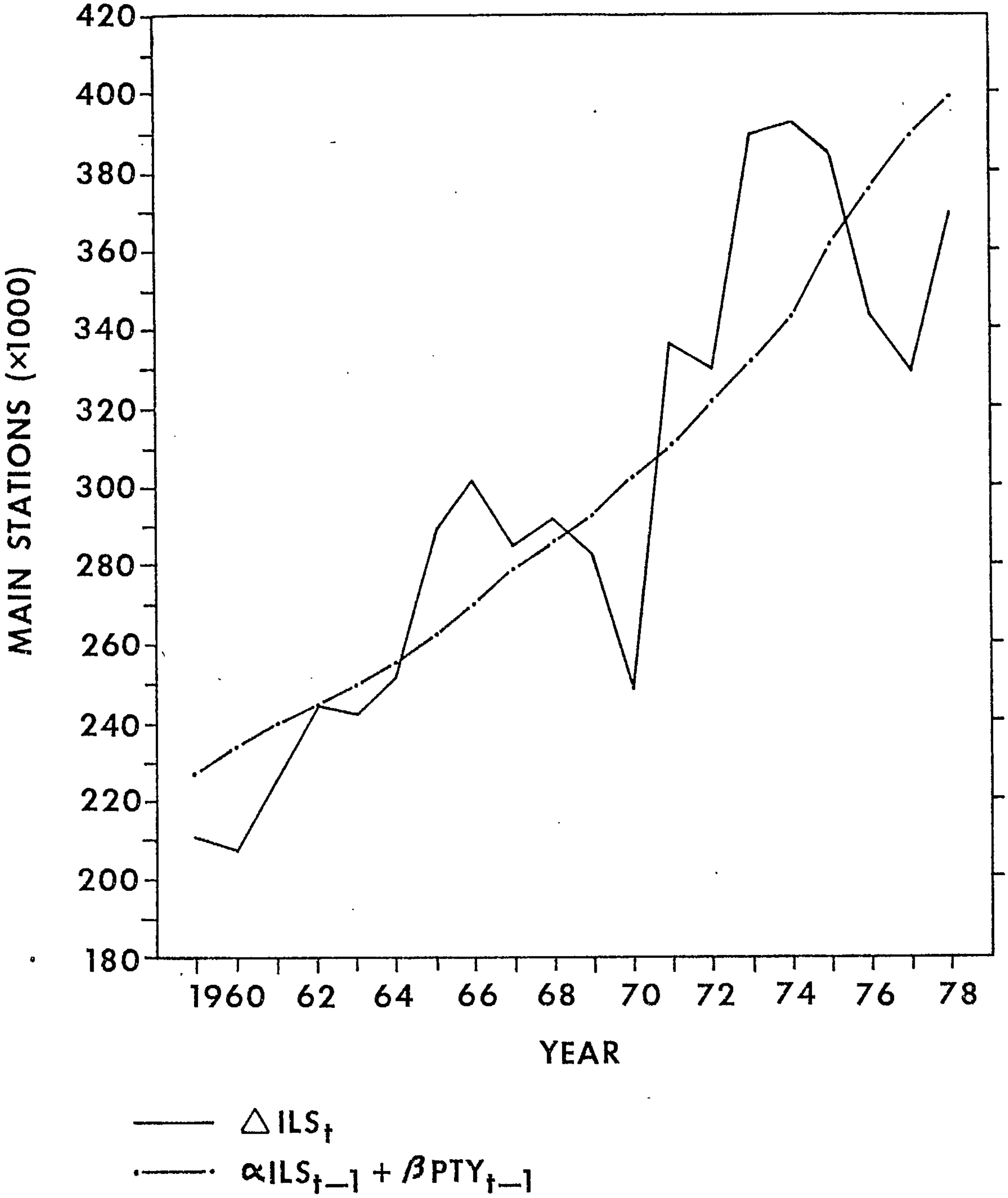

FIGURE G.2 ANNUAL GROWTH IN INDIVIDUAL LINE TELEPHONES ($\triangle ILS_t$) AND THE FITTED REGRESSION EQUATION IN CANADA 1959 – 1978

TABLE G.3: ESTIMATED UPGRADING RATE, β, AND 90% CONFIDENCE INTERVAL

REGION OR TELCO	UPGRADING RATE IN PERCENT	90% CONFIDENCE INTERVAL
Canada	7.89%	± 1.65
NBTel	7.45	± 3.32
MTS	12.72	± 3.23
Sask Tel	10.77	± 9.73
AGT	114.77	±82.03
Bell Canada	11.42	± 2.25
BCTel	4.66	± 1.80
REA Borrowers	-5.07	±26.24
US Independents	3.62	±12.64

In some cases (e.g. Canada, Bell Canada and BCTel) a "tight" estimate of the upgrading rate is available; in others (Sask Tel, AGT and the US groups), the estimate is less useful. The problem with Sask Tel is simply that the uncertainty associated with β is too high to take the estimate very seriously. In the cases of AGT, it is apparent that the estimation procedure has been thrown off by the fact that ILS_t and PTY_t are both rising over time. The estimates for β and α (the internal growth rate of the ILS population) are highly correlated, and the regression procedure cannot distinguish between them. The US estimates are not reliable because there is not a long enough series of data available for estimation purposes.

Table G.4 shows the estimated rural lines for the selected telcos and regions. Again, some of these must be treated with caution. The lines for Sask Tel are probably too high because of the high estimate for the upgrading rate. If we take the lower bound for the 90% confidence interval (i.e. β = 1.04) then the average rural lines per year would only be 880.

TABLE G.4: AVERAGE RURAL LINES PER YEAR 1980-1989

REGION OR TELCO	AVG. DECLINE (GROWTH) IN PARTY PHONES	NET DECLINE (GROWTH) RATE IN PERCENT	UPGRADING RATE IN PERCENT	AVG. RURAL LINES PER YEAR
Canada	24,500	2.31%	7.89	76,000
NBTel	630	1.77	7.45	2,400
MTS	1,400	3.52	12.72	4,600
Sask Tel	(500)	(0.82)	10.77	7,400
AGT	(6,900)	(5.95)	0*	2,300
Bell Canada	14,700	3.48	11.42	43,000
BCTel	4,700	2.36	4.66	7,700
REA Borrowers	33,400	4.19	4.19*	22,000
US Independents	151,000	5.32	5.32*	101,000

* Upgrading rates assumed

In the case of AGT, the upgrading rate has been set at zero. This is consistent with the telco's policy regarding upgrading. If we make the value 2% per year, then the rural lines per year would be 4,600.

For the US groups, the upgrading rate was made equal to the rate of decline in party-lines. This is conservative, but the rationale is (given the lack of a reliable estimate from any other source) that conversion to ILS is occurring rapidly. Therefore, telcos will be reluctant to place very many new lines to accommodate party-line growth**.

** One way to look at the ratio - $U_t/\Delta PTY_t$ is that it is equal to $(\Delta PTY_t - GP_t)/\Delta PTY_t$. Thus, if GP_t is zero, the ratio is equal to 1.0 in value; i.e. $\beta = 1-e^{b2}$.

The effect of changing this assumption can be illustrated as follows. The Canadian rate of growth in party-lines is evidently about 5.58% (i.e. the difference between the upgrading rate and actual decline in party-line telephones). If this rate holds for the US, then the up-grading rate for the REA borrowers and the US Independents would be 9.77% and 10.90% respectively. The rural lines per year are then 68,000 and 259,000. However, the small bit of evidence available on US up-grading rate (Table G.3) makes this high a value unlikely (though not impossible).

A modest growth rate for US party-line telephones would be 3% per year. This would give markets of 46,000 and 186,000 lines per year for REA borrowers and Independents respectively.

G.4 REFERENCES

1) Household and Family Projections for Canada and the Provinces to 2001, Statistics Canada, catalogue 91-517.

2) Household Facilities and Equipment, Statistics Canada, catalogue 64-202.

3) Market Penetration by New Innovations: The Technological Literature, Hunter and Rubenstein, Technological Forecasting and Social Change, Vol. II, No. 3 (1978).

4) Household Facilities by Income and Other Characteristics, Statistics Canada, catalogue 13-540 (1968), 13-560 (1972), 13-565 (1974) and 13-567 (1976).

APPENDIX H: COST CALCULATIONS

Details of cost calculations were given throughout the study in the interim reports, and have undergone several revisions as new information became available and a more definitive system design emerged. This Appendix details the latest estimates for both manufacturing and installed costs, and provides a summary of previous estimates of the provision of services with existing carrier systems.

H.1 MANUFACTURING COSTS

The cost estimates for the system described in VOLUME 3 - SYSTEM DOCUMENT of this study are detailed in tables H.1 to H.4. They are based on producing 100 systems with an average of 30 lines per system. To ensure a high level of confidence for these estimates, the most detailed analysis was done for the remote terminals, which are expected to dominate the system cost, especially in a distributed system configuration. A repeater cost is also given based on the same manufacturing practices. While it is questionable that the repeater board itself can be produced cheaper than the commercially available units, the enclosures certainly can be. Available repeater boxes are designed to house a minimum of six duplex repeaters and are therefore unnecessarily large and expensive.

A discussion on conversion to prices has been given in Section 5.

TABLE H.1A REMOTE TERMINAL COSTS

Boards	Material	Labour	Testing
Main Electronics	$120	$ 43	0.15 hrs.
Repeater and Power Supply	$130	$ 53	0.15 hrs.
Linecard (2 lines)	$140	$ 43	0.15 hrs.
Linecard (2 lines)	$140	$ 43	0.15 hrs.
Alarm and Backup Switching	$ 80	$ 43	0.15 hrs.
Packaging (5 boxes)	$ 3	0.15 hrs	

Box Assembly for 1 to 4 Lines	Material	Labour	Testing
Box (10" x 14" x 6")	$ 70	0.45 hrs	
Cable stub with strain relief fitting fitting	$ 14	0.50 hrs	
Lightning protection (8 cable pairs)	$100	0.20 hrs	
Address Strapping	$ 4		
Card Cage (5 slots)	$ 20	0.50 hrs	
Motherboard (10" x 15")	$ 15	0.15 hrs	
Card Connectors (5)	$ 25		
Orderwire Fitting	$ 6		
Pole Mounting Hardware	$ 20		
Testing for Continuity			0.15 hrs
Packaging	$ 1	0.10 hrs	
TOTAL	$275	1.90 hrs	0.15 hrs

Box Assembly for up to 64 Lines	Material	Labour	Testing
Box	$200	0.65 hrs	
Cable stub with strain relief fitting	$ 14	0.50 hrs	
Lightning Protection	$100+10n	0.35 hrs	
Address Strapping	$ 64	0.70 hrs	
Card Cages	$200	0.20 hrs	
Motherboards	$ 60		
Card Connectors	$170		
Orderwire Fitting	$ 6		
Pole Mounting Hardware	$ 20		
Testing for Continuity			0.15 hrs
Packaging	$ 2	0.10 hrs	
TOTAL	$836+10n	2.50 hrs	0.15 hrs

TABLE H.1B REMOTE TERMINAL COSTS

Single Line Without Alarms	Boards	Box	Total
Labour (Assembler @ $17.00)	132	35	167
Labour (Technician @ $20.00)	9		9
Materials	321	245	566
	(643 + 1(99))		$742

Four Lines Without Alarms	Boards	Box	Total
Labour (Assembler @ $17.00)	185	35	220
Labour (Technician @ $20.00)	12		12
Materials	532	275	807
	(643 + 4(99))		$1039

Up to 64 Lines Without Alarms	Boards	Box	Total
Labour (Assembler @ $17.00)	96 + 22n	45	141 + 22.0n
Labour (Technician @ $20.00)	6 + 1.5n		6 + 1.5n
Materials	250 +70.5n	836+10n	1086 + 80.5n
			$1233 + 104.0n

Alarm and Backup Switching Option	Boards	Box	Total
Labour (Assembler @ $17.00)	45	-	45
Labour (Technician @ $20.00)	3		3
Materials	81		81
			$129

TABLE H.2 CENTRAL OFFICE TERMINAL COST

Boards (including labour)

Main Electronics	$ 170
Repeater	80
Concentration	1000
Alarm and Backup	500
Line Card (Single line)	103

Cabinet (including labour)

Shelf (16 slots)	$ 260
Front Panel	200
10V Power Supply	400
±150V Power Supply	300
Mounting Hardware	200

Complete Terminal

Main Electronics	$ 170	
Repeater	80	
Line Cards (46)		103n
Shelf (4)	1040	
Front Panel	200	
Power Supplies	700	
Mounting Hardware	200	
TOTAL	$2390 +	103n

Alarm and Backup Switching Option $ 500

Concentration Option $1000

TABLE H.3 REMOTE TERMINAL POWER PACK COST

Battery Pack	$ 120
AC Charger	50
DC to DC Converter	100
Box	200
Labour	180
TOTAL	$ 650

TABLE H.4 REPEATER COST

Main Board	$ 55
Fault Locate Board	30
Box	95
Labour	20
TOTAL	$ 200

H.2 INSTALLED COSTS

The system price estimates were submitted to the telcos for the application of their economic analysis. Sask Tel provided most of the comparative calculations throughout the study, and the following discussions are based on their practices. To gain an appreciation of the differences in telco practices, sample calculations from NBTel and MTS were also obtained.

H.2.1 Standard Case

To gauge the cost performance of the proposed system against the existing alternative carrier systems, a standard system configuration was selected. It includes only one remote terminal at a distance of twenty miles from the central office. This case is typical of a small community or town, but does not provide specific comparisons for distributed installations. It is doubtful, however, that sample calculations for distributed installations insofar that they are possible with existing systems, will show considerable differences in the relative costs of the various systems.

Figure H.1 shows the cost per subscriber versus the number of subscribers per installation for the provision of ILS to a "standard case" town. The most cost effective system is the ES-1 concentrator, which, strictly speaking, is not a carrier system. It simply provides a 4 to 1 concentration and as such has a relatively low pair gain since VF transmission is used.

The proposed carrier system is next lowest in cost and is shown for two versions, PCM and 32 kbit/s ADM. Below 25 and above 46 subscriber both cost approximately the same (within the tolerance of the estimate), which corresponds to an unconcentrated and concentrated system respectively. Between 25 and 46 lines the use of the concentrator is conditional on the number of channels available, consequently the lower cost refers to the 46 channel ADM version.

All other systems studied (including some which are not shown) were considerably more expensive.

A similar case was evaluated by NBTel using their own costing practices. The detailed calculations are shown in Table H.5. Case A refers to a clustered configuration with a single remote terminal, linked to the central office terminal via 12 repeaters (15 to 20 miles depending on cable gauge). Case B refers to a simple distributed installation with one 22 line and two 4 line remote terminal. Again 12 repeaters were used. Concentration is added for the 120 and 64 line cases only, both 30 line cases assume a 46 channel ADM system. It is interesting to note the higher loading costs employed, which result in an approximately 25% higher installed cost. For example the 64 line system is estimated at $817, compared to $666 for Sask Tel. The 30 line installations were priced at $1245 and $911 respectively.

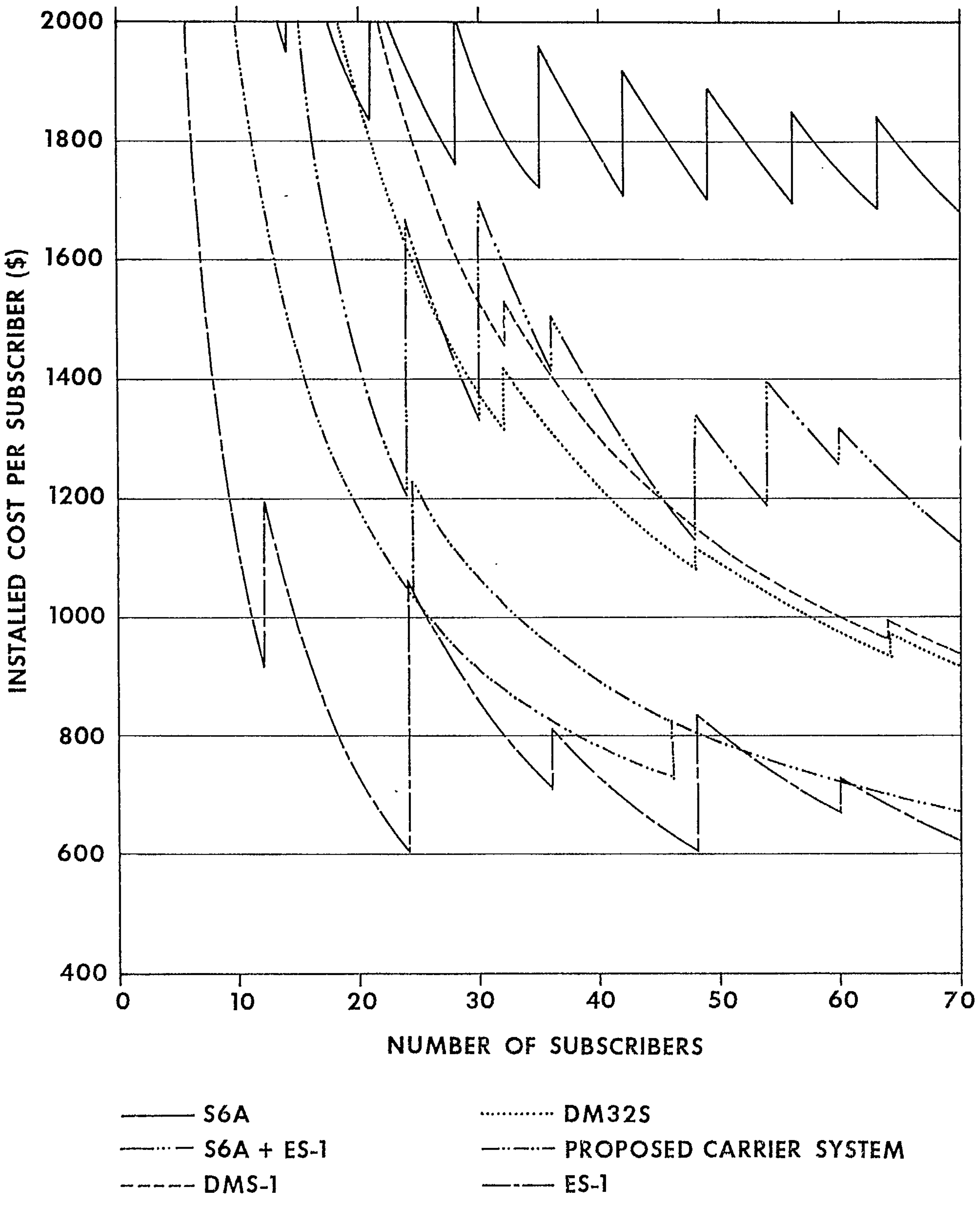

FIGURE H.1 COMPARATIVE INSTALLED COSTS OF CARRIER SYSTEMS

TABLE H.5 INSTALLED COST FOR THE PROPOSED CARRIER SYSTEM CALCULATED BY NBTEL

		A			B	
		120L	64L	30L	30L	
1.	Central Office Terminal	$22777	$13873	$8467	$8467	
1A.	Concentrator	4036	4036			
2.	Alarm & Backup Sw. (COT)	774	774	774	774	
3.	Remote Terminal	21073	12057	6583	5295	
					1607	
					1607	
4.	Alarm & Backup Sw. (RT)	200	200	200	200	
					200	
					200	
5.	Power Pack	1006	1006	1006	1006	
6A.	Line Repeaters (1 line)	3708	3708	3708	3090	
6B.	Line Repeaters (2 lines)	7416	7416	7416	6180	
7.	Engineering	5000	5000	5000	5000	- COT
		500	500	500	500	- RT
					400	- RT
					400	- RT
8.	Installation & Test	6000	6000	6000	6000	- COT
		1800	1800	1800	1800	- RT
					1500	- RT
					1500	- RT
9.	Interest during Construction	1500	1500	1500	1500	
10.	Transportation	500	500	500	500	
11.	O.P.	1000	1000	1000	1200	
12.	Cable Cond.	2000	2000	2000	2000	
13.	Maintenance Spares	3000	3000	3000	3000	
TOTALS						
i)	Exclude Alarm Ext. & Cost of one T1 Line (2,4, & 6)	70192 585	52272 817	37356 1245	43282 1443	- Total - Per line
ii)	Cost of i plus cost of one T1 line (i + 62)	73900 616	55980 875	41064 1369	46372 1545	- Total - Per line
iii)	Cost of ii plus cost of alarm ext. and spare line (ii + 2 + 4 + 62)	78582 655	60662 948	45746 1525	50836 1695	- Total - Per line

H.2.2. Actual Cases

Comparative studies were made for several scenarios where the proposed subscriber carrier system could be applied. The largest number of cases were evaluated for upgrading residences to ILS, which was felt to be the most suitable application. Upgrading farms to 4PL was considered only for Saskatchewan, the only province where planned upgrading would not be complete at the anticipated time of introduction of the proposed carrier system. Tables H.6B to H.6F summarize the following case studies and their results:

- Upgrade communities to ILS
- Upgrade resort areas to ILS
- Upgrade farms to ILS
- Upgrade farms to 4PL
- Accommodate growth in 4PL to farms

Table H.6A summarizes the Sask Tel standard case. Details for the three cases of upgrading to ILS are given in Tables H.7 to H.9.

The actual costs calculated in Tables H.7 and H.8 are also plotted in Figure H.2 on the same relative scale as the standard case. Interestingly, these costs are lower than those shown in Figure H.1, and is a direct result of a lower average distance from the central office.

Three of the cases of Table H.9, provisioning of ILS to farms, are illustrated in Figures H.3 to H.5. These configurations were designed to test the effects of distribution on the installed costs, and are therefore not necessarily optimum. Especially in the Lloydminster area of Figure H.3 some clustering of remote terminals may be beneficial, and would also lighten the administrative and maintenance loads such configurations could impose on the telcos. Nevertheless the potential of distribution and its competitive cost is evident.

TABLE H.6A COMPARATIVE ECONOMIC EVALUATIONS

Scenario	UPGRADE COMMUNITIES TO ILS	
Location	Saskatchewan	
Actual/ Theoretical	Theoretical (Standard case)	
Available Cable Pairs	Sufficient	
Distance from C.O.	20 miles	
Subscriber Density	Clustered	
Number of Subscribers	0 to 70	
Alternative Technologies	S6A, EV-1, S6A + ES-1, DMS-1, DM32S	
Results	Proposed system approximately 30% cheaper than DM32S above 24 lines, 20% cheaper than S6A + ES-1 below 24 lines.	

TABLE H.6B COMPARATIVE ECONOMIC EVALUATIONS

Scenario	UPGRADE COMMUNITIES TO ILS	
Location	Saskatchewan (9 cases)	Manitoba* (2 cases)
Actual/ Theoretical	Actual	
Available Cable Pairs	Sufficient	
Distance from C.O.	7 to 28 miles (14 mi. average)	9 and 13 mi.
Subscriber Density	Clustered	
Number of Subscribers	20 to 64 (40 average)	30 and 32
Alternative Technologies	S6A + ES-1 DM32S	DM32S
Results	Proposed system 16% cheaper than S6A + ES-1	Proposed system 49% cheaper * Using Sask Tel loadings

TABLE H.6C COMPARATIVE ECONOMIC EVALUATIONS

Scenario	UPGRADE RESORT AREAS TO ILS		
Location	Saskatchewan (5 cases)	AGT*	NBTel*
Actual/ Theoretical	Actual		
Available Cable Pairs	Sufficient		
Distance from C.O.	7 to 15 miles (11.7 average)	16 mi.	13 mi.
Subscriber Density	Clustered		
Number of Subscribers	24 to 96 (50.4 average)	38	96
Alternative Technologies	ES-1 + S6A DM32S	DM32S	DM32S
Results	Proposed system 20% cheaper than S6A + ES-1	Proposed system 54% cheaper than DM32S	Proposed system 51% cheaper than DM32S

* Using Sask Tel loadings

TABLE H.6D COMPARATIVE ECONOMIC EVALUATIONS

Scenario	UPGRADE FARMS TO ILS	
Location	Saskatchewan (5 cases)	Manitoba
Actual/ Theoretical	Actual	Actual
Available Cable Pairs	11% of subscriber on VF cable Cable cost 10% of total	Sufficient
Distance from C.O.	Largest sub 13 to 32 miles Remote length 18 to 93 miles	11.4 miles
Subscriber Density	Distributed	Clustered and distributed
Number of Subscribers	28 to 198 (99 average)	46
Alternative Technologies	S6A VF Cable	VF Fine Gauge design Conventional digital design Analog carrier (distributed) Analog carrier (centralized)
Results	Proposed system equal in cost to S6A but 39% less than all VF cable	Centralized: Proposed system 45% of VF cost, 63% of conventional digital cost, and 85% of analog cost Distributed: Proposed system 76% of VF cost and equal to analog cost

TABLE H.6E COMPARATIVE ECONOMIC EVALUATIONS

Scenario	UPGRADE FARMS TO 4PL	
Location	Saskatchewan (1 case: N.E. Lloydminster)	
Actual/ Theoretical	Actual	
Available Cable Pairs	42% of subscribers on VF cable Cable cost 60% of total	
Distance from C.O.	Up to 35 miles	
Subscriber Density	Distributed	
Number of Subscribers	177	
Alternative Technologies	S6A, VF Cable	
Results	Proposed system is 30% cheaper than VF cable and 22% cheaper than S6A.	

TABLE H.6F COMPARATIVE ECONOMIC EVALUATIONS

Scenario	ACCOMMODATE GROWTH IN 4PL TO FARMS	
Location	Saskatchewan (1 case: Kyle)	
Actual/ Theoretical	Actual area with hypothetical growth	
Available Cable Pairs	Sufficient	
Distance from C.O.	1.0 to 17 miles (11.3 average)	
Subscriber Density	Distributed	
Number of Subscribers	75, growth of 1/year for 12 years	
Alternative Technologies	S6A, VF cable	
Results	Proposed system 25% cheaper than VF cable but 60% more expensive than S6A.	

TABLE H.7 UPGRADE OF COMMUNITIES TO ILS

TELCO	LOCATION	EXCHANGE AREA	DISTANCE	TOTAL SUBS	CARRIER	LOADING	TOTAL	PER SUB
SASK TEL	Arlee	Perdue	19 mi	30	$19,764	$ 6,403	$26,167	$ 872
	Dilke	Holdfast	13	64	33,454	8,841	42,295	661
	Marchwell	Langenburg	7	56	28,731	7,596	36,327	649
	Orkney	Val Marie	15	20	16,564	5,563	22,127	1,106
	Pleasantdale	Naicam	13	60	30,629	8,276	38,905	648
	Sonningdale	Perdue	28	45	26,109	8,122	34,231	761
	White Bear	Kyle	12	30	18,837	5,867	24,704	823
	Willmar	Arcola	10	20	15,328	5,066	20,394	1,020
	Woodrow	LaFleche	8	36	19,830	5,866	25,696	714
Total			125 mi	361	$209,246 ($580 per sub)	$61,600	$270,846	--
Average			13.9 mi	40.1	$ 23,250	$ 6,844	$ 30,094	$ 750
Percentage of Total					77%	23%		
MTS	Brunkild	Sanford	9	32	$ 18,241	$ 5,598	$ 23,839	$ 745
	Domain	Sanford	13	30	18,219	5,794	24,013	800
Total			22	62	$ 36,460	$11,392	$ 47,852	--
Average			11	31	18,230	5,696	23,926	$ 772

TABLE H.8 UPGRADE OF RESORT AREAS TO ILS

TELCO	LOCATION	EXCHANGE AREA	DISTANCE	TOTAL SUBS	CARRIER	LOADING	TOTAL	PER SUB
SASK TEL	Clearwater Lake	Kyle	7.5 mi	40	$21,110	$ 6,097	$ 27,207	$ 680
	Lac Pelletier	Neville	15	60	31,247	8,499	39,746	662
	Madge Lake	Kamsack	15	96	43,076	10,865	53,941	562
	Redberry Lake	Hafford	7	24	16,608	5,172	21,780	908
	Wee Too Beach	Holdfast	14	32	20.095	6,219	26,314	822
Total			58.5	252	132,136	36,852	168,988	--
Average			11.7	50.4	($524 per sub)			671
AGT	Silver Lagoon	Innisfail	16	38	22,015	6,703	28,718	756
NBTel	Lake George	Harvey Station	13	96	42,458	10,642	53,100	553

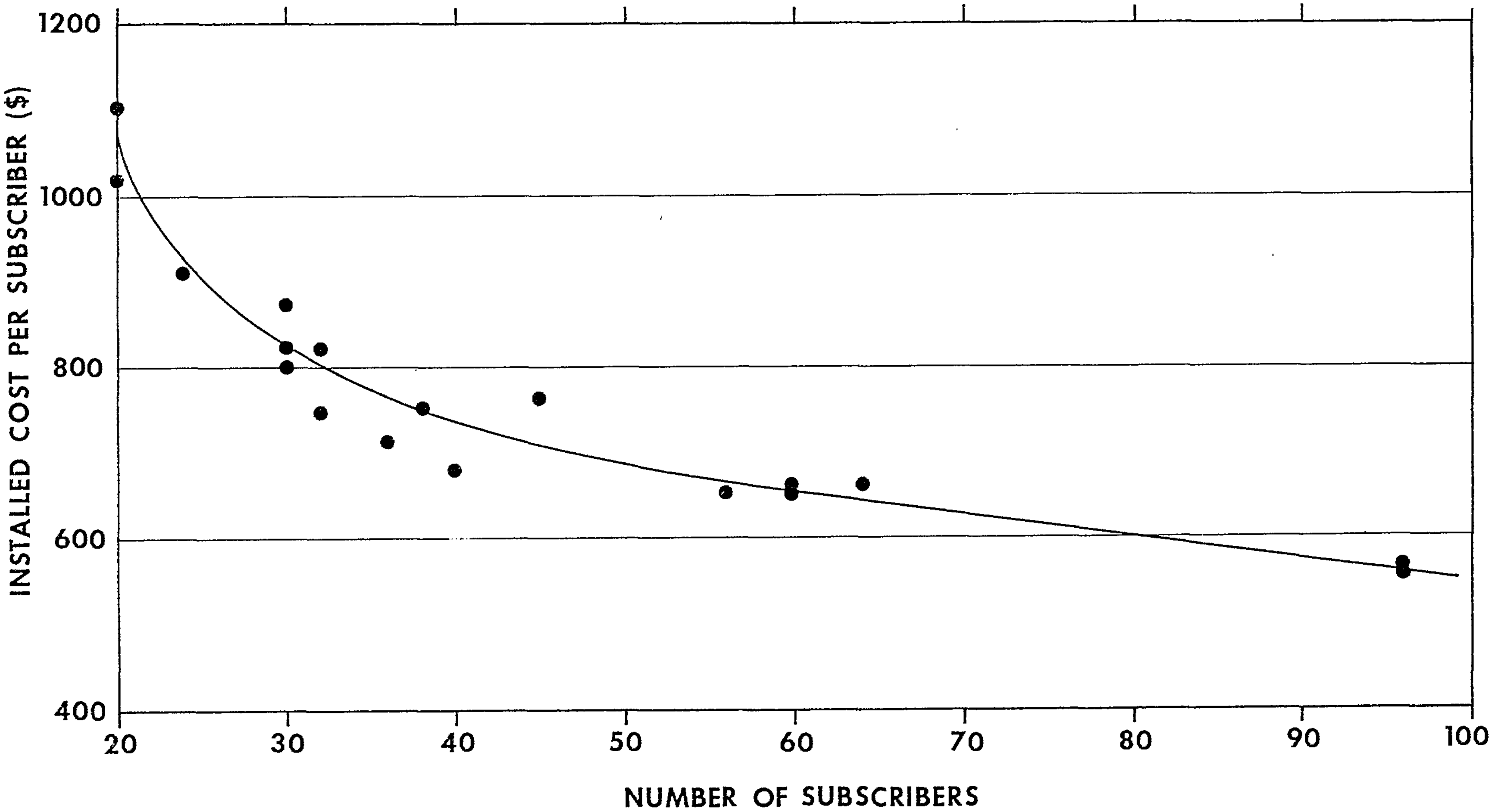

FIGURE H.2 ACTUAL INSTALLED COST OF PROPOSED CARRIER SYSTEM

TABLE H.9 UPGRADE OF FARMS TO ILS

SASK TEL EXCHANGE AREAS

EXCHANGE	ROUTE LENGTH (mi)	CARRIER SUBS	VF SUBS	CARRIER $	LOADING $	CABLE $	TOTAL $	$ PER CARRIER SUB	$ PER TOTAL SUB
Frontier	31	41	10	33,358	9,722	519	43,599	1,063	855
Kyle	32	61	14	55,265	14,153	24,087	93,505	1,533	1,247
Ormiston N.	73	137	6	123,713	29,893	19,895	173,501	1,266	1,213
Ormiston S.	18	24	4	25,127	7,425	2,329	34,881	1,453	1,246
Lloydminster	93	178	19	150,541	39,258	9,169	198,968	1,118	1,010
TOTAL	247	441	53	388,004	100,451	55,999	544,454	--	--
AVERAGE	49.4	88.2	10.6	77,601	20,090	11,200	108,891	1,235	1,102
				71%	18%	11%			

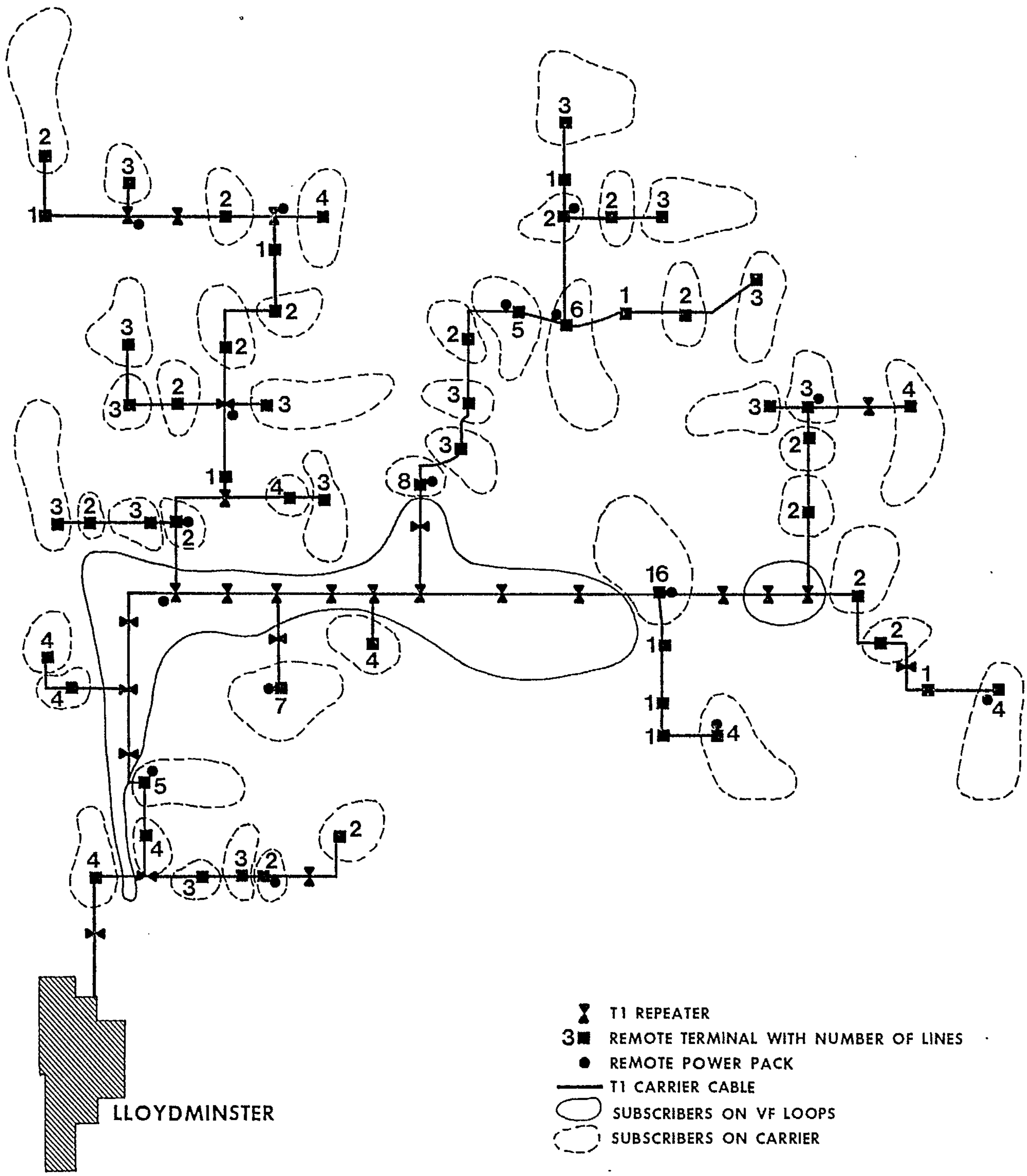

FIGURE H.3 PROVISIONING OF ILS FOR THE LLOYDMINSTER EXCHANGE AREA

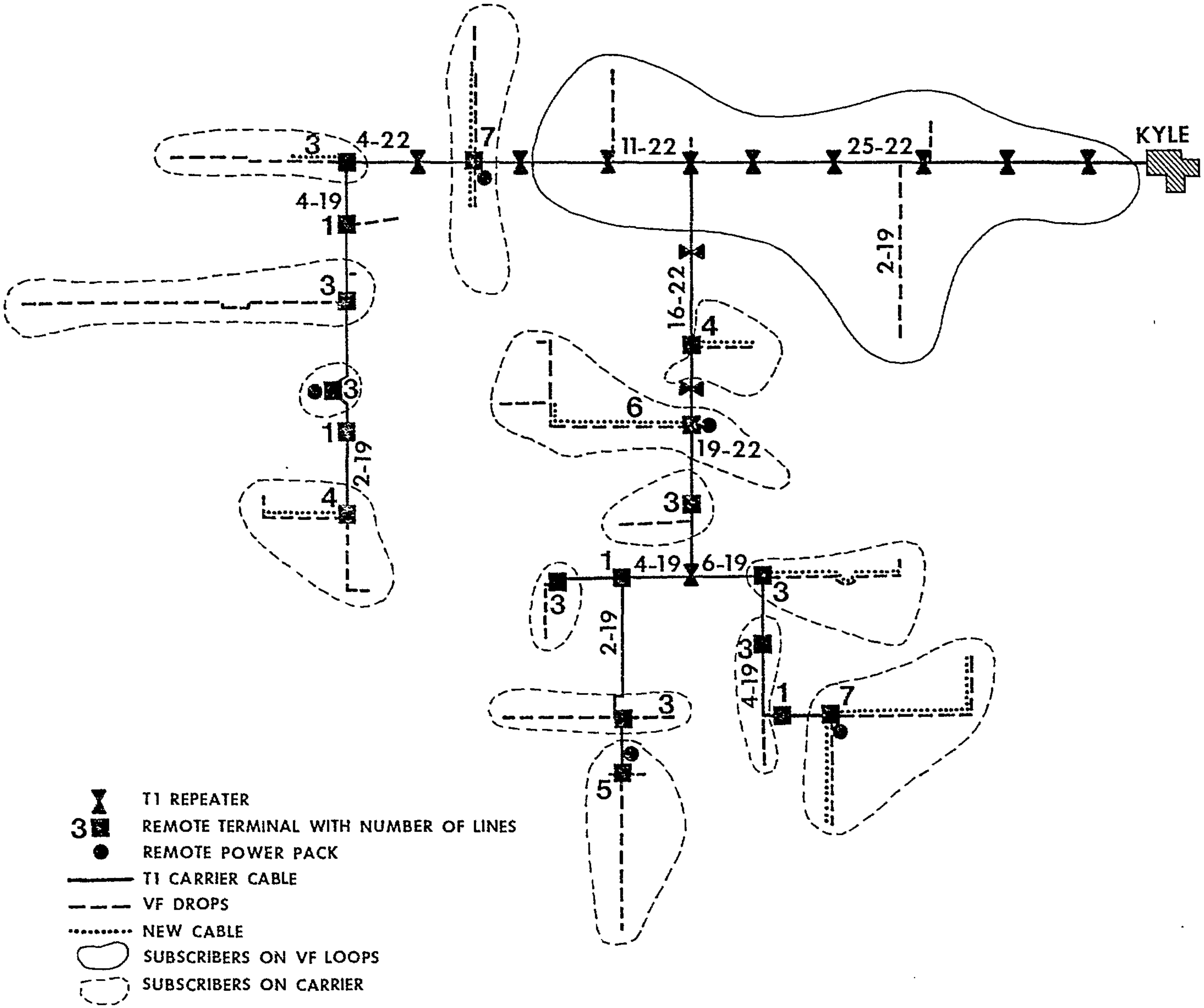

FIGURE H.4 PROVISIONING OF ILS FOR THE KYLE EXCHANGE AREA

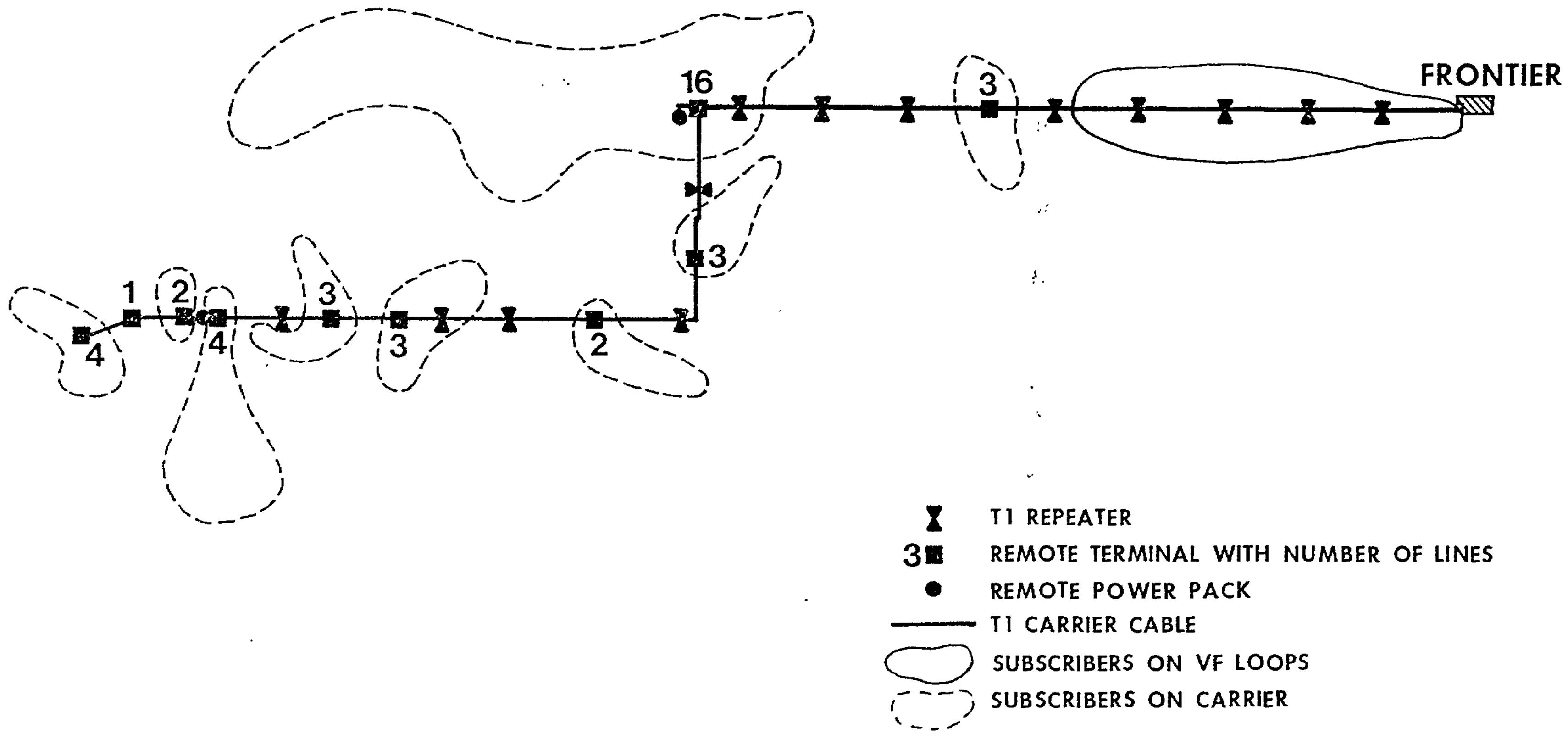

FIGURE H.5 PROVISIONING OF ILS FOR THE FRONTIER EXCHANGE AREA