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New Concepts in Exchange Outside Plant Engineering

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Concentrated study by the American Telephone and Telegraph Co. and Bell Telephone Laboratories has resulted in several engineering and design innovations that permit more efficient utilization of the exchange cable network. As a first step, a mathematical model of the customer loop plant was developed from survey data. With this model, studies have been made of the transmission properties of the loop plant at both voice-band and carrier frequencies via computer analysis. Results of such studies have been useful in planning plant improvement programs and have also been used to evaluate such new concepts as "dedicated outside plant" and "uniform-gauge customer cable plant."

Other computer programs have been and are being developed to aid in engineering cable routes for future growth and to evaluate alternatives to placing new cable, such as concentrators and exchange carrier systems. Studies to optimize the placement of new switching centers, taking into account existing wire centers and forecasts of growth for the area, have been made by computer analyses. These computer programs aid engineers in making studies in much more depth and in less time than was possible with older cut-and-try methods.

I. INTRODUCTION

Since World War II there have been major changes in exchange outside plant cable networks. Polyethylene has replaced lead for cable sheaths, and in the distribution plant, polyethylene insulated conductor cable (PIC) and ready-access terminals have replaced paper insulated cable and sealed terminals. Concentrator and carrier systems permit more efficient use of copper in feeder and trunk cables.

In the early stages of these wide-sweeping changes, the major advances were in hardware, as enumerated above; however, exchange plant engineering methods were being analyzed and revised to take full advantage of these innovations. The PIC cable and ready-access terminals had implications on exchange plant installation and maintenance much broader than the purely hardware ones. For instance, the installation of distribution terminals for access to the cable conductors could be postponed economically until required to satisfy a request for service.

Concurrently, unrelated activities were producing results applicable to the plant engineer's problem. Operations research techniques (which aim to optimize an existing system) were being used. More sophisticated electronic computers became available and provided the tools of calculations and machine decision logic on a scale impossible in the past. All of these factors sparked a revolution in the tools and methods used by the engineer to study and evaluate the exchange outside plant as a system, with the ultimate objective of improved service for customers.

It is the purpose of this paper to show how these modern engineering tools and methods are making possible new concepts in the engineering and utilization of the exchange outside plant. Initially, the exchange outside plant was studied as an integrated system. As the work progressed, it was necessary due to the size and complexity of the study to consider each engineering activity as an entity rather than a part of a system. Therefore, for ease of exposition, this paper covers each engineering activity as it was developed during the exchange outside plant engineering study.

II. BACKGROUND

An exchange outside plant cable network (Fig. 1) serves as a medium to connect the central office and station equipment in a manner which is compatible with signaling, supervision and transmission requirements. These requirements usually are stated in terms of circuit resistance and transmission limits. The cable networks are designed to keep within these limits regardless of the distance between the office and the customers. This is accomplished by planning the network around the several options of wire gauges (19, 22, 24 and 26), carrier systems, and the many loading arrangements (H88 and H44, etc.).

Interface problems become quite complex with a cable network that is laid out to connect all customers in an area to a central office. Such a

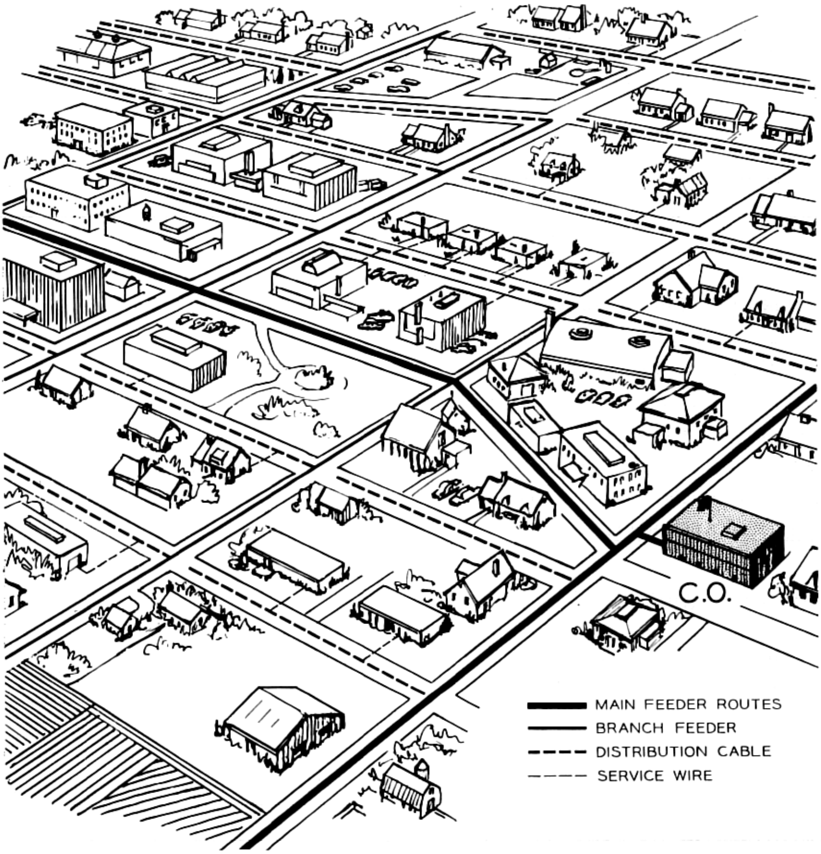

Fig. 1 — Exchange cable network.

network may serve a high-density area of 100,000 customers or more per square mile, as in New York City, or a few hundred customers spread over many square miles, as in some areas of the West. Regardless of area size and type of switching equipment, each network must be carefully designed for the customers it is to serve. Although the size of an area or the number of customers may vary widely, the engineering methods throughout the Bell System are similar. However, these methods reflect the individuality and philosophy of the engineer and the associated company far more than in any other part of the communications system.

The job of engineering facilities in relatively small increments to meet the unique conditions of the area and customer requirements inherently results in a specific network design. This in turn has made it difficult to both obtain and analyze system-wide data about these networks and to set requirements for new systems with confidence that the proposed system when developed would be of optimal usefulness to all associated companies.

In the past, small segments of the plant judged to be representative of the Bell System were studied in detail. These studies evaluated, from the system viewpoint, transmission improvement characteristics or economic advantages of a new development. This procedure was time-consuming and unsatisfactory, and the time associated with obtaining, processing, and analyzing system-wide data was prohibitive. However, by 1958 the application of computer data reduction and analysis techniques made it possible to obtain a much more comprehensive and accurate picture of the exchange plant than had theretofore been possible. This was one of the most basic steps in the application of the new systems engineering concepts and led to several other surveys of the physical and electrical characteristics of the telephone plant.

III. SUBSCRIBER LOOP SURVEY

In 1960 a sampling survey was designed to yield statistically sound estimates of important characteristics of the customer loop plant. A sample of loops, representative of the facilities provided to the approximately 40 million residential and business customers served by the Bell System, was taken. The loop selections were made from a sampling frame containing a complete list of all central office buildings in the Bell System, together with the central office prefixes assigned in each building, and the total number of customers served from each prefix. From this list, in which each customer was implicitly numbered, 1000 telephone numbers were picked in such a way as to form an optimum stratified random sample,[1] with heavier concentration in office sizes expected to contribute the most variability.

The desired information concerning physical composition of the loop plant was obtained from the outside plant cable and wire records maintained by the associated companies. Fig. 2 represents the kind of information provided for each sampled loop.

To derive transmission properties the computer had to be programmed to reconstruct each loop exactly as it appeared in the physical plant. The computer converted the entire loop between the serving central office and the sample telephone into an equivalent T network at each frequency of interest in the voice band. More details on the

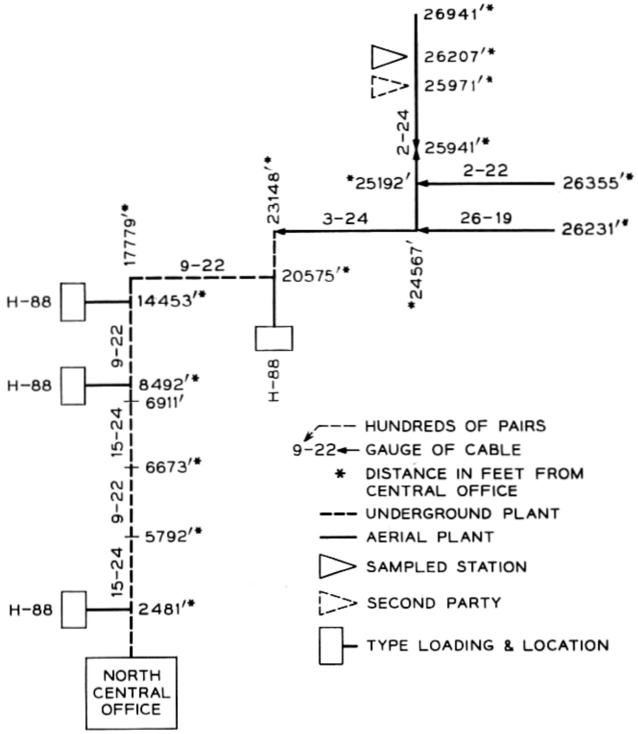

Fig. 2 — Physical composition of loop plant: information from wire and cable records.

method of computing transmission characteristics and specific results are given in Ref. 2.

The more important survey results were summarized as statistical distributions. As examples: (1) the average working distance to a customer in the Bell System was found to be 10,300 feet with 90 per cent confidence limits on this mean value of ±450 feet, as presented in Fig. 3; (2) cumulative insertion losses at seven discrete frequencies in the band from 200 to 3000 cycles are given in Fig. 4. At 1 kc the mean value of insertion loss in loop plant was found to be 3.5 db with 90 per cent confidence limits of ±0.1 db. (3) The degree to which exchange loop input impedance (including station set) matches the toll network is shown by using return loss at each of the six frequency distributions shown in Fig. 5. The best return loss is at midband — around 1 kc, where the mean return loss is 15.0 db with 90 per cent confidence limits of ±0.15 db. The lowest return loss at 3 kc is representative of high

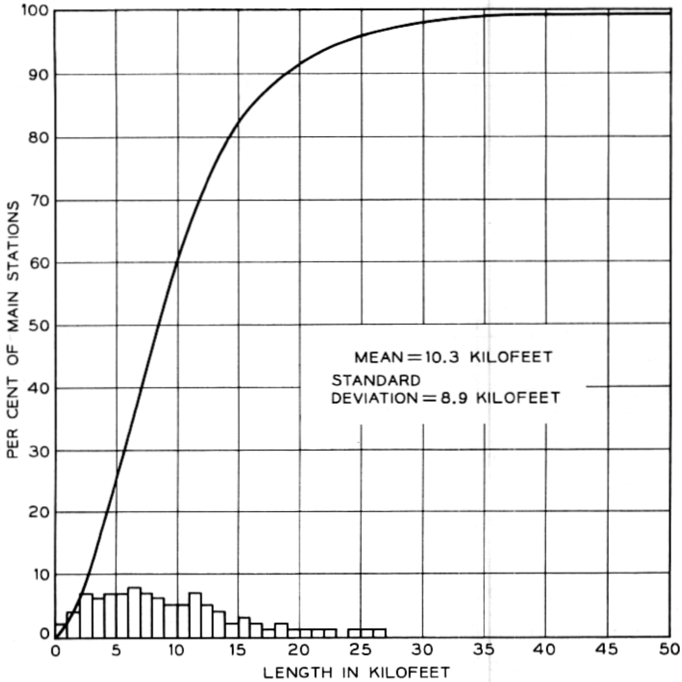

Fig. 3 — Distribution of working lengths to sampled main stations.

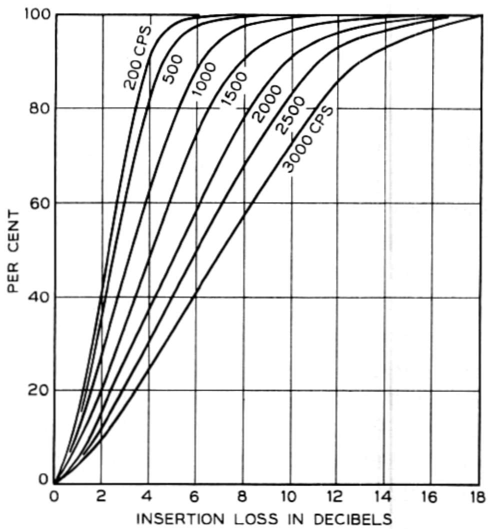

Fig. 4 — Cumulative insertion loss distributions for Bell System loop plant, 200–3000 cps (measured between 900-ohm terminations).

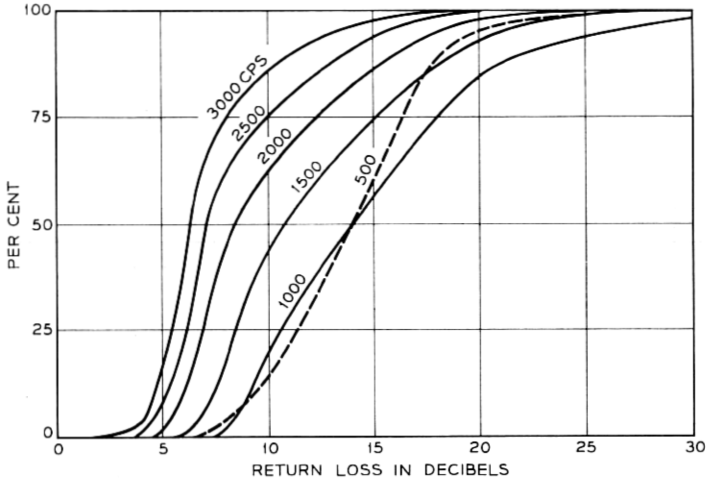

Fig. 5 — Cumulative return loss distributions for Bell System loop plant, 500–3000 cps (measured against 900-ohm + 2 μf compromise balancing network with loop terminated in actual station set impedance).

singing frequencies, where the mean value was found to be 7.2 ± 0.2 db.

One phase of this survey of particular significance was determination of loops that had design irregularities. With these data (composed of the percentage of irregularities by type), the magnitude of the job required to correct these conditions could be estimated and a realistic plant improvement program planned.

In addition to providing guidance for an improvement program, the survey made it possible to develop a statistically sound mathematical model of the existing customer loop plant. This model has been used with considerable manpower savings over the analytical procedures used by Bell Laboratories in the past to determine accurately the transmission effects of new developments designed to be used with the existing plant. With this new tool, studies have been made of (a) effect of cable capacitance variation on transmission properties of loop plant, (b) input impedance of loop plant both at the customer and office end of the loop, (c) need for impedance compensation networks at the central office, (d) characteristics of loop plant at carrier and PICTUREPHONE system frequencies, and (e) the optimum telephone set impedance characteristics. Other uses of these data have to do with the evaluation of new methods of laying out a cable network such as "dedicated outside plant" and "uniform-gauge subscriber cable plant."

IV. DEDICATED PLANT

The dedicated plant concept involves the permanent assignment of a cable pair from the central office to each main station. All party lines are bridged at the central office. This new method of laying out plant was preceded by a gradual but definite change in the composition of telephone plant and customer requirements that began in the early 1950's. Developments such as PIC cable and ready-access terminals provided greater possibilities of circuit availability than did the pulp insulated cables and hermetically sealed terminals previously used. The percentage of households without service was steadily dropping, and at the same time there was an increasing demand for individual line service (see Fig. 6). The labor costs were increasing rapidly for the plant rearrangements necessary to satisfy the changing service requests of customers. All of these favored a more permanent plan of outside plant pair connection than current multiple schemes.

Cable and wire plant is sized on the basis of growth forecasts not only to meet known requirements but to be adequate for some predetermined time in the future. It is difficult to predict the growth pattern, the number of lines, and the type of service for a central office area, and it is even more hazardous to estimate the growth along any given cable route. These uncertainties, along with the inherent difficulty of obtaining access to pairs of pulp insulated distribution cable used in

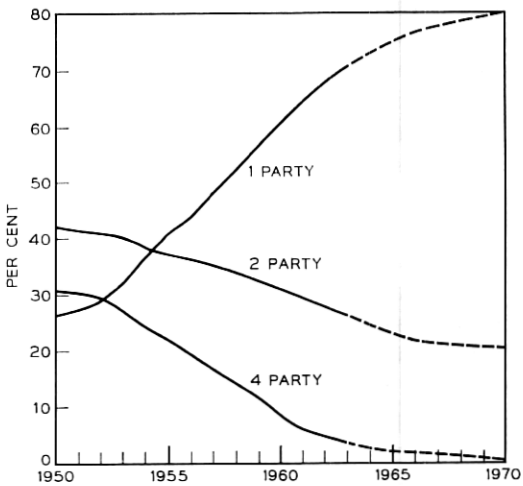

Fig. 6 — Distribution of party line service for all associated companies at end of year shown, with forecast for 1965–1970.

the past, led to the multiple appearance of subscriber cable pairs, not only in several cables, but also at a number of customer terminal locations following a predetermined pattern as shown in Fig. 7. (The multipling of cable pairs is illustrated by the termination of the 1800-pair feeder cable with a 600- and 900-pair branch feeder and a 900-pair main feeder.) Multipling was also necessary to achieve high cable pair utilization and to provide party line association. However, as actual demand does not always match the anticipated growth, it is necessary under this system as growth develops either to rearrange the cable pair layout and unmultiple the pairs, or to leave unused copper in the plant.

The use of multipled cables, cross-connect terminals, and rearrangement of cable complements imposes technical problems and ever-increasing

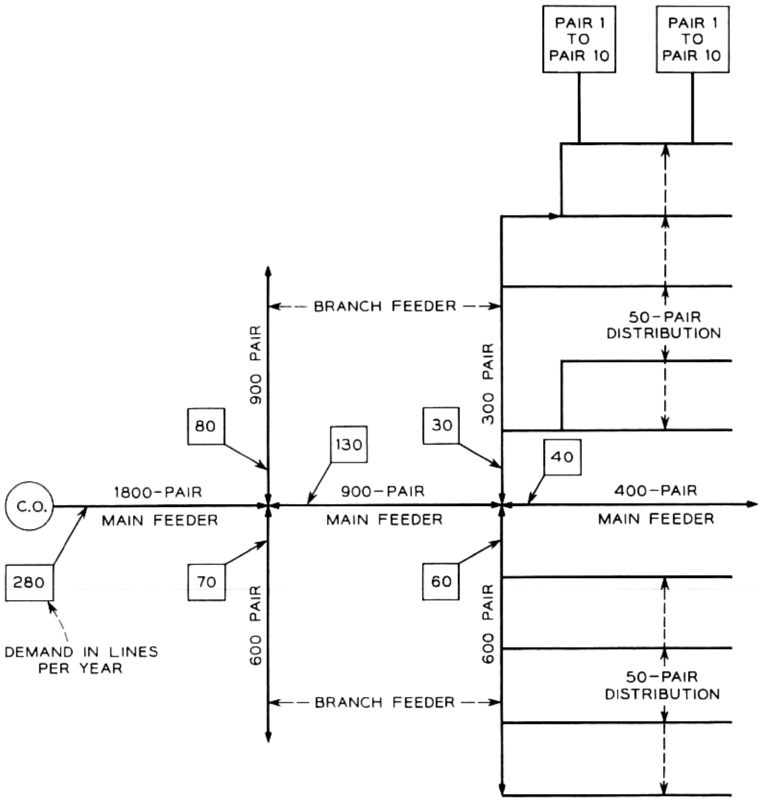

Fig. 7 — Typical feeder route, showing main and branch feeder and distribution cables.

operating costs. For example, when plant rearrangements are required to provide service to a new subscriber cable, pairs must be meticulously searched out, identified, and (often in more than one place) cross connected or spliced. All of these activities require extensive labor. The costs are high and the likelihood of error is always present along with possible interruptions to service.

In view of the recent innovations in hardware and the increasing demand for individual telephone service, this method of laying out plant left something to be desired. Therefore it was necessary to come up with a new scheme that involved completely new cable network design principles capable of virtually eliminating cable rearrangements while retaining the ability to handle growth on increasingly shorter time intervals. Such a scheme was made possible by initially dedicating a percentage of cable feeder pairs to serve a specific area along the route and keeping the remainder in reserve as spares to be dedicated to an area later, as required to satisfy requests for service. The optimum percentage of feeder pairs designated as spares was determined by using computer simulation techniques to study a number of actual plant growth situations. Flexibility points ("control" and "access" points) were conceived to permit ready access to the spare pairs as dictated by future needs along the feeder route.

The use of this dedicated pair concept eliminates the need for multiple appearances of the pairs and permits direct wiring of the customer's residence to the central office while still providing sufficient flexibility (Fig. 8 shows a multipled designed loop by dotted lines and a dedicated loop by solid lines). Once a pair has been assigned to an address, it remains dedicated to that location whether the pair is working or idle, and regardless of class of service. Any required bridging of party lines will of necessity be done at the central office, utilizing switch-like devices to remove the effect of other party stations during conversation. Theoretically, this connection arrangement would result in some advance in capital expenditures for additional feeder cable pairs and other apparatus; however, the savings in the cost of day-to-day operation derived with such a plant design will far outweigh the carrying charges on the advanced capital. Also, ultimately less total capital will be invested due to increased flexibility and the elimination of the multipled portion of all circuits, which also results in an improvement in transmission.

The feasibility of converting existing plant and of installing new plant under the dedicated concept has been studied. The study results indicate that this concept is economically attractive for all residential loops up to approximately 30 kilofeet in length.

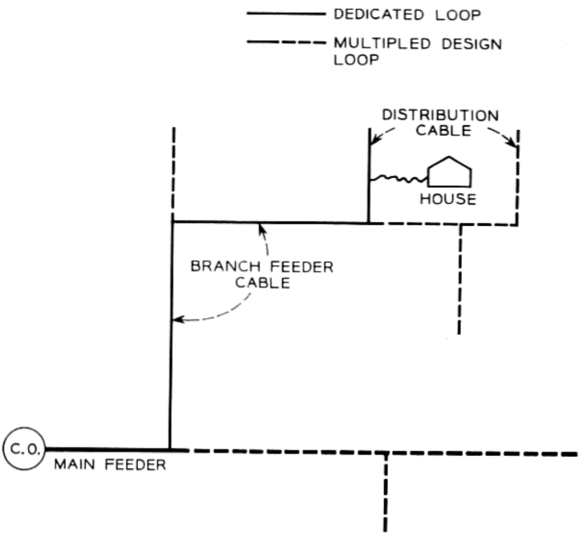

Fig. 8 — Dedicated outside plant, typical feeder route.

The implementation of the dedicated plant technique throughout the Bell System requires familiarizing practically every department with the advantages of such a system and also with how it will affect current methods of operation. Some of the advantages of the new concept borne out by field trial and further confirmed by actual field experience are:

(a) improved efficiency of over-all copper usage,*

(b) reduction in cost of installed cable,†

(c) better transmission through reduction in length of bridge tap,††

(d) virtual elimination of cable, service wire, and central office main frame transfers, thus simplifying assignment and installation procedures (see Table I), and

(e) simplified records, resulting in faster handling of customers' orders.

Actual system application of this concept will be a gradual process, but it is expected that the plant will be converted fully by about 1970, and that large savings will be produced by the elimination of rearrangements and changes in the cable plant, including changes that are at present made for higher cable fills (see Table II).

* Since there are no end sections or multipled connections under the spare pair concept, the entire length of all used cable pairs ultimately will be working.

† Fewer multiple wire connections to make when splicing cables together at junctions of feeder and branch cables.

†† The unused copper in a subscriber's circuit is referred to as bridge tap.

TABLE I — RESULTS OF STUDY AND FIELD TRIAL

Operation	% Reduction	
	Predicted	Actual
Cable pair and service wire transfers	90	97
Cable pair transfers	90	100
Central office main frame transfers	90	97
Service order assignment — residential	40	unknown*
Installation time	substantial	65

* Conversion to simplified records had not been completed during first 7 months.

Dedicated plant will not, however, eliminate rearrangements and changes necessary to reroute customer service to a different central office due to shortage of switching equipment in a specific exchange area or recovery of coarse (19 and 22) gauge cable plant.

V. MULTIGAUGE DESIGN

Before discussing the desirability of further reducing the number of rearrangements and changes in the cable plant, it is appropriate to explore another reason for such activity. The per pair cost of cable conductors varies widely; first as to gauge of the conductors used and second as an inverse function of the total number of pairs included under a given cable sheath. With the coarser gauge the cost per pair rises rapidly due to the increased cost of the copper used. On the other hand, as the size of a cable of given gauge is increased the cost per pair in plant goes down due to both the lesser relative cost of cable sheath and the more or less common placing cost (see Fig. 9)

Because of transmission and resistance limits of both station and central office equipment and the economic factors outlined previously, it is

TABLE II — RESULTS OF FIELD TRIAL CONVERSION TO DEDICATED PLANT

Date	% Pairs in Use at Central Office	
	Working	Assigned
Before dedication		
January 1, 1962	75.8	75.8
After dedication		
March 1, 1962	76.5	92.1
January 1, 1963	78.2	94.0

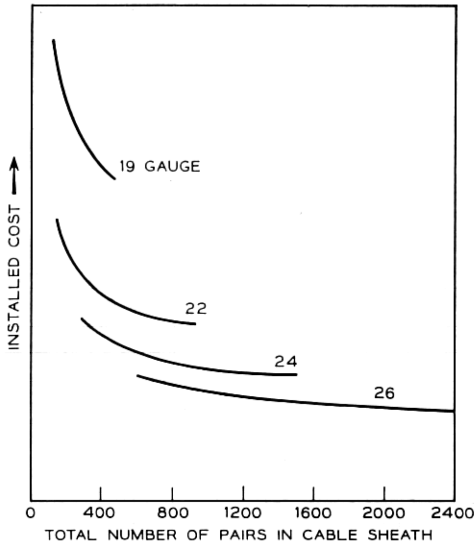

Fig. 9 — Installed costs per circuit mile of underground cable.

a common occurrence to find three or four gauges of cable (from 19-gauge to 26-gauge) in a single exchange cable route (Fig. 2). Frequently, the initial cable placed in the route is coarse-gauge in order to satisfy the requirements of the longer circuits (see Fig. 10). To provide facilities for a reasonable period of time, it contains more total pairs than are currently required in the coarse-gauge area. Then, to postpone the cost of also placing fine-gauge cables, these coarse-gauge pairs are used temporarily for service in areas where fine (26) gauge is sufficient. (This practice is usually followed rather than that of installing composite cables with two gauges of conductors contained in a single sheath.) Later, when customers' requests for service at the extreme end of the route require the remaining coarse-gauge pairs, a finer-gauge cable is placed from the central office, and the circuits which were temporarily served by the initial coarse-gauge cable are transferred to the new cable. Not only is such transfer work costly, but, in addition, the handling of working cable pairs is always at the risk of interference with customer service.

A similar problem arises with special design considerations necessary to meet transmission requirements on the longer loops. Specific pairs of a cable are selected and loaded at discrete distances along the pair. This added complexity results in administration problems, particularly if

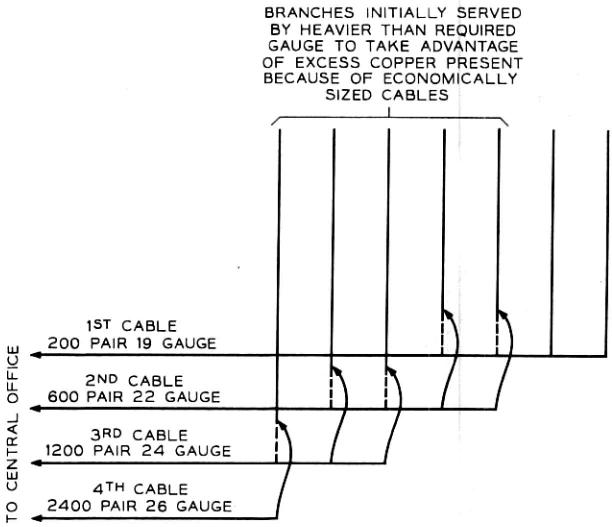

Fig. 10 — Feeder cable route, illustrating gauge requirements.

the pairs are needed in the future for a different service. The loading must then be removed or changed, depending upon proposed circuit requirements.

VI. UNIFORM-GAUGE SUBSCRIBER CABLE PLANT

If it were practical to design and operate a cable feeder route containing only pairs of a single fine gauge and minimum loading, savings would be realized both in capital investment and in operating expense. For example, all the line growth in the route would be absorbed in the single gauge rather than spread over several as is presently the case. An immediate effect of this would be that cables placed in the route would tend to be larger in total number of pairs. Thus not only would the advantage of per-pair cost reduction with the larger cables be realized, but the total number of cables in the route would diminish. Also, fewer ducts would be specified in underground cable structures (conduit) and existing conduit would be used more efficiently. Of course the need to transfer branches to recover coarse gauge would be entirely eliminated, along with its high expense and adverse effect on service.

The engineering of a single-gauge feeder cable relief project would be tremendously simplified, with resultant reductions in engineering costs. Also, the over-all efficiency of the route would be improved, as spare cable pairs would be needed for only a single gauge, as compared to spare pairs for each of the four gauges which are considered as separate entities under the multigauge plant. Naturally, there will be some offsetting penalties resulting from the need to compensate for the added loss and resistance of the finer-gauge cable.

Studies undertaken to explore the technical and economic factors involved in realizing this objective indicate the feasibility of serving customers within 30 kilofeet of No. 5 crossbar and No. 1 electronic central offices with all 26-gauge cable and less than half the loading now required in loop plant. The customers located beyond 30 kilofeet from their serving central offices would still require coarser-gauge facilities and loading. Requirements for new gain devices and signaling range extension equipment are being developed to implement this concept, including the electronic devices necessary to meet special service transmission objectives. When proven operational, this concept, combined with dedicated plant, will result in a completely new method of laying out customer loop plant, with a great reduction in the multigauge problems mentioned previously.

VII. COMPUTER METHODS

Along with these new engineering concepts, electronic computer programs have been developed and others are being developed to aid the engineer in making studies to determine the optimum plant layout and how best to introduce new engineering and system designs into the exchange network.

To engineer a cable addition to an existing network, data pertaining to the status of each cable pair are gathered from the cable location records. With this information and a forecast of growth requirements, engineering plans are formulated for a number of possible solutions to satisfy the demand for service. The conception of alternate plans and the final decision require engineering judgment which is a function of the engineer's training and knowledge of the area. Having selected a number of plans, the engineer makes a detailed analysis of each possible solution to determine its feasibility and cost. This repetitious analysis is a major time-consuming task, particularly if several solutions appear worth studying.

Careful review of the analysis and evaluation techniques revealed that the modern digital computer was ideally suited to aid the engineer in making these studies. It was possible to formalize parts of the engineering know-how so that data (see Fig. 11) could be entered by simple language into a computer, where its equivalent representation could be manipulated more rapidly and precisely than by the engineer. Thus

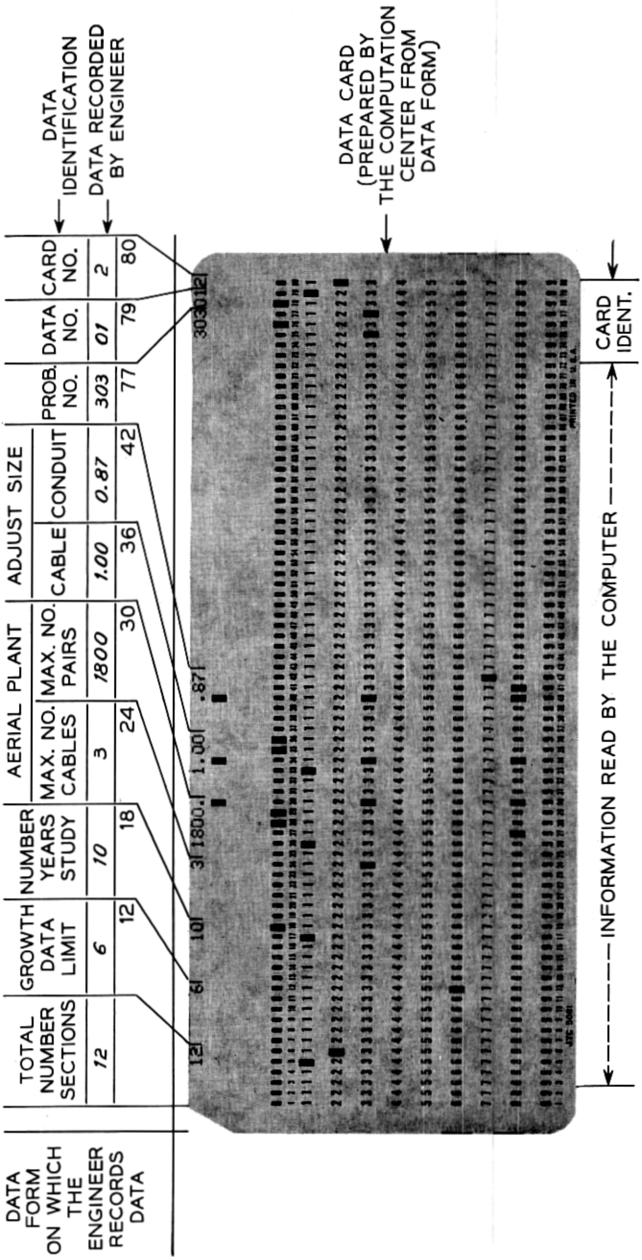

Fig. 11 — Cable relief study data.

freed of the detailed calculations, the engineer could concentrate on the design activities which could not be treated mathematically.

The resulting computer program (see Refs. 3 and 4) produces a complete cable route design for each year of the study period. It is very flexible, permitting the use of local cost data and design rules. Even the most complex cable problems can be handled and an optimum solution obtained for the engineer's final evaluation. Fig. 12 illustrates in schematic form the computer solution to a simple cable relief problem. Although only fourteen sections are shown, the program is capable of handling 99 sections. This program is available on a Bell System basis and is now operational in most of the operating companies.

Of particular interest is the fact that the computer has the capability of exploring the effect of modified rates of growth in a particular cable section more rapidly and economically than possible by the engineer repeating the numerous hand calculations. With this capability, the engineer can consult frequently with the forecaster to obtain his views with respect to areas having unusual growth potential, as well as any substantial deviations from trend which may not have been reflected in the forecast. Forecasting growth in an exchange area will be discussed in more detail later.

In the past when additional pairs were required in the cable route, small increments of cable were added as needed. Now, in addition to cable, new systems such as concentrators and carriers are beginning to play an important role in providing relief facilities. Superimposing electronic equipment on the cable network will have far-reaching effects upon construction and maintenance of the plant. Also, as each new switching or transmission system creates another alternative solution for each cable network growth problem, engineering becomes more involved, time-consuming, and costly.

Therefore a computer program has also been written to explore the cost of using multiplexing systems such as concentrators to postpone cable relief. In addition, this program evaluates all important and unique features of the route and determines an installation and removal date for each of the concentrators.

VIII. WIRE CENTERING

Programs developed for engineering cable routes and evaluating the use of concentrators are also valuable for calculating costs associated with major switching additions to exchange networks. These costs constitute a major factor in deciding where to add additional switching centers in a growing community.

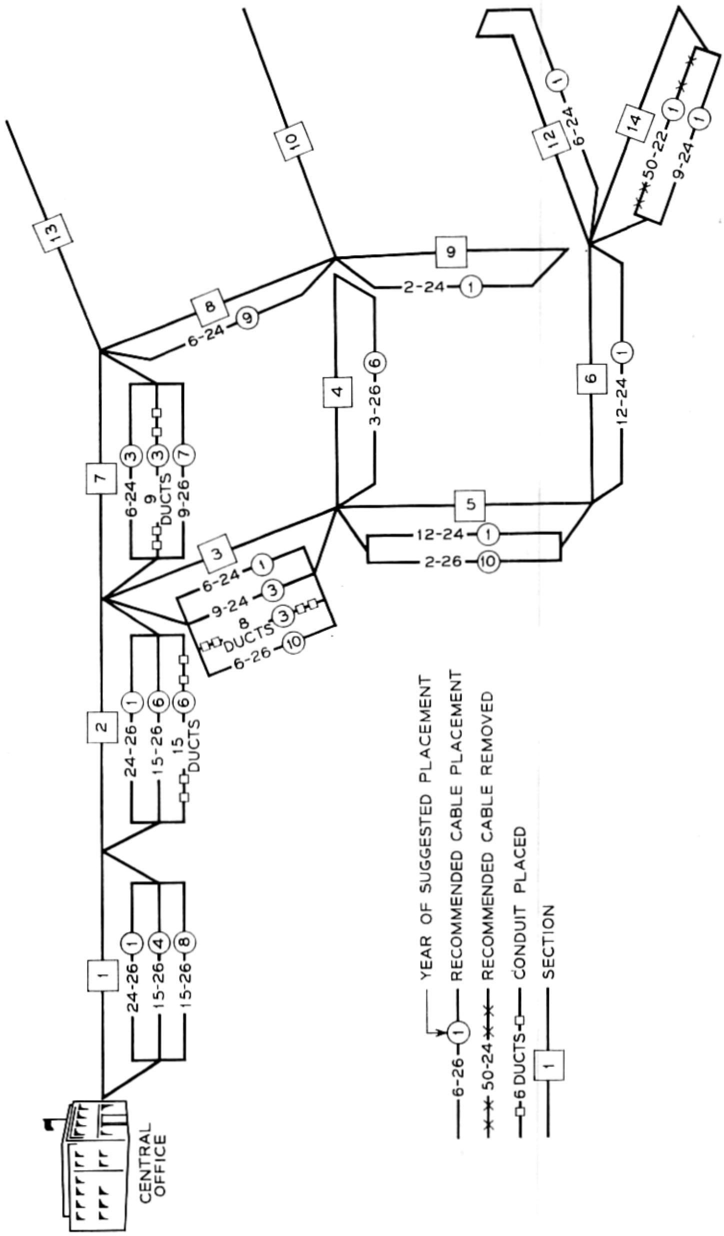

Fig. 12 — Schematic of cable relief study.

Studies made to determine when and where new switching centers should be established are commonly called wire centering studies. The over-all purpose is to obtain the optimum economic combination of outside plant and switching equipment in geographical areas as large as several hundred square miles. More specifically stated, the problem is to determine when and where to add new central offices in the area, considering the configuration of the existing plant, the anticipated growth and the costs associated with reinforcing and extending existing outside plant facilities.

Wire centering studies usually begin with a growth forecast by outside plant cable route sections and an estimate of traffic loads anticipated for the period under study. The first phase is known as a cross-sectional study, an analysis of the situation at a specific future point in time. This type of study gives some idea of the need for additional wire centers and determines approximately their location to satisfy forecasted requirements for customer service.

Usually, the engineer estimates the cost of providing facilities to meet anticipated customer demand from existing wire centers. This estimate is needed as a basis for comparisons of alternate means of providing service. Alternative solutions are then evaluated to determine if the total cost of providing service at this point in time would be less if the area were to be served by additional wire centers at a number of different locations within the area. These cross-sectional studies are repeated using various numbers of switching centers, several growth estimates for the area, and different time intervals. The number of combinations explored can number in the thousands, especially when four, five, or six new wire centers are being considered.

The second phase of the study consists of determining more accurately where and when additional wire centers should be added. This involves making detailed present worth of annual charges (PWAC) comparisons over a 20–30 year study period, first serving a study area by an existing feeder route or routes from one or more existing wire centers and then serving the same area from the combination of existing routes and wire centers with one or more wire centers added. Until now, these studies have been made on a cut-and-try basis and are time-consuming, costly and laborious. Frequently, in fast-growing areas, it is necessary to reach a decision and start the construction of either a new office or additional outside plant before the study is completed.

The cross-sectional method for determining the number and approximate location of new wire centers has been studied and a computer program developed which mechanizes many computations heretofore tediously performed by the engineer. The engineer is still required to gather the same initial information as needed for a manual wire centering study, except that with the wire centering program the data are used as input to the computer. The required data are as follows:

(1) anticipated number of subscriber lines and their location for each year to be studied (Typically, these data are required for 5, 10, 15 or 20 years into the future.)

(2) number of existing wire centers, their location, and other pertinent characteristics

(3) trunk pattern between existing wire centers

(4) average cost of loops and trunks as a function of length

(5) number of proposed wire centers to be considered.

All of this information must be recorded so that the computer can store and manipulate the data. This is accomplished by superimposing a grid system over the area to be studied and associating all growth and wire center locations with this grid system. The growth of 100 customers at an intersection of grids 5,5 is shown in Fig. 13 as an example.

With the quantity and the location of subscriber lines determined, the engineer is ready to proceed with the study by having the computer

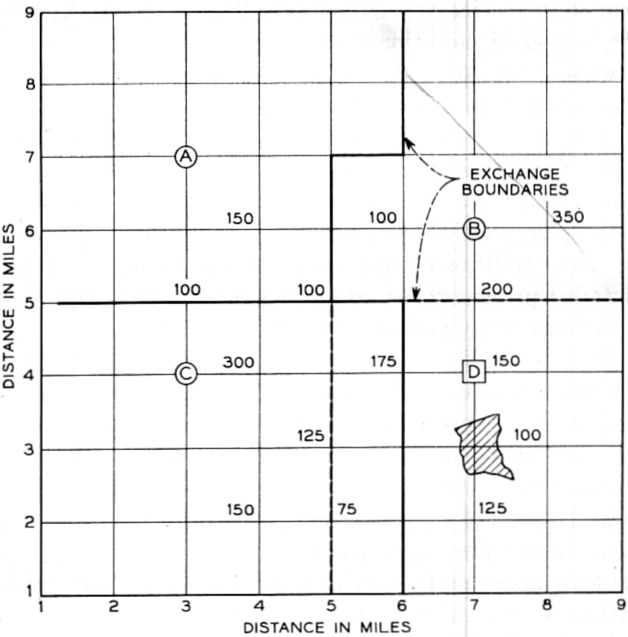

Fig. 13 — Wire centering study area.

calculate the outside plant costs for the study areas considering only the existing offices. After the outside plant costs are calculated for a study area, the building additions, equipment, and additional land costs are estimated by the engineer. Essentially, the entire plant required for serving the customers with existing offices is priced out for each study year. Costs for building additions are needed, since this is usually an important reason for considering a new wire center in the first place. These costs become the reference against which all other possible solutions will be compared. The present computer program will handle eighteen existing wire centers and six proposed centers in a study area. Forty trial locations for each proposed center are possible.

The redistribution of customers to wire centers affects the traffic load within and between centers. This is recognized, and the program distributes the traffic loads in proportion to the customers transferred into and/or out of each wire center.

The output of the computer includes (1) general information regarding the problem, such as the study date, (2) existing wire center data such as present trunk pattern and cost of providing service with existing centers, (3) a list (see Fig. 14) of the ten most economical proposed wire center locations and their associated cost, and (4) a detailed description of the outside plant assignment and the trunk pattern for the best solution. After several field trials of this program, it was accepted as a useful planning tool and has been made available for Bell System adoption.

The primary advantage of using the computer program is its flexibility for examining quickly many alternatives and variations of a given problem which previously could not be examined without complete expensive manual recalculations. If changes occur which were not originally anticipated, a restudy of the area can be made by simply changing the affected information (stored on punched cards) and resubmitting the problem to a computer center.

The program will aid in keeping future plans up to date with a minimum of effort on the part of the planning engineer. Thus with current engineering plans, decisions can be made more deliberately. In addition, the engineer will be in an even better position with a computer program now being developed to aid in determining when a new center can most economically be constructed.

Along with the engineering of cable routes and wire centering studies, other related factors are being considered. As an example, there exists a close economic relationship between the switching techniques, the degree of decentralization of switching equipment, and the configuration of the interoffice trunk cable networks which may be combined with

```
NO WIRE CENTER(S) ADDED
      LOOPS ----------$ 3215722
      TRUNKS ---------$ 1195623
      TOTAL - LOOPS AND TRUNKS ------------$ 4411345
      LAND -------------------------------$       0
      BUILDING ---------------------------$       0
      CENTRAL OFFICE EQUIPMENT -----------$       0
      TOTAL -----------------------------------------------$ 4411345
 4 WIRE CENTER(S) ADDED
      LOOPS ----------$ 2313992
      TRUNKS ---------$ 1329133
      TOTAL - LOOPS AND TRUNKS ------------$ 3643125
      LAND -------------------------------$       0
      BUILDING ---------------------------$       0
      CENTRAL OFFICE EQUIPMENT -----------$       0
      TOTAL -----------------------------------------------$ 3643125
 ECONOMIC ADVANTAGE OF ADDING WIRE CENTERS --------------$  768219
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LIST OF TEN BEST SOLUTIONS AND ANNUAL CHARGES

LOOPS	TRUNKS	TOTAL	PENALTY	LOCATION(S) OF ADDED WIRE CENTER(S)			
$ 2313992.22	$ 1329133.48	$ 3643125.72	$ 0.	(16.5,20.0)	(18.5,23.0)	(12.0,22.0)	(13.0,26.0)
$ 2323909.50	$ 1326039.36	$ 3649948.88	$ 6823.16	(16.5,20.0)	(17.5,24.0)	(12.0,22.0)	(13.0,26.0)
$ 2326183.09	$ 1335968.23	$ 3662151.34	$ 19025.63	(16.5,20.0)	(19.5,24.0)	(12.0,22.0)	(13.0,26.0)
$ 2361164.34	$ 1318489.83	$ 3679654.19	$ 36528.47	(15.5,19.0)	(18.5,23.0)	(12.0,22.0)	(13.0,26.0)
$ 2347148.28	$ 1333569.05	$ 3680717.34	$ 37591.63	(16.5,20.0)	(18.5,23.0)	(12.0,22.0)	(14.0,27.0)
$ 2357065.59	$ 1330218.39	$ 3687284.00	$ 44158.28	(16.5,20.0)	(17.5,24.0)	(12.0,22.0)	(14.0,27.0)
$ 2359339.16	$ 1340834.95	$ 3700174.13	$ 57048.41	(16.5,20.0)	(19.5,24.0)	(12.0,22.0)	(14.0,27.0)
$ 2373477.06	$ 1332824.52	$ 3706301.59	$ 63175.88	(16.5,20.0)	(17.5,24.0)	(12.0,22.0)	(12.0,27.0)
$ 2394320.44	$ 1322845.81	$ 3717166.25	$ 74040.53	(15.5,19.0)	(18.5,23.0)	(12.0,22.0)	(14.0,27.0)
$ 2439273.88	$ 1283318.17	$ 3722592.06	$ 79466.34	(14.5,20.0)	(18.5,23.0)	(12.0,22.0)	(13.0,26.0)

Fig. 14 — Economic summary — annual changes, year 1990.

subscriber cable facilities. Potentially large savings in copper conductors are possible, particularly through the location of switching equipment near maximum subscriber density. These techniques must, of course, be supplemented with reasonably accurate forecast of future customer requirements.

IX. FORECASTING

A large segment of the Bell System's investment for new construction is spent each year on additions to exchange outside plant. The quality of techniques for making forecasts and decisions as to where, when, and what additional telephone facilities are required greatly affects the efficiency of the large annual plant construction program and may result in failure to meet customers' telephone needs on time. Present forecast results are not altogether satisfactory in spite of much effort on the part of both commercial forecast and development personnel and plant engineering forces. Errors in prediction are costly, sometimes sufficiently so to offset the advantages of the most carefully engineered project. Outside plant forecasting therefore is an important function worthy of the forecaster's best efforts — certainly it is an area where improvement could result in substantial dollar savings.

Generally, the growth rate of an area is not constant, although there are some patterns of cumulative growth which will be discussed later. Wide fluctuations in the rate of growth can occur for a variety of reasons. These include the location and accessibility of the land, ownership and value of the property, availability of utilities (particularly sewage disposal), development of adjacent areas, penetration of the housing market, political or municipal climate or action, changes in the level of business activity, employment opportunities, zoning restrictions, tax structure, and a host of others. It is important that the forecaster and the engineer recognize these factors. They also present a good argument for considering each forecast section on its own individual merits and against adopting a purely mechanical forecasting procedure which might preclude sound business judgment.

Procedures for maintaining outside plant planning studies covering fundamental feeder routes on a current basis have been implemented. Cable facility charts which graphically display the relationship between existing cable pairs, usable pairs, past trends of working pairs and forecasts of line growth have proved to be invaluable to both the forecaster and the engineer of outside plant in interpretation and analysis (see Fig. 15). Such charts permit more complete and sharper analysis of growth, both past and forecasted, and its relationship to engineering planning and programming.

An ideal forecasting method should be sensitive to the whole spectrum of economic and demographic factors which influence the direction and magnitude of population growth and also the extent of usage of telephone service. Unfortunately, no such comprehensive solution is yet in sight, although its achievement remains a desirable goal towards which to work. In the meantime, work has been done and the search continues for a worthwhile improvement over present methods.

Studies show that cumulative growth of a central office area over a

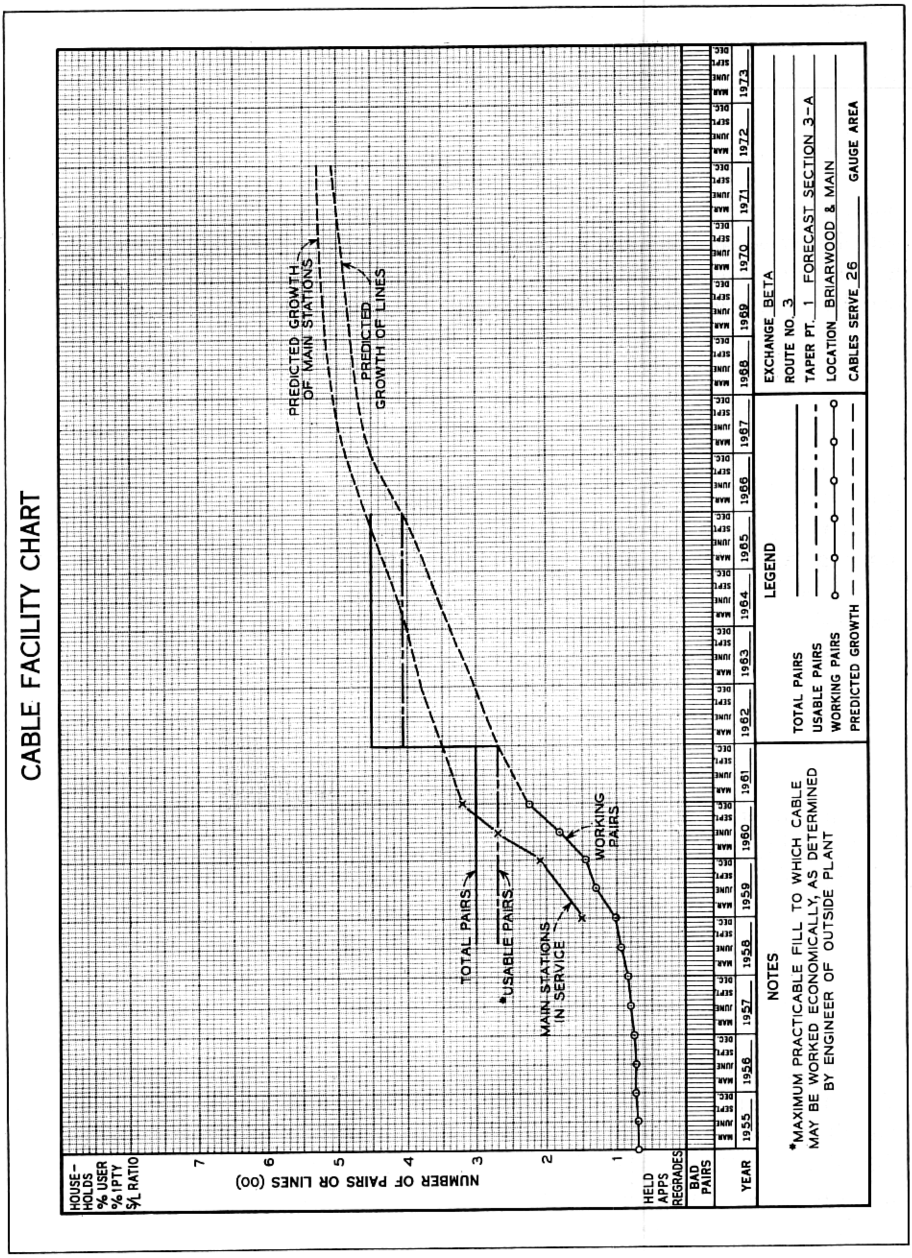

Fig. 15 — Cable facility chart.

period of years exhibits an "S" shape characteristic (Fig. 16). For example, an initial period of slow growth in undeveloped areas is followed by a transition into a period of sharply accelerated growth characteristic in the development of large tracts. Next, the growth tapers off (fill-in development takes place) as smaller developers working on scattered parcels of land tend to predominate. Finally, a terminal condition is reached during which little or no growth occurs, and even some decline may be experienced. At some point during this latter period, land usage may change and a new growth cycle begin in the form of land clearance, rehabilitation, or conversion to higher-density residential or commercial use.

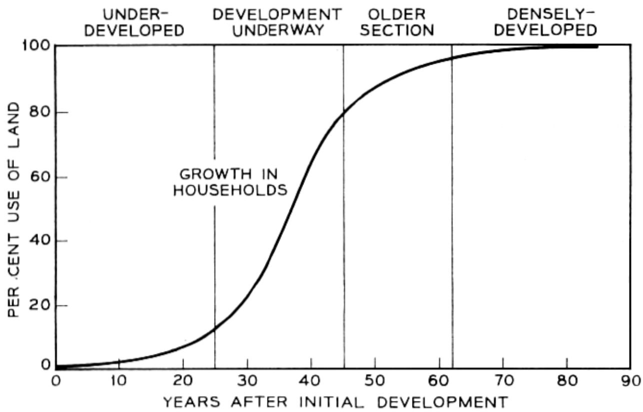

Fig. 16 — Urban land goes through a growth cycle.

The initial effort to improve forecasting was mainly directed toward capitalizing on the existence of these growth patterns. The technique proposed for growth prediction involved selection of a suitable mathematical expression which exhibits the same general "S" shape (so far the simple logistic function* has been used) and estimating the parameters of the function in a particular area from records of growth and the estimated level of the area's maximum development for the present growth cycle.

* Cumulative growth, $G = K/[1 + \exp(\alpha + \beta t)]$, of an area requires making estimates of the three parameters K, α, and β. K corresponds to the maximum development level of the area and can be estimated from knowledge of current and anticipated land usage. Values of the parameters α and β are estimated from the growth records by using the linear transformation, $\log_e[(K - G)/G] = \alpha + \beta t$. In this form a plot of cumulative growth as a function of time appears linear. The values of α and β can be derived by least square methods. This fitted function would then be used to predict future growth.

It should be pointed out that these procedures have proved most useful in growth areas having the following characteristics: boundaries which have remained relatively constant (or growth records which could be readily adjusted to reflect changes), availability of good historical information on households (or main telephones) and at least 20 per cent but not over 80 per cent of ultimate saturation realized. Realistic estimates of ultimate capacity based on sound business judgment and a careful analysis of basic assumptions and growth factors are of course the key to successful forecasts made by this method.

This technique, while of primary use in long-term projections, is also useful in medium- and short-term forecasting. For the latter a forecast may be derived by weighting current experience to reflect short-term trends and to place more emphasis on the more recent growth patterns. A computer program has been written which will allow the exponentially weighted forecast to be programmed along with the logistic function. This allows the weighting to be a function of the actual gain currently being experienced.

Work is planned on an important related factor: timing plant additions requiring a short-term forecast. Of necessity, short-term forecasts should project growth by months or quarters for at least the current year and preferably the following year. To accomplish this, a good short-term forecasting system must be sensitive to fine-grain fluctuations in demand around the long-term trend. However, the forecast cannot be made for an area and forgotten; adjustments are necessary from time to time to reflect new growth data and any changes that affect the saturation level.

As part of the short-term forecasting system, criteria need to be developed for determining whether actual growth falls reasonably close to expected demand, or whether deviations are large enough to warrant review of the forecast.

X. EXCHANGE AREA PLANNING — SUMMARY

A very important function of the engineer in the associated company is medium- and long-range planning of the exchange plant. He must allocate the company's resources in such a manner as to maintain a desirable relationship between cable network and central office equipment investments and also make future additions in each area as needed to meet service requests. To accomplish this task, the exchange feeder route analysis program, the exchange line multiplexing analysis program, the wire centering programs, and forecasting methods combined will aid the engineers and planners in establishing plans for exchange areas as well as in administering the exchange plant. With these tools the associated company will be better able to estimate current and medium-term construction programs including manpower, materials, and money.

XI. FUTURE WORK

The complete implementation of these new concepts in the Bell System will require extensive training, coordination, and the working out of difficulties that will arise in any program of this magnitude. The people involved will have accomplished an Herculean task if the adoption is complete by the early seventies. The future extending past 1970 is extremely difficult to predict, except that many worthwhile innovations employing more sophisticated engineering skills and programming techniques will probably be superimposed on the concepts discussed in this paper. This is particularly true of some of the analytical techniques used, as in this first application methods were selected to insure that theoretical difficulties would be held to a minimum.

Bell Laboratories can use these same computer techniques in assessing the longer-term requirements for new laboratory developments by extrapolation of the data used by the associated companies for their day-to-day planning. With this capability, systems engineering studies can be completed more quickly and yield results more accurately reflecting future development needs of the Bell System.

XII. ACKNOWLEDGMENTS

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