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Loop Plant Electronics:

Planning for Loop Electronic Systems

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Loop electronics planning is important to the overall telephone loop planning process. It is important to the operating companies because they must determine the most economical solution to each specific facility relief problem. In addition, it is important for Bell Laboratories to understand the economics of loop electronics systems in order to define and evaluate the potential impact of new loop electronic system designs on the Bell System, to develop new planning techniques, and to assist, along with AT&T, the operating companies with specific applications. This paper describes the development planning process used at Bell Labs to define new loop electronics systems and applications. It also describes the planning techniques used in the operating companies to identify and evaluate applications of loop electronics. The interrelationships of these two activities are also discussed.

I. INTRODUCTION

Planning for loop electronics in the Bell System responds to at least two distinct, but interrelated, areas of need. The operating telephone companies plan for the use of loop electronics as part of their annual construction program, and Bell Laboratories, together with AT&T, plans the development of new systems and new applications for existing systems. These two planning functions, occurring at two different levels throughout the entire Bell System, are interrelated.

This paper describes the planning process for loop electronics now recommended for use in the Bell System companies as well as the development planning process in use at Bell Labs and AT&T. The interrelationships and interdependencies of these two processes are outlined in Fig. 1.

Development planning for loop electronics is needed to guide devel-

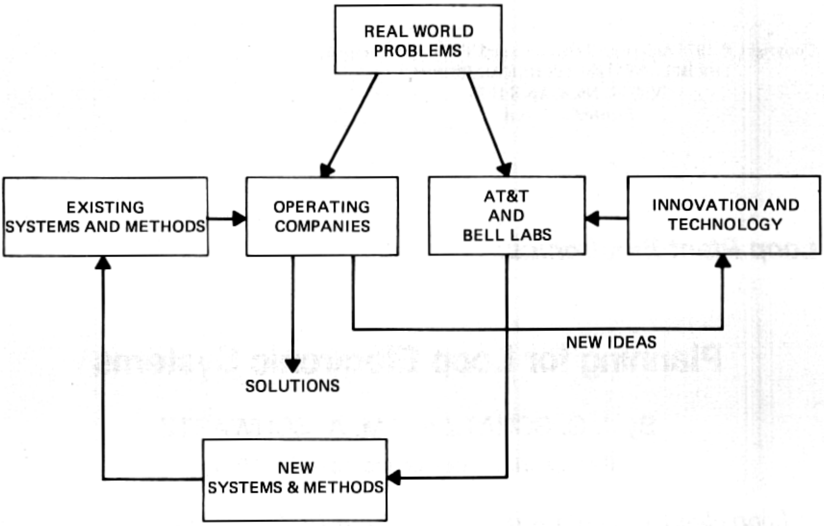


Fig. 1—Interrelated planning process.

opment of new systems, to identify new applications for both new and existing systems, and to estimate the economic benefits of these actions across the Bell System. This planning represents a means of providing for present and future needs of the operating companies and allows for the timely introduction of new systems and new applications in anticipation of those needs. This permits the operating companies to achieve the maximum economic benefits with a minimal amount of delay.

Bell Laboratories development planning is based on the use of a "bottom up" study technique, that is, loop electronic systems are considered as solutions in a small but carefully selected set of facility relief problems. These results are then used iteratively to reconfigure the proposed systems or techniques under consideration in order to maximize savings. The results of this analysis are then extrapolated to the whole Bell System by conducting surveys in the operating telephone companies.

The operating companies, on the other hand, must evaluate the alternatives available to provide outside plant facilities for specific projects. The problem has become more complex with the introduction of loop electronics. Planning must now include the decision on whether or not to use loop electronics on a project, as well as decisions on which system to use, how many to use, and when and where to install them. Planning enables the operating company to identify the specific projects for which loop electronics can be economical and to evaluate the magnitude of those benefits.

Section II describes the development planning process used at Bell Labs and AT&T to determine future generations of loop electronics systems. The methods used to hypothesize new system configurations and new applications for existing systems are discussed, along with the techniques used to test these hypotheses against the economics and constraints of the real world. The interrelationships among Bell Labs, AT&T, and the operating companies are also described.

Section III describes the operating company planning process. This includes a discussion of screening guidelines, practical considerations, and study tools. The methods have been available to the operating companies for almost two years and are being implemented through the Bell System.

Section IV gives an illustrative example, describing the results of both the operating company planning process and the Bell Labs planning process. The example demonstrates how operating company planning can lead to innovative applications and how the identification of these applications can stimulate the study of new system configurations.

II. LOOP ELECTRONICS DEVELOPMENT PLANNING

2.1 The need for the detailed study

Many attempts have been made to simplify the planning associated with the application of loop electronic systems. Some of these simplifications, however, can result in misleading conclusions. For example, one of these approaches compares the average installed first cost of a loop (as a function of the cable distance between the central office and the customer's premises) with the installed first cost per pair gained on a loop pair gain system. This latter quantity is a standard figure of merit for pair gain devices and is defined as the total installed first cost of a system divided by the number of incremental communication channels provided. Thus, a 40-channel carrier system that uses four cable pairs and costs \$3600 has a cost per pair gained of 3600/(40 − 4) = \$100. Based on the cable-electronics cost comparison illustrated in Fig. 2, it might be concluded that it is economical to use pair gain systems to derive all loops whose length is greater than L. This comparison is misleading for the following reasons:

(*i*) The first cost of outside plant facilities is generally capitalized. Long term studies must reflect the amortization and income tax effects that result from this capitalization. The present worth of annual charge (PWAC) technique that includes these effects is, therefore, a better method of comparison than installed first cost.

(*ii*) Because of the economies of scale associated with cable placement, low cost feeder route expansion strategies dictate the placement of larger size cables than are required to satisfy short term subscriber demand forecasts. Hence, at a given instant of time, there may be excess cable facilities available on a given cable section. Because of this in-

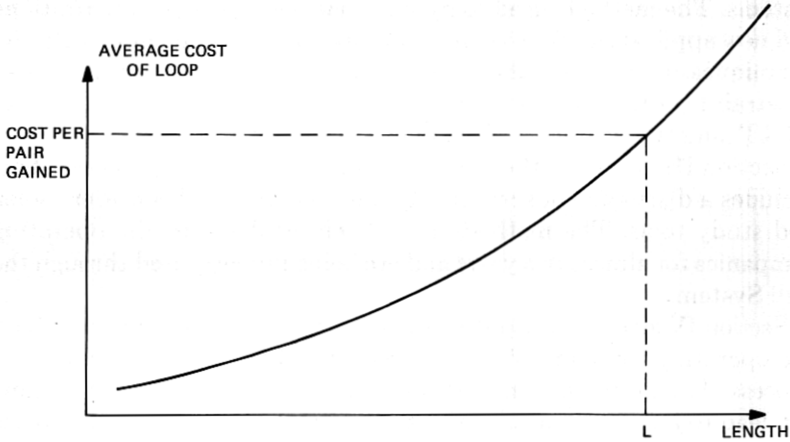


Fig. 2—Electronics—cable cost comparison.

ventory, the provision of a loop of length L may require the addition of only $L_1 < L$ feet of cable.

(*iii*) Pair gain systems, as well as cable, come in discrete sizes. Thus, while a specific system may have an extremely low cost per pair gained, it may also provide a large and unneeded number of communication channels.

This example suggests that, unless the detailed mechanics of the facility expansion process are examined in conjunction with exact pair gain system configurations, faulty conclusions can be reached.

2.2 The Bell System application study

Because of their high cost, early loop electronic systems could not be considered as potential universal alternatives to cable. Rather, their cost tended to justify their use only in the very long loop rural areas. As new, lower cost systems have been developed, however, the list of generic applications in which they could be used economically expanded to include their temporary and permanent placement in suburban areas. The use of this generic applications list somewhat simplifies the process of operating company planning by automatically eliminating areas where electronics should not normally be considered as alternatives to cable.

Detailed feeder route studies must be conducted in order to both identify new generic applications for existing or hypothetical systems and to evaluate the impact that hypothetical systems could have when used in generic applications. Thus, at the heart of the development planning process for loop electronics is the aptly named "application study." This type of study should not be confused with an operating company planning study which evaluates the suitability of using loop electronic devices to solve a particular facility relief problem.

As is shown in Fig. 3, the motivation for a particular application may come from the following four different areas:

(*i*) Identification by the operating companies or AT&T of a particular type of facility relief problem, for example, the extremely high cost of providing service to subscribers who live in remote rural areas.

(*ii*) Anticipation of future problems by Bell Labs, for example, the facility problems that will arise from a large growth in the demand for wideband data services.

(*iii*) Development of a new technology that might aid in solving an existing problem, for example, the use of optical fibers as a loop transmission medium.

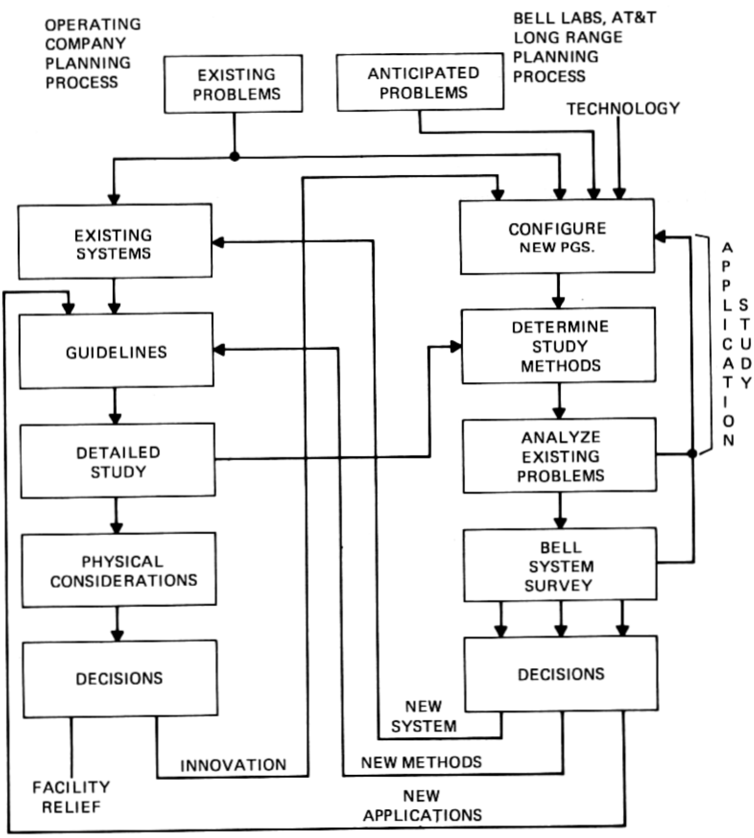


Fig. 3—Development planning flow chart.

(*iv*) Innovative use by the operating companies of existing systems to solve new problems. An example of this kind of motivation, which involved an operating company's use of the *SLM*™ system to defer large suburban conduit additions, is described in Section IV.

Based on these motivations, AT&T may commission an applications study in a single Bell System operating company. As Fig. 4 indicates, the telephone company has the responsibility for supplying the description of the feeder routes to be considered. This includes providing information on route topology; existing cable facilities; forecasts of subscriber

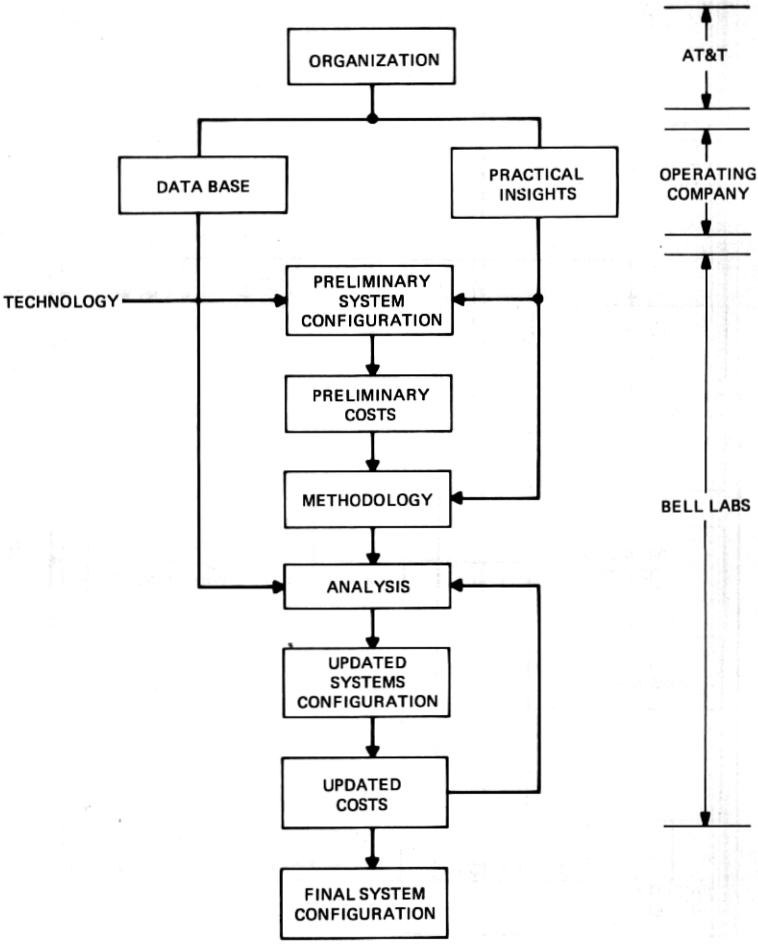


Fig. 4—Application study flow chart.

demand; local installed costs for such things as cable, conduit, pole lines; as well as outside plant maintenance and rearrangement costs. Operating companies also provide practical insights that can be used in the development of systems concepts. For example, local land usage may make it necessary to design a new pair gain device for only underground mounting. In addition, because of their familiarity with their own problems and their previous use of loop electronic systems, operating companies can also provide valuable advice on the assumptions and approaches to be used in the actual economic analysis.

Primary responsibility for the generation of new loop electronic system concepts and the estimation of their preliminary costs is that of Bell Laboratories. These concepts are influenced both by the characteristics of the problem under consideration and the current state of technology. A list of preliminary pair gain system parameters that might be identified at the beginning of an application study is contained in Table I.

Economic analyses are used to evaluate these preliminary configurations as alternatives to cable. In such analyses, an optimum or suboptimum feeder relief plan is identified that minimizes the PWAC required to provide service over the study period. The actual methods used to obtain this plan vary greatly. In some cases, standard Western Electric computer programs such as EFRAP[1], LFRAP[2] or LCAP[2], which utilize branch and bound optimization algorithms, are employed. In other instances, variations of the guidelines approach discussed in Section III or the analytical minimization techniques discussed in Ref. 3 are found appropriate. A typical analysis approach that is used by Bell Labs is described in Ref. 4.

Analysis of the preliminary system generally indicates that the PWAC savings attributable to the use of a device can be increased by changing several of its key parameters. As is illustrated in Section IV, system and module sizes are typical parameters that are adjusted. At this early

Table I — Preliminary pair gain system design parameters

Size:	
	System size
	Module size
Transmission:	
	Type: analog, digital or baseband
	Maximum resistance of cable between RT and customers' premises
	Transmission line repeater spacing
Mechanical:	
	RT mounting configuration
Traffic:	
	Maximum customer traffic handling capability
Features:	
	Testing
	Maintenance
	Powering

stage of the development planning process, an estimate of the price at which this reconfigured system might be made available to the operating companies is also provided. This is a critical step. It is the point where the possible problems and resultant costs associated with manufacturing a new technology system are included in the planning process.

The steps just outlined are designed to yield the configuration of new loop electronic systems. If existing systems rather than hypothetical configurations are used, however, the same process provides an evaluation of the suitability of using these systems in new generic applications.

The analysis methodology used by Bell Labs during the applications study may also be suitable for use by the operating companies in their loop electronic planning process. The LFRAP program is an example of standard Bell System planning software that had its genesis in a Bell Labs applications study.

2.3 Bell System survey

The results of an application study apply only to the small number of feeder routes actually considered. To estimate the number of routes in the Bell System that have the same characteristics, surveys must be conducted in other operating companies. These surveys are then used to extrapolate to the total Bell System the applicability of the systems, applications and methods identified in the application study.

The collection of Bell System surveys and data bases is generally conducted by AT&T, with technical support from Bell Labs. One of the best examples of such an activity is the Long Route Data Base,[4] compiled in 1968. This survey represents a 2 percent sample of all Bell System wire centers that have at least one loop whose length exceeds 40 kft. A map indicating the location of the 110 wire centers in the survey is shown in Fig. 5.

The Long Route Data Base contains information that describes in detail the 363 feeder routes in the sampled centers. A partial listing of the data available is contained in Table II. This information was used to evaluate the impact that the *SLC*™-8, *SLC*™-40 and the Loop Switching System (LSS) might have in Bell System rural areas.

Frequently, however, the results of these surveys may indicate that in a given configuration, a proposed system or technique is not broadly applicable to all operating companies. The process of reconfiguration and analysis can then be repeated to increase the potential usefulness of the proposed system.

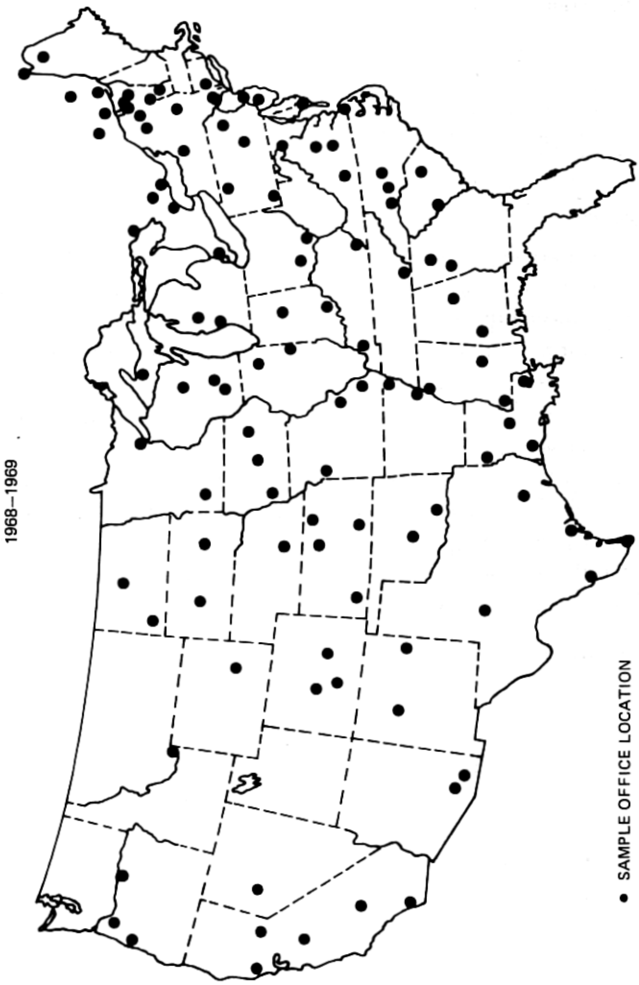


Fig. 5—1968 long route survey.

Table II — Partial listing of information in 1968 Long Route Data Base

Central office data:
Name
Location
Type of switching machine
Route data:
Route identification
Length of longest loop
Number of sections on route
Section data:
Section identification
Length
Identification of preceding section
Type of cable or wire on section and the number of pairs provided
Existing telephone subscriber demand
Forecast subscriber demand

2.4 Decisions

Bell System surveys provide a means for estimating the effect that new loop electronic systems, application strategies, and analysis techniques might have on all the operating companies. If the economic savings are sufficient, these new approaches are developed and ultimately appear as inputs into the operating company planning process. It is important to note, however, that since the Bell Labs development planning process is motivated by real problems, the outputs of the process are in fact tailored to the needs of the operating companies. The extent to which these new approaches can impact on operating company problems is, therefore, optimized. A description of how operating companies actually use new electronic systems, planning techniques, and application strategies is described in the next section.

III. THE OPERATING COMPANY PLANNING PROCESS

3.1 Specific relief problems and available solutions

The operating company outside plant planning engineer is continually faced with the problem of planning cable relief projects for congested cable routes. These relief requirements are usually identified through the records of existing facilities and the evaluation of new forecast information. Often, the engineer uses qualitative forecast information gathered from contacts in the area, including real estate developers and planning boards, to identify potential facility congestion areas.

The addition of cable facilities to an existing feeder route can be extremely costly. Preparation of a long term facility addition plan is complicated, not only by the economies of scale associated with placing cable, but also by the discrete sizes in which cable is manufactured. Optimization programs, such as the Exchange Feeder Route Analysis Program (EFRAP) are, therefore, often used to prepare a basic long range facility addition plan for individual feeder routes.

Electronic systems can also be used to provide loop services, often at a total cost lower than that of the cable alternative. Since electronic systems increase the number of alternatives to be considered, the complexity of the facility expansion problem is increased. The increased complexity emphasizes the importance of systematic and effective methods for planning relief with electronics.

Planning methods that deal with relief using cable and structure facilities are well established. They include sizing guidelines and mechanized study procedures that assist the engineer in timing, sizing and pricing the relief alternatives. These techniques are continually being improved and modernized.[1,5]

Planning methods that deal with the application of pair gain systems to provide facility relief are newer. These methods include both guidelines and detailed economic study techniques. The guidelines quickly indicate whether further consideration of pair gain systems is worthwhile. The detailed economic study methods, both mechanized and manual, help the engineer develop and cost the pair gain relief plan.[6] Since the planning engineer is usually limited to the use of existing systems in standard modes of application, both the guidelines and detailed study methods assist the engineer in the evaluation of the applications of a specific pair gain system to a specific relief problem. This systematic planning procedure is illustrated in the left hand side of Fig. 3.

The following sections will describe the pair gain system planning methods now available for use in the Bell System. These methods are not tied to specific hardware, but can be easily adapted to the evaluation of any pair gain system. They can, therefore, be used to identify and study the vast majority of pair gain applications.

3.1.1 A rule of thumb

The first step in the study process, once the congestion problem is identified, is to decide whether or not pair gain systems should be considered, and whether they should be considered as a permanent or temporary alternative. A permanent application is defined as one in which the pair gain system is used until the economic life of the equipment is over, at which time it is replaced with like equipment. Temporary applications are defined as those in which the intent is to remove the pair gain system, and perhaps reuse it, in a time period less than the economic life of the alternative cable or conduit. Typical temporary applications last from two to five years. A more detailed discussion of the economics of temporary applications can be found in Ref. 4.

The operating company engineer uses previous experience and knowledge of typical economic pair gain applications to decide whether or not pair gain devices should even be considered. The engineer then decides to consider either a permanent or temporary application by using the following rule of thumb: A pair gain application should be permanent unless (*i*) route parameters may change significantly in the next few years, or (*ii*) the growth is so high that too many pair gain systems (physical or practical limits) would be needed to provide relief over the study period. Condition (*i*) refers to events, such as a future route rearrangement necessitated by the construction of a new highway or wire center. Condition (*ii*) usually applies in suburban and light urban areas, where growth can be high and space for remote terminal (RT) sites limited. Since this decision is based on a rule of thumb, it is by no means irrevocable. There are several points in the process where the engineer can reconsider this decision if the situation warrants it.

3.1.2 Economic guidelines

Once the preliminary decision to consider either a permanent or temporary application is made, the engineer applies the appropriate pair gain systems guidelines. The form of these guidelines differs somewhat for permanent and for temporary applications, but similar functions are performed in either case.

The guidelines enable the engineer to determine quickly whether or not the pair gain systems being considered have potential economic benefit. If they do not, the engineer can immediately proceed to study the cable alternatives without further consideration of pair gain. If a potential economic benefit is indicated, the guidelines can assist in rank ordering the systems by their potential economic savings.

3.2 Study methods for rural permanent pair gain applications

3.2.1 Economic guidelines for rural permanent applications

Guideline curves for rural permanent applications are break-even PWAC curves of a pair gain solution versus a cable solution on a model of a route. The model route is characterized by its length, called weighted loop length (WLL), and by the size of cable needed to satisfy 15 years of growth, called weighted cable size (WCS). WLL and WCS are present worth equivalents of route length and cable shortages. Present worth equivalents are used because cable relief requirements are spread out over time. The PWAC of placing a cable of size WCS and length WLL is compared to the PWAC of placing a series of installations of the particular pair gain system to satisfy the same growth over the study period. The resulting break-even curve is dependent on the getting-started and per-line installed costs (commonly referred to as A and B costs, respectively) of both cable and pair gain, their associated annual charge rates, and on the size and pair gain of the system being considered. Telephone company staffs can create and publish series of curves for the systems they use and for local variations in both cable and pair gain installed costs, using calculation methods provided by AT&T. An example of such a curve is shown in Fig. 6a.

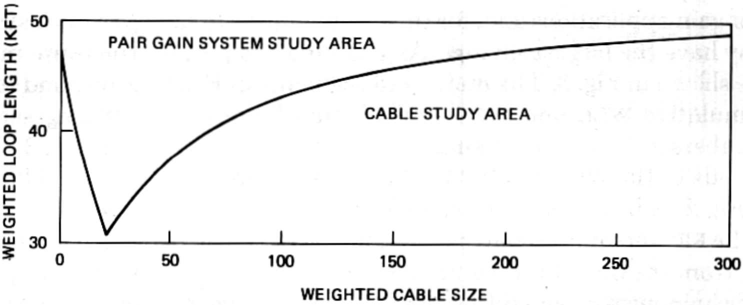
To use these curves, an engineer in the field need compute only the WLL and WCS equivalents of each section of the route under study and then plot the cumulative results on the appropriate break-even curves. These computations can often be done in less than 15 minutes. The resulting plots can indicate which routes are definitely not economic for pair gain applications and, for those that may have savings, which system may have the largest savings. An example of a plot for the route in Fig. 7 is shown in Fig. 8. The numbered segments in Fig. 8 correspond to the cumulative WLL and WCS equivalents of the corresponding section numbers in Fig. 7. For example, the point at the end of 3 in Fig. 8 corresponds to the WLL and WCS of Sections 1 through 3 in Fig. 7. The plot in Fig. 8 indicates that the sample system would probably be economic if the RT were placed beyond the end of Section 5, or approximately 63 kft from the CO. This does not lead to the conclusion that the proposed pair gain system should be used. It does, however, indicate that it is worthwhile to make a detailed economic study comparing the use of this pair gain system with the cable alternative.

These guidelines resolve many of the inaccuracies that arise from the use of the approach described in Section 2.1. The validity of the permanent applications guidelines has been established by testing their effectiveness on the 363 routes of the Long Route Data Base.

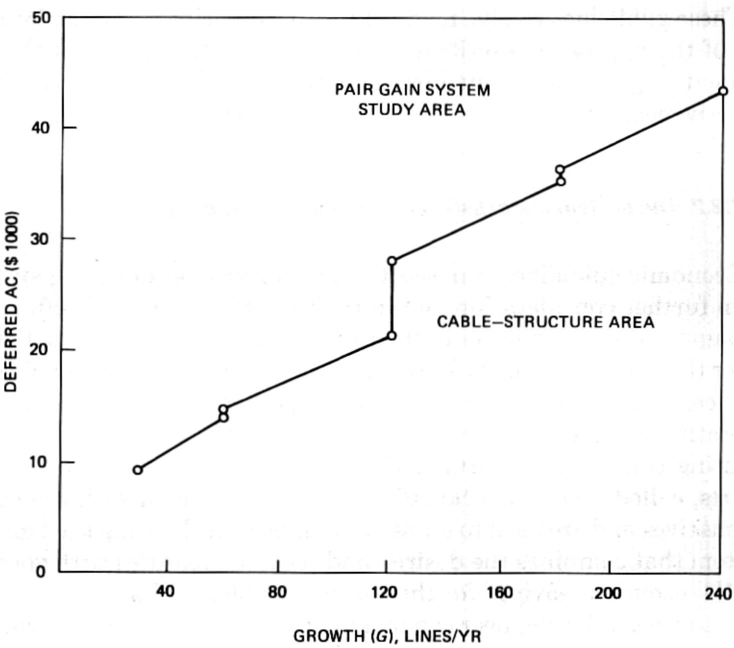
3.2.2 The system checklist—considering other factors

Economic guidelines can assist the engineer in eliminating systems from further consideration and in ranking, with a minimal effort, the remaining systems in order of their potential economic savings. Factors other than economics must be considered, however, such as the physical, service, and technical features of the proposed pair gain system. The operating companies have been provided with a standard format for creating comparison charts of these features for each system. These charts, called system checklists, are usually provided with the curves themselves and are used to guide the engineer in choosing the pair gain system that combines the desired and required features with good potential economic savings for the specific problem at hand.

In this way, the engineer can make the decision to eliminate pair gain systems from further study or to choose one system to study, with a minimal effort for each relief problem. The speed of this method allows the engineer to consider pair gain solutions for relief problems on many routes, without spending a lot of time. The engineer can then efficiently select the alternatives to be studied in detail with a high degree of confidence that these alternatives will result in maximum savings.



(a)



(b)

Fig. 6—(a) Permanent guidelines (sample system). (b) Temporary guidelines (sample system).

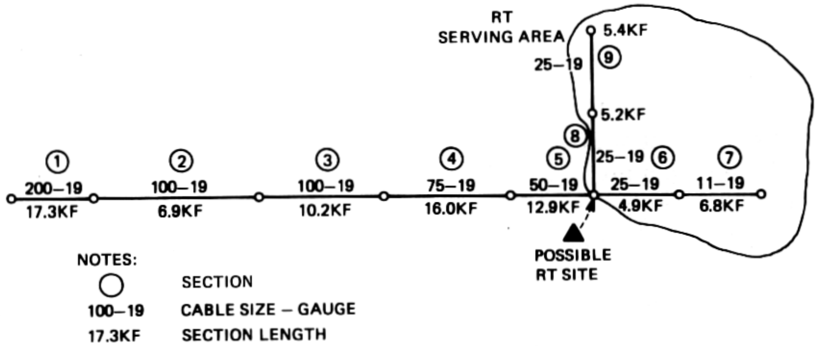


Fig. 7—Route example.

3.2.3 Detailed economic studies of permanent appreciations

When the use of the guidelines of 3.2.1 results in a decision to study a particular pair gain system for a particular relief project, the engineer uses one of a family of available study techniques. These include fully

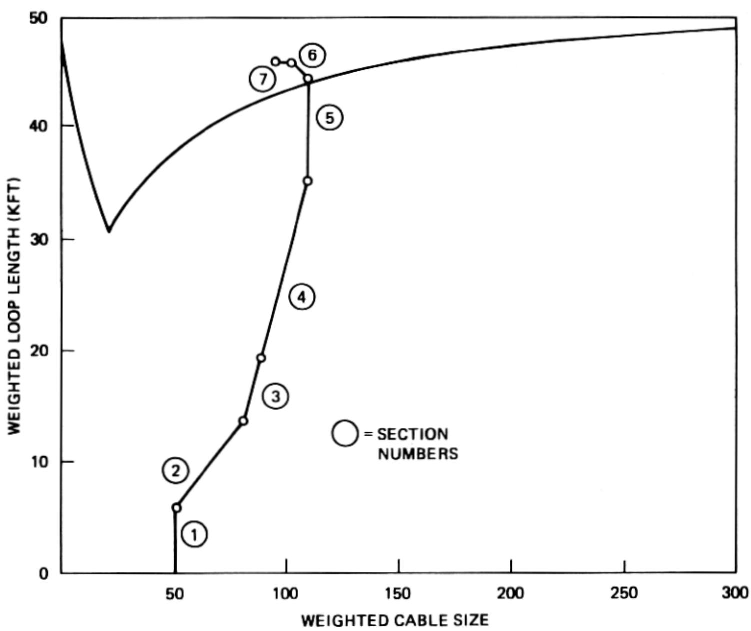


Fig. 8—Permanent economic guidelines plot of example route.

mechanized computer techniques such as LCAP (Loop Carrier Analysis Program) for distributed[7] systems or LFRAP (Long Feeder Route Analysis Program) for lumped[7] systems. These programs, for use on rural routes, provide the engineer with a computer-generated relief plan that, with minimum PWAC, satisfies all facility shortages over the entire study interval, using a mix of cable and pair gain and then compares that solution to an all-cable solution. The all-cable solution may include the use of voice frequency range extension devices, if desired. The engineer uses these computer results and practical knowledge of the specific project to develop a realizable and economic relief plan.

As an alternative to LCAP/LFRAP, the engineer can develop relief plans manually and test the PWAC of each with any one of a variety of cost analysis programs available to Bell System companies. These include TOPPS (Time Share Outside Plant PWAC Studies), EASOP (Economic Alternative Selection for Outside Plant) and CUCRIT (Capital Utilization Criteria). With the manual approach, the engineer has more control over the design of the relief plan, but the plan may not achieve the optimal PWAC savings obtained via LCAP/LFRAP. In either case, the engineer must insure that, in addition to economic savings, the relief plan meets all physical, service and technical requirements for the project.

3.3 Study methods for temporary applications of pair gain systems

3.3.1 Economic guidelines for temporary pair gain applications

Guideline curves for temporary applications are break-even annual charge curves that compare the annual charge of deferring a construction project for one year with the annual charges of the construction project itself. Deferrals that cannot save money for one year are usually uneconomic for longer periods. The guidelines, therefore, can eliminate pair gain systems from further consideration by indicating negative savings in the first year. These temporary application break-even curves do not depend on a model of the route, but are rather a direct plot of the annual charges associated with accommodating a particular growth rate through use of the pair gain system. [See Fig. 6(b).] As with permanent curves, temporary guideline curves can be created and published by telephone company staffs for any pair gain system eligible for use and for local variations in installed costs.

To use these curves, the engineer determines both the annual charge of the project to be deferred and the associated growth and then plots the associated point on the graph. The difference between this point and the break-even curve is the estimated saving for one year. Points above the curve indicate positive savings. The engineer can easily investigate the effect of deferring parts of a project as well as the difference in savings because of the use of different systems. As with permanent guidelines, this procedure usually takes 15 minutes or less.

The system checklist, described in 3.2.2, is also used in temporary studies to insure that any pair gain system selected from the guidelines would meet all route requirements.

3.3.2 Detailed economic studies of temporary appreciations

The currently recommended approach to temporary studies is to manually develop relief plans and to test the PWAC of each plan with a cost analysis program as described in 3.2.3. This manual effort is complicated by the fact that the extra degree of freedom added to temporary plans by the unknown deferral interval makes temporary plans more difficult to optimize than permanent plans.

The guidelines process includes a method for estimating the deferral interval that maximizes PWAC savings. This estimate can be used as a starting point in manually generating relief plans for computerized cost analysis with TOPPS, EASOP, or CUCRIT.

The manual development of relief plans for temporary applications allows the engineer to include physical design considerations as an intrinsic part of the plan. Typical physical design considerations are discussed in 3.4.2. This takes on more significance in temporary studies than in permanent studies because temporary applications are often found in suburban or light urban areas where physical design considerations can be quite constraining. Manual plan development for temporary applications offers the engineer the fine control needed to apply pair gain systems in these areas.

3.4 Relief decisions

The engineer uses the results of the studies described above to develop a relief plan. This plan is based on both economic and practical parameters. These decision criteria are described in more detail below.

3.4.1 Economic decision criteria

The basic economic criterion on which relief decisions are based is PWAC. This allows the engineer to include the long term effects of the plan as well as differences in annual expenses, such as maintenance and administrative costs. The consideration of annual costs allows the engineer to account for differences among capital cost intensive plans that result in different depreciation schedules, tax credits or relief timing. Minimum PWAC is the optimization criterion used in LFRAP and should be the prime economic factor in any relief decision.

Another important economic criterion is "early" IFC (Installed First Cost), that is, the capital costs associated with the plan in the first few years. This can be important because of construction budget constraints that may limit the amount of capital available in any year. The effect of such a constraint may be the choice of a pair gain plan over a cable plan, even when the long-term PWAC of the cable plan is lower. This could occur if the size of the pair gain system in the plan allows the placing of relief in smaller line increments than the cable in the plan. Similarly, budget constraints may tend to favor the placing of smaller pair gain systems in order to more closely match the facility requirements and keep first costs low.

When budget constraints are important, but not controlling, combinations of PWAC and IFC can be used as decision criteria. This allows the engineer to consider the long term costs and varying expenses between plans, using PWAC, while also accounting for total capital costs, and with the early years emphasized.

Since local constraints must always be considered, the economic decision criteria to be used are a local decision. In all cases, however, the effects of today's decisions on future decisions should be weighed.

3.4.2 Physical decision criteria

The physical constraints of the relief problem are as important as the economic criteria described above. The feasibility of a pair gain solution is usually insured by the use of the guidelines and system checklist. However, physical constraints can have a significant impact on the details of the relief plan.

One important physical constraint applies to the location of the remote terminals of the pair gain system. The economically optimum site location may not be practical because of too few assignable customers beyond the site or because of insufficient or unsuitable trunk facilities to the site. In the first instance, there may be too few customers available in any one year to sufficiently fill the system to utilize the available pair gain. In the second instance, existing facilities up to the proposed RT site may not be sufficient to allow a smooth cutover to the system without temporarily taking customers out of service or the facilities may be in such poor condition that transmission would be unreliable. In either case, a new RT site may have to be chosen, changing the economics.

Physical factors such as right-of-way, available space, building codes or highway safety regulations may also affect RT placement. In addition, the administration of the RT serving area (see Fig. 7), in both the short and long term, must be considered. RT placements can affect the transmission design of cable beyond the RT, which in turn can have both administrative and capital cost effects not previously considered.

In each of these instances, the economic plan must be adjusted and reevaluated to assess the impact of satisfying these constraints. The engineer has the same tools available for restudy as for the initial study, but because of limited time, often uses abbreviated methods to evaluate differences in costs. Fortunately, the economic impact of meeting the reality of the physical world, while not insignificant, is often not decisive. While details may change, the most economic relief plan usually remains relatively unchanged.

3.5 Unusual circumstances and innovative solutions

The preceding discussion was based on the engineer's encountering problems amenable to standard solutions and study techniques. Although the possible combinations of cable and pair gain systems provide great flexibility in solving problems and, although the study techniques are general in nature, the engineer is often faced with atypical problems. When this is recognized, the engineer must innovate. Today's innovations, of course, may well become tomorrow's standard applications.

Examples of these situations, by their very nature, cannot readily be hypothesized. Existing examples can be described, however. For example, when Mountain Bell was faced with the need to convert PBX facilities to centrex CO at a large Idaho installation, they chose to use digital carrier (*SLC*-40) to provide the additional circuits between customer premises and the serving central office. In another instance, Bell of Pennsylvania deferred a wire center in the Pocono Mountain resort area by using *SLM* and, later, *SLC*-40. Since these installations were planned, the innovative use of pair gain to provide centrex CO service or to defer wire centers has become more commonplace and is now considered a standard application.

IV. ILLUSTRATIVE PLANNING EXAMPLE

Because of the high inflation rate in the early 1970s, the cost of installing conduit in suburban areas was becoming prohibitive. Several operating companies began using the 80-line *SLM* system. This system was originally configured for rural application and was not ideally suited in terms of cost and module size for widespread permanent or temporary suburban use.

As a consequence, at least one operating company contacted AT&T and Bell Labs on the possibility of designing a new pair gain system whose characteristics would be better suited for suburban use. In response, AT&T commissioned a joint application study with this operating company. Bell Labs analyzed the use of a new 96-line, 32 trunk, subscriber loop concentrator for temporarily deferring conduit additions on sixteen selected feeder routes. This preliminary analysis showed that, for maximum economic savings, the concentrator should be composed of not one but two 96-line modules. A subsequent economic analysis confirmed that this postulated two-module system would indeed be more effective in deferring conduit additions.

This conclusion was reached through an analysis of feeder routes from a single operating company. To extrapolate this conclusion to other operating companies, AT&T conducted a survey of five additional companies. That survey substantiated the proposal that a 192-line loop concentrator could generate large PWAC savings when used on suburban feeder routes. This system has now been developed by Bell Labs and is currently being manufactured by Western Electric. It is the Loop Switching System that is described in this issue of the Bell System Technical Journal.[8]

The application study mentioned above resulted not only in the development of the LSS, but also indicated that other pair gain systems, such as the *SLM* and *SLC*-40 systems, could also be used in conduit deferral applications. The study also resulted in the development of the temporary application guideline curves that were described in Section 3.3.1.

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