No. 180

The Institution of Post Office Electrical Engineers.

Subscribers' Cable Distribution

Some Further Considerations

F. SUMMERS, A.M.I.E.E.

A Paper read before the Harrogate Sub-Centre on the 10th February, 1944, and at other Centres during the Session.

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INTRODUCTION.

The Engineer-in-Chief's Lines Branch has, during the past few months, given close consideration to the problem of post-war subscribers' line plant provision. Special difficulties will undoubtedly arise as a result of the war, and these emphasize the need for considering changes in practice and the possibility of obtaining increased flexibility by the adoption of methods used in other telephone administrations.

1.1 Resume of position as at date of I.P.O.E.E. Printed Paper No. 170.

Early in 1939 a paper by the late Mr. L. Meek[1] dealt with the most recent developments in local line plant provision. The paper now presented is regarded as an extension to that paper and it is only necessary to mention a few of the most important features brought out therein in order to provide a basis for describing the further developments which have been investigated, and in particular how the various alternative methods of plant provision described fit in with assumed post-war conditions. In Paper No. 170, which was based on the findings of the Subscribers' Distribution Committee, reference was made to the comparatively high proportion of capital invested in line plant in relation to the total capital values of all telephone plant, the figure quoted being 76% of the total, which included junction and trunk lines, plus repeaters. 40% of the total capital is invested in the subscribers' line plant alone.

In discussing the question of telephone forecasts, attention was drawn to the well-known fact that forecast accuracy is greatest when dealing with the bulk figures applicable to a whole exchange area and diminishes as that area is divided into cable areas and D.P. areas. Considerable emphasis was given to the need for plant provision methods to furnish the utmost flexibility in the local line network to meet the inaccuracies which were bound to result when dealing with such small units of telephone development as are given by D.P. areas.

In 1939 the periods for which subscribers' cables were provided had recently been changed to eight years for main cable plant and 20 years for distribution plant, as these periods appeared to give the most suitable ratio between the two portions of the cable layout to enable the requisite flexibility to be provided.

The paper also gave a description of two methods, adopted in other countries, which expressly aimed at giving a high degree of flexibility in the cable network, one of these methods being that adopted in Scandinavia which relies on the use of cross-connexion frames and cabinets, the other method being that used in the U.S.A. and many other countries, which relies on systematic multipling of the cable pairs. The conclusion arrived at by the author regarding the merits of these two methods as compared with the Post Office system of flexibility by means of teeing and auxiliary joints, was that the multipling method adopted by the American systems seemed to afford the greatest advantage.

Some consideration was also given to the problem of providing economically direct underground distribution as an alternative to overhead D.P.s where new estate development was concerned, and a description of the Australian pillar for providing the necessary flexibility and disconnexion facilities was given together with the proposed method of simplifying local treatment of each case so that the time normally required to compile development details and cost comparisons together with legal formalities could be considerably curtailed.

The outbreak of war in 1939 naturally prevented the somewhat indeterminate conclusions reached at that date being further dealt with, but, prior to that, two areas had been selected for a physical trial of the American method. The results of this trial could not of course be dealt with at that time, but reports now received comment favourably on the scheme. In particular it is mentioned that the necessary records present no difficulty and that no maintenance trouble has arisen.

2. EFFECT OF THE WAR.

2.1 Stagnation of plant provision during the war.

In considering the effect of the war on post-war local line plant provision, it has to be borne in mind that during the war years very little plant has been laid which is likely to be of service for normal development requirements. A fair amount of plant has of course been provided for war purposes (see Fig. 1),

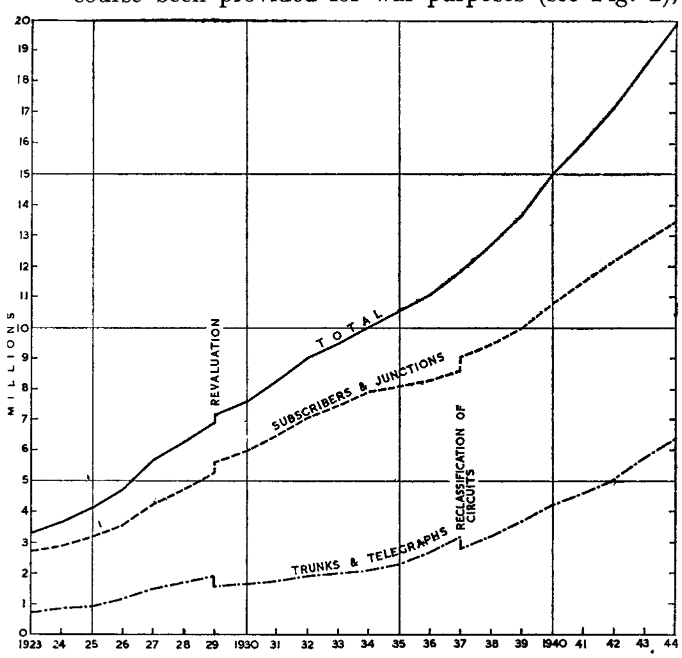

FIG. 1.—UNDERGROUND PLANT WIRE MILEAGES.

(1) See Bibliography.

but inquiry has shown that such of it as will be freed when the war is over will either be unsuitably located for normal development needs or will be of use for junction purposes only. Fig. **2** shows the C.L. expenditure over the past 20 years, and it will be seen that the peak expenditure during 1925 and 1939 of over four millions fell during the war years to an average of three-quarters of a million. Although the reduction in the rate of connexion of new lines has been very material during the war years (see Fig. **3**), it is clear that the expenditure in line plant has fallen substantially below the amount necessary to meet even the reduced demands, and a considerable lee-way in such expenditure must be made good if the line plant is to be brought up to the same adequacy as in pre-war years. The effect of this reduction in line plant provision has had a marked bearing on the utilization of D.P. spares, as shown by Fig. **4**.

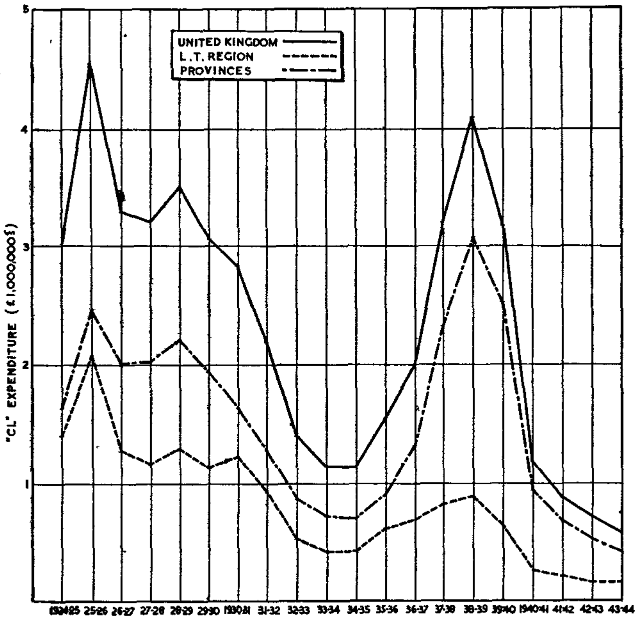

FIG. 2.—ANNUAL 'CL' EXPENDITURE, 1924-44.

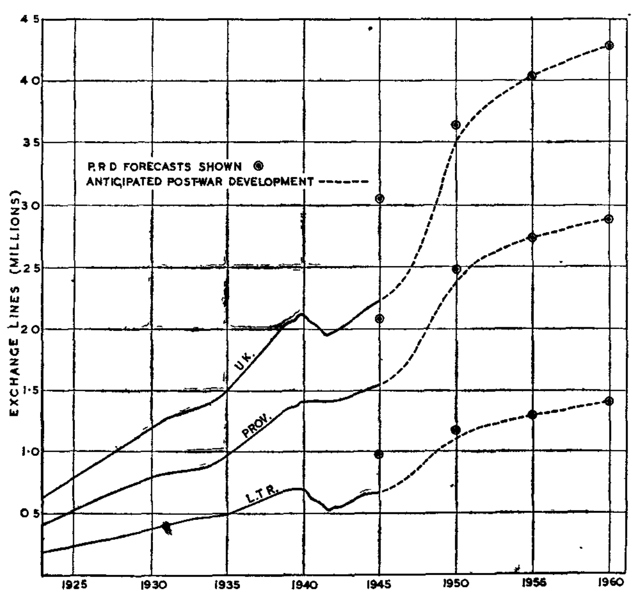

FIG. 3.—VARIATION IN TELEPHONE DEVELOPMENT.

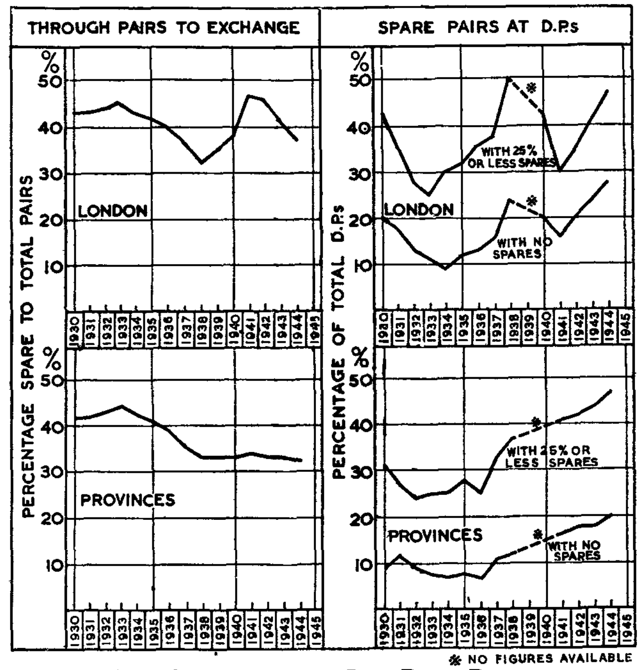

FIG. 4.—VARIATION IN LINE PLANT POSITION.

2.2 Provision of flexibility during pre-war years.

Many capable engineers(2) have studied the problem of flexibility and economic design of subscribers' cables and at about 1930 methods of providing flexibility in the local line plant network were introduced, either by adopting some form of systematic teeing or by the provision of auxiliary joints. Generally the use of teeing was found, except in certain areas, to give rise to difficulties of maintenance, with a result that flexibility by teeing was not being provided in the Post Office system to the extent contemplated. The mechanical type of auxiliary joint overcame some of the difficulties encountered with auxiliary joints, and the introduction of flexibility by this method became increasingly popular. The curtailment of plant provision during the war has meant that a large proportion of the flexibility provision which would undoubtedly have been made during the past four or five years had to be suspended. This lack of flexibility has given rise to serious difficulties during the war years in meeting the demands for essential circuits and has involved an appreciable cost in uneconomical rearrangements of line plant. A recent review of all exchanges of 2000 lines and over throughout the country has shown that only about 20% of the necessary flexibility which should have been provided to give full flexibility over the whole network has actually been installed.

(2) See Bibliography.

3 POST-WAR PROBLEMS.

3.1 Post-war development, and anticipated post-war changes.

In the immediate pre-war years a complete re-forecast had been completed by the Public Relations Department, and it was hoped that this forecast would provide a reasonably accurate basis on which the extensive plant provision of succeeding years could be made. Fig. 3 shows the results obtained by the study referred to, and it will be seen that it is expected that on the assumption that the European war will terminate about 1945, the original forecast will be reached by about 1950. It may be regarded as somewhat problematic whether the marked diminution in the rate of growth beyond 1950 given by the forecast will be experienced, or whether a much greater increase will be realized due to changes in post-war conditions tending to popularize the telephone service —either by a change in the telephone habits of the general public or by improvements in plant design and methods—which would enable existing tariffs to be reduced, thus giving a higher telephone penetration. (In this connexion the present forecast for 1950, which is based on the assumption that there will be no reduction in rentals, is equivalent to a penetration of 10.9 stations per 100 population, whereas in the U.S.A., in 1941, the penetration was 17.9 stations per 100 population.) However that may be, it is clear that there will be some danger in providing extensive plant on these forecasts without review by the Public Relations Department, and particularly so when the very material changes likely to be introduced by post-war reconstruction are considered. Apart from the reconstruction necessitated by the fairly extensive war damage throughout the country, there are the changes envisaged in the Barlow, Uthwatt and Scott reports, each of which makes it clear that the Line Plant Planning Engineers will have a very difficult problem to face for some years to come. The activities of the various local authorities in post-war reconstruction mean that many, if not all, existing " block survey " studies, especially in the larger cities, will require extensive revision and it may well be that these uncertainties will give prominence to the merits of any method of plant provision which enables the minimum initial plant to be laid.

3.2 Average line costs, and effect on tariffs.

A most important feature in the approach to the problem of post-war line plant provision is the question of the cost of an average line, this being the basis of tariff charges. An investigation into the subject made recently revealed that of the average total annual cost of a direct exchange line (comprising instrument, line plant and proportion of exchange apparatus and including all relative maintenance, and indirect charges), the line plant alone accounted for 57% in London and 69% in the Provinces. This investigation also showed that quite considerable items of the line plant expenditure were spare wire margin on the one hand, and rearrangement costs on the other. A typical make-up of these proportionate costs, expressed as a percentage of the total, is given in Fig. 5. These proportions would obviously vary with the method of plant provision, *e.g.*, if the whole of the existing network were converted to one which eliminated rearrangement costs, a greater margin of spare wire could be permitted without affecting the total annual cost of the line.

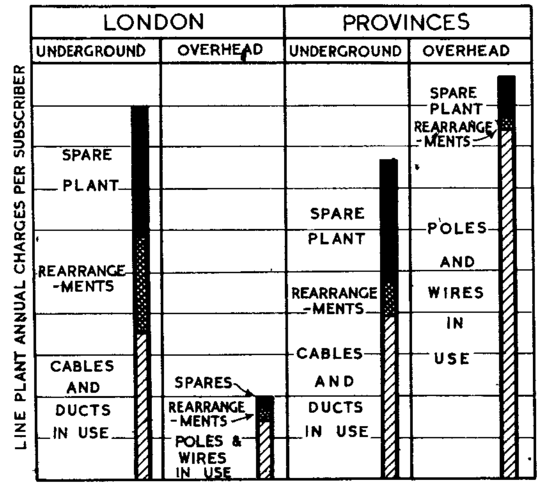

FIG. 5.—LINE PLANT COSTS.

At first sight the proportionate cost represented by the spare wire margin may appear high, but it has to be borne in mind that normal economy in plant provision necessitates the inclusion of an appreciable amount of spare wire in the cable network in order that cables be laid on an economic planning basis. Apart from this, however, it is possible by closer attention to the constructional features of line plant to limit the proportion of spare wire which is of a non-revenue-earning character. Examination of typical line plant throughout the country shows that a much higher proportion of what is termed " dead wire " exists than there should be and, in arriving at the average proportion of spare wire margin in relation to an exchange line, it has been necessary to consider not only the amount of spare wire available between the exchange and the D.P.s which can be used for the immediate connexion of new services, but the amount of spare wire which is not terminated at the exchange and may indeed be completely lost by the jointing conditions along the cable network. Inquiry has shown that the proportion of this unusable spare wire is between 20 and 30% of the total wire mileage; some of this is of course readily available where auxiliary joints had been provided in the network. It is clear, therefore, that one of the aims in new plant design should be to limit the provision of unusable spare wire to the minimum. Typical conditions which have given rise to unusable spare wire are shown in Fig. 6.

3.3 Spare-wire margin, and effect on rearrangement costs.

With a completely flexible cable network, rearrangements of individual pairs would logically be reduced to the lowest practicable limit, and probably the most important aim of any new method of plant provision should be to eliminate such costs. Rearrangements

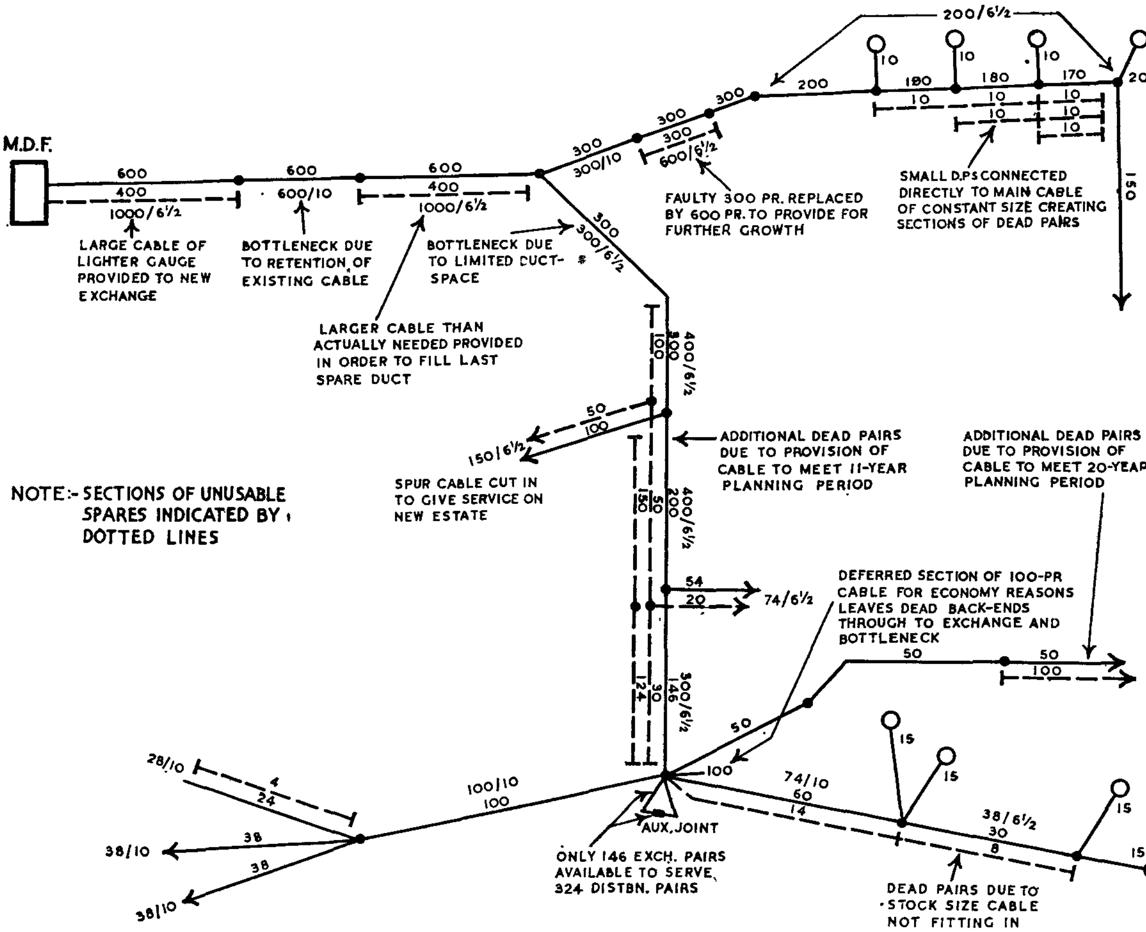

FIG. 6.—TYPICAL REPRESENTATION OF LOCAL LINE PLANT LAYOUTS.

of line plant increase the fault liability of the plant affected and add nothing to its capital value. On the other hand, rearrangements cannot be avoided unless a high margin of spare wire is provided in the right place, and there is undoubtedly an economic balance between spare wire provision and rearrangement cost liability which must be determined when considering new methods. The present cost of line plant rearrangements is not representative of the latest Post Office practice, in view of the fact that such a large proportion of the line plant has no flexibility provision. The proportionate cost of rearrangements shown in Fig. 5 should, therefore, be regarded as a maximum, as it is assumed that future plant provision will entail less rearrangement cost. It is not true, however, to assume that rearrangements will disappear with any new method featuring the fullest flexibility, as it is well known that there are certain unavoidable causes of rearrangements such as road and building improvements, wayleave difficulties, exchange transfers, relief of congested routes and jointing chambers. Then again, the marrying-up of new plant provision with existing cables in order to avoid uneconomic withdrawal or abandonment of existing plant, involves rearrangement costs which cannot be eliminated.

Summing up the problem of local line plant provision in relation to the special difficulties visualised in the post-war period, it is clear that the method which meets requirements should be one which provide for (*a*) the minimum initial capital outlay without entailing uneconomic plant provision, the minimum rearrangement liability, and the minimum fault liability, together with (*b*) maximum flexibility, maximum speed of new installation provision, and maximum facilities for augmenting the plant in a simple manner.

Close attention has been given recently to these requirements with the object of ascertaining if the existing Post Office practice can be improved to meet all or any of these requirements, or alternatively whether drastic changes in plant provision methods should be introduced when dealing with the heavy programme of post-war plant provision.

4. FURTHER CONSIDERATIONS OF VARIOUS SYSTEMS IN RELATION TO POST-WAR REQUIREMENTS.

4.1 The Post Office Scheme—its limitations and the need for spare wire.

The Post Office system of plant provision relies on " tapered " cable to limit the amount of spare wire by relating it as closely as possible to the development forecast to be covered in the cable sections concerned, fluctuations within reasonable limits between the rates of growth at the individual D.P.s being covered by the provision of flexibility measures at key points in the local line network. Discretionary powers were vested in the local line planning officers as to the choice between teeing or the use of auxiliary joints to provide this flexibility. The Post Office method of teeing is, however, fundamentally different from the multiple teeing method used in the American system and, as already stated, the comparatively few cases in which this method of flexibility has been resorted to have shown certain disadvantages tending to make it somewhat unpopular. In spite of the marked improvement given by these flexibility measures as compared with the previous practice, it is clear that the Post Office system does not meet requirements, and particularly will not fulfil the more stringent demands of post-war conditions. The flexibility of the system is limited to the areas served by each auxiliary joint or teed joint and, unless special arrangements are made, there are no means of meeting unexpected development in one flexibility area by utilizing unwanted spare pairs in another flexibility area. The system also does not meet a material unexpected growth in the areas served by particular D.P.s and it does not cater for wide variations in development on individual branch cables within any one flexibility area. The most serious disadvantage, however, is the extensive rearrangement involved when the time comes to augment the main cable provision to any particular flexibility area. It is usually found that new main cable provision necessitates fairly extensive rearrangement of the branch cable pairs, and, in many cases, the modification of the branch cable area, involving a considerable amount of time in the requisite surveys and estimates.

The extent of flexibility in the Post Office system is normally limited to a proportion of the main cable capacity, of the order of 25 to 30%. Experience has indicated that this is an inadequate proportion, and the fact that 70 to 75% of the main cable pairs have to be connected directly to D.P.s means that a fairly low efficiency factor has to be accepted for the main cable system, the figure at present worked to being 80%, *i.e.*, a cable is regarded as for all practical purposes fully utilized when 80% of the pairs are in use, the remainder being regarded as the necessary margin to allow for unusable pairs and to give the requisite time for the preparation of relief schemes and for the necessary construction work. It has, however, been found to be extremely difficult, if not impossible, to attain this efficiency in practice. With increased flexibility and particularly with increased simplification of new plant provision, a higher efficiency factor could be obtained.

4.2 Ericsson or Cabinet System.

In considering alternative methods which claim to have those special features which are particularly suitable for post-war requirements, a fresh review has been made of the methods described in Paper No. 170. The new approach to this problem revealed such striking advantages in the Ericsson system that it was thought undesirable to dismiss without further consideration the use of cross-connexion frames and cabinets on the score of possible maintenance and wayleave difficulties. A striking feature of this system is the separation of the main and branch cable networks, so that the two networks can be built up quite independently. The advantage of the greater flexibility obtained by the use of cross-connexion frames is a particularly real one when considering the undoubted fluctuations in development which will occur in post-war years. Another feature of the Ericsson system to which further attention has been directed is the comparatively short-term cable provision which this system provides for. It is possible under this system to provide—quite economically—main cables which, in many cases, may only serve for two or three years, and such a feature is of considerable importance in connexion with the many exchanges which, pending reconstruction and transfer, have a limited capacity. There is also the fact that, so far as the branch cable network is concerned, it is possible to provide economically for a much shorter period than is necessary in the Post Office system, and, bearing in mind the probable unreliability of long-term post-war forecasts, it is obviously desirable to limit cable provision until firm figures can be made available. A further advantage of the cabinet system is the facility with which miscellaneous circuits such as private circuits and external extensions can be provided with minimum wire mileage and transmission difficulty. In the normal Post Office system it is usually necessary to bring such circuits in and out of the exchange main frame, although here and there it is possible to use the " auxiliary joint " flexibility for the purpose.

A potential disadvantage of cross-connexion cabinets is the possibility of low insulation, and the adoption of a distribution scheme involving the use of such cabinets would undoubtedly necessitate careful consideration of the problem of maintaining the requisite insulation.

There is no doubt that in view of the growing objection to overground structures on public thoroughfares, the use of a cross-connexion cabinet (which would constitute an additional obstruction) would not ease the situation, and it may be necessary under post-war conditions to strengthen the Department's attitude—and possibly its powers—if it is decided to introduce cabinets.

Other adverse features of the cabinet system which would have to be carefully considered are:—

(*a*) The undesirability of introducing a jumper field for the fairly high proportion of circuits which in the average network may remain stable for a long period.

(*b*) The difficulty of preventing access to the cabinets for other than essential purposes.

(*c*) The ease with which records might be disturbed as the result of circuit diversions by the construction and maintenance force at the cabinets; this could, however, be dealt with by record control organization.

(*d*) Experience with the Post Office terminal block shows that there is a tendency for the screws to be displaced, inefficiently replaced, and even lost; the possibility of corrosion is also introduced.

Nevertheless, the system has such marked advantages that it may be necessary to accept certain initial weaknesses and to endeavour to minimise the latter by improvements in design, etc.

4.3 The American Multipling System.

This scheme, fully described in Paper No. 170, constitutes a radical change from both the normal Post Office and the Ericsson systems. The problem of " mushroom " growth in the telephone service has constantly been much greater in America than in Europe. Building construction is much more rapid and the fluctuations in demands for telephone service are considerably greater. It is for these reasons that the American administrations regard flexibility in plant provision as being of over-riding importance. In addition, the use of party lines has been developed to a very great extent. The multipling arrangement provided for in the American system, not only gives the utmost flexibility but enables party lines to be provided readily without making use of cable pairs in and out of the exchange. Another important feature of the American system, which cannot be covered by the normal " tapering " cable system, is the ease with which large blocks of an exchange area can be transferred with minimum rearrangement to feed in a new direction to another exchange, or via another main cable route to the same exchange for relief purposes, or in connexion with the opening of a new exchange to relieve congested equipment. Such transfers as these are likely to occur fairly frequently under post-war conditions.

It is assumed that the principles of the American multipling scheme are to some extent known by Post Office engineers, and it is only necessary to emphasize the ease with which additions can be made to the network once the initial plant provision has been made, as the fundamental plan incorporates particulars of the points in the cable network at which relief cables should be terminated. In other words, the great attention paid at the outset to the first instalment of cable in a development scheme enables all future additions to be made in the form of independent small relief measures rather than the normal Post Office process of comprehensive re-development, and this has decided advantages in obtaining an even flow of plant provision which can be closely related to the construction force available year by year.

The provision of flexibility by means of multipled joints, which once made never require to be opened during the service life of the cable concerned, is undoubtedly an attractive feature, access to manholes containing these joints being unnecessary except where mechanical breakdown is experienced. New services are provided mainly through office organization, and usually are effected by the simple connexion of a service lead into the pole terminal block concerned. The employment of jointers for ordinary installation work is thus rendered largely unnecessary.

The use of multipling enables cable planning periods to be made as short as is economically possible. In the branch and distribution network, relief can be provided with such simplicity that rearrangements involve the minimum cost, and the adoption of a policy of providing the cables in two or more stages at intervals of years, instead of the normal Post Office practice of providing these cables for the ultimate requirements at the outset, is practicable. As regards the main cable network, the multipling enables the same advantage to be obtained as has already been referred to in connexion with the Ericsson system, *i.e.*, a main cable filling a duct can be laid even although the cable pairs provide for two or three years only. This is because relief can be obtained in the same simple way by a straightforward cut-over to a second cable laid when required.

There are, however, certain disadvantages in the system which require close consideration, namely:—

(*a*) The multipling involves additional attenuation at the higher speech frequencies essential for good articulation, see Fig. **7**. It also involves an increase in cross-talk and, consequently, a lowering of the signal-to-noise ratio.

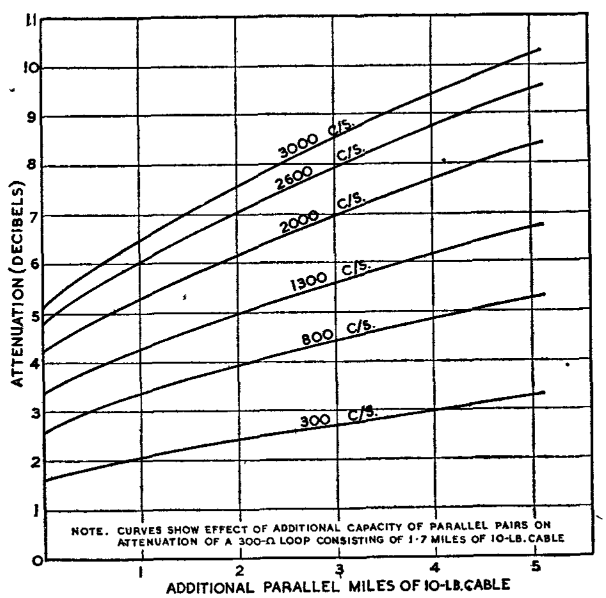

FIG. 7.—EFFECT OF MULTIPLING ON TRANSMISSION LOSSES.

(*b*) Cable breakdowns might involve the interruption of service to a greater number of subscribers than would be the case in a non-multiple arrangement.

(*c*) The appearance of the same main cable pair at several D.P.s may result in insulation difficulties, although this could be overcome by improved design of D.P. termination.

(*d*) With the growing use of direct underground distribution service in this country, it will be necessary to provide some means of breaking the electrical continuity of direct underground subscribers' circuits. This could readily be effected by the use of a form of Australian pillar.

(*e*) The present practice of leaving ceased lines on overhead D.P.s still connected through the D.P. terminal block to the exchange will require to be changed, making it necessary for a visit to the D.P. concerned to disconnect the circuit at the block.

(*f*) The use of multipling necessitates group colour scheme cables in order that jointing complications may be avoided. This involves consideration of either adopting the American type of twin cable having group colours, or introducing a group colour scheme in star-quad cable manufacture. This point is referred to in more detail in the section dealing with cable provision economics.

5. LINE PLANT PLANNING PERIODS.

It has already been mentioned that the present cable-planning periods used in Post Office practice are eight years for main cable provision and 20 years for distribution cable provision, flexibility measures being introduced at the junction of the main and distribution cables. Standing instructions on the matter specifically refer to the fact that these planning periods are average ones only and must be used with full knowledge of the basis on which the periods were arrived at, and particularly that jointing simplicity should not be sacrificed by a too rigid application of the periods. Reference has also been made to the fact that the Post Office planning periods allow for the cost of rearrangements involved when cables are added to the network from time to time, and an indication has been given that the planning periods might be materially effected by a reduction in such rearrangement costs. In considering cable-planning periods in relation to post-war conditions, it has been necessary to deal with a further factor which has an important bearing on economic cable provision, namely, a variation in prime costs of material and labour. The first post-war years will involve cable provision at a time when these costs are at a high level, but it is reasonable to assume that, in course of time, costs will become lower and it is obviously uneconomical to provide at a high cost level when a proportion of the plant provision could be deferred to a period when costs are appreciably lower.

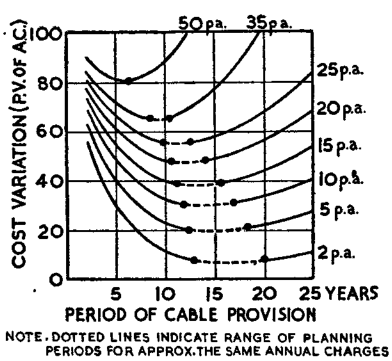

FIG. 8.—VARIATION OF PLANNING PERIODS WITH RATE OF GROWTH.

Fig. 8 shows the fundamental calculations on which the present planning periods have been based and indicates clearly how necessary it is to regard the 8- and 20-year periods as a guide only; *e.g.*, in the case of the smaller-size cables, which represent a large proportion of the distribution network, there is very little difference in the P.V.A.C. cost if the plant is provided a few years under or over the 20-year period.

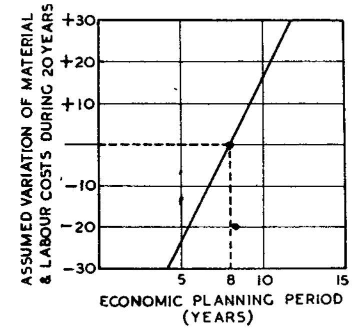

FIG. 9.—VARIATION OF PLANNING PERIOD WITH COST VARIATION.

Fig. 9 illustrates approximately how the economic planning periods would vary if the prime costs of future instalments of plant were lower or higher than at present. It illustrates the variation for a particular case. A series of calculations is being made to cover other conditions in order that the possibilities of reduced planning periods, with the consequent advantages, can be determined.

In connexion with the problem of economic cable provision, it has been necessary to review the relative advantages of various types of cable and to reconsider the basis on which the quad type of cable for subscribers' purposes was introduced a few years before the war. The change-over to quad from twin-type cable was largely influenced by the greater number of pairs which could be accommodated in a given diameter of lead sheath and by the more even electrical characteristics. The cost of manufacture was also appreciably lower. On the other hand there is no doubt that the quad-type cable is more costly from the point of view of jointing in the field and also when dealing with joint openings for rearrangement

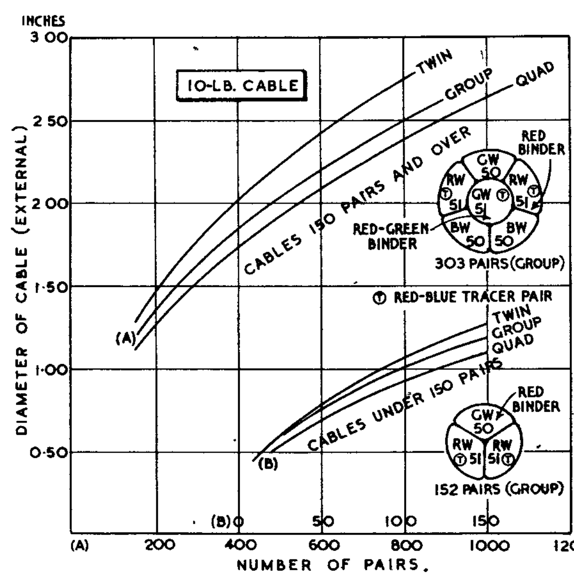

FIG. 10.—COMPARATIVE DIAMETERS OF TWIN, STAR QUAD AND AMERICAN GROUP PAIR CABLES.

or maintenance purposes. The American type of group colour cable gives less pairs than the quad type for a given sheath diameter; the cables are, however, more flexible and thus provide greater ease in handling and drawing-in to conduits, whilst the separation of the cable pairs into 100-pair or 50-pair blocks respectively under a group colour scheme enables a marked improvement in jointing costs to be obtained. Fig. **10** shows a typical cross-section of the American group colour cable, and also the variation in diameters between the Post Office twin, quad, and American cables. For cables of 400 pairs and over, the construction is similar, but each group contains 100 pairs.

6. LOCAL LINE TRANSMISSION AND SIGNALLING.

A paper on subscribers' cable distribution would, it is thought, be incomplete without a reference to transmission and signalling, since these factors are inseparably linked with the economic provision of plant.

6.1 Local Line Transmission.

The general basis adopted in this country for Telephone Transmission over lines is detailed in I.P.O.E.E. Printed Paper No. 153[3], in which the authors described the measures being taken to ensure high-grade transmission over the trunk network of this country. Considerable differences in the performance of subscribers' lines and junctions tend to nullify somewhat the useful work done on the trunk network, and suggestions are given in this paper which would result in correspondingly important improvements in subscribers' and junction lines.

6.1.1 *Subscribers' Lines.*

The present method of design of subscribers' cable networks—on a " volume efficiency " basis—assumes that standard transmission is obtained on cable circuits of various conductor weights having the same over-all resistance. It has been realized for some considerable time that cable capacity causes additional losses on the higher frequencies necessary for good articulation, and to some extent this has been compensated for in the design of instruments.

The subject of transmission over lines has received a considerable amount of investigation in the United States of America, as a result of which a change-over to an " effective transmission " basis has been made. The Post Office Research Branch has in recent years given close consideration to this problem also. No matter from what angle the subject is viewed, the criterion of good transmission is the assurance that the transmitted speech will be reproduced as faithfully as possible, and the purpose of " effective transmission " data is to give a means of calculating from the physical details of a complete circuit, *i.e.*, line, instrument and exchange, the " effectiveness " of the transmission between individual subscribers. Thus two complete circuits have the same " effective transmission " when, under the same conditions of use, they give the same grade of service as indicated by the " repetition rate," the basis accepted by the C.C.I.F. as the best at present available for assessing " effective transmission," losses being expressed in decibels in the same way as on a " volume efficiency " basis. The " effective transmission " basis takes account not only of the volume, but also the other controlling variables, *e.g.*, sidetone, distortion, and noise. The effective transmission loss of a 20-lb. cable loop is considerably higher than that of a loop of the same resistance of 10-lb. cable, due to the frequency distortion resulting from increased capacity. Table I gives the results of a large range of tests made by the Research Branch on typical circuits[4]. It shows primarily how rapidly the permissible loop resistance falls with increase in conductor gauge, and how on an " effective transmission " basis, economy in cable provision is possible since, in general, longer lengths of smaller-gauge cables can be used as compared with present practice. Conversely and contrary to current practice, considerably lower loop resistances are permissible with the heavier-gauge conductors. Table I shows also how with the older types of instruments, *e.g.*, Tele. No. 150, the maximum permissible mileage of cable, to give the same transmission on an "effective" basis, is approximately the same irrespective of gauge of conductor or type of exchange. On the other hand, the more modern instruments permit relatively-high loop resistances, and if the associated exchange-signalling problems can be solved it would be possible to give standard transmission to a large proportion of subscribers with 6½-lb. cable. Fig. **11** shows the comparisons between the " effective transmission " basis and the " volume efficiency " basis for typical subscribers' loops; the diagram shows some interesting comparisons. It will be seen that on a " volume efficiency " basis the 50-volt ballast-resistor exchange gives a decided improvement and approximately the same transmission level at 600 ohms as the 22-volt exchange with 300 ohms. On an " effective transmission " basis both the sending and receiving allowances are considerably worse than on a " volume " basis. Thus on an " effective " basis the ballast-resistor exchange does not give the improvement for which it was designed. The curves in Fig. **11** are for a Tele. No. 162, but better results are obtainable with more modern instruments as revealed in Table I.

The American administrations not only make use of various types of subscribers' telephone instruments designed to work over high resistances and incorporating facilities to overcome the associated signalling difficulty, but are apparently satisfied that the coil loading of long subscribers' lines is practical and economical.

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[3] [4] See Bibliography.

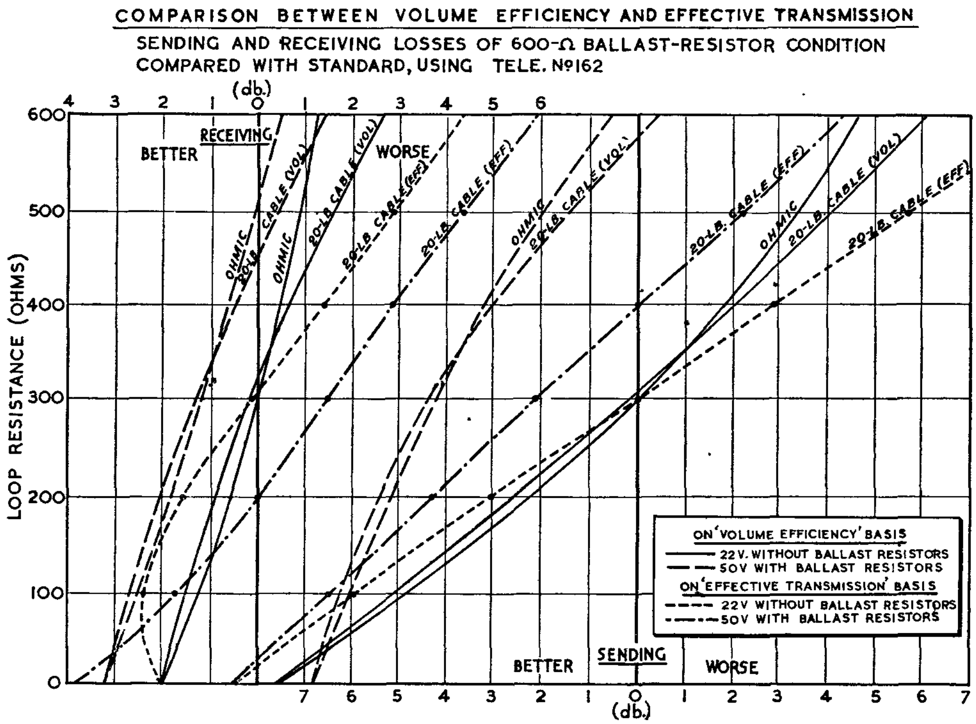
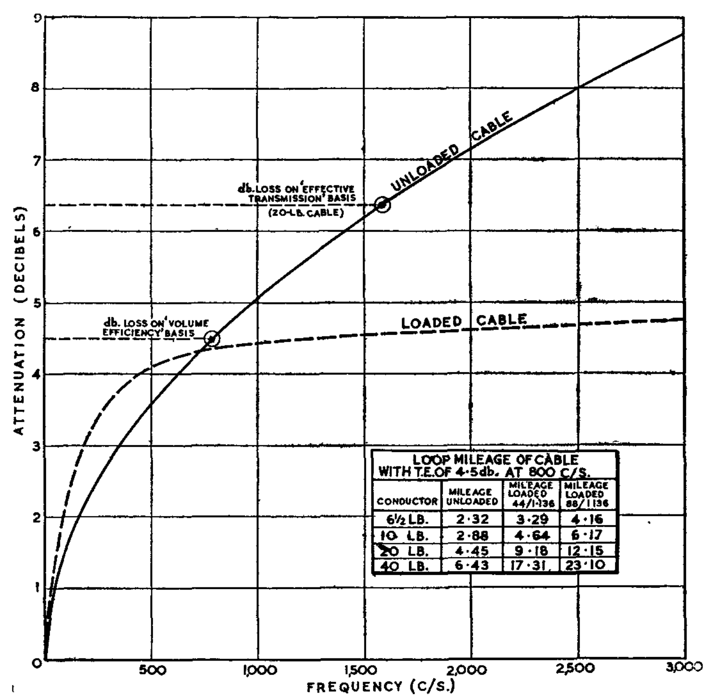


Fig. 11.—Local Line Sending and Receiving Allowances.

Further economies in subscribers' line plant are obtained in the U.S.A. by allotting to each exchange a maximum permissible local line loss (sending plus receiving), depending on its relation to the Group Centre exchange. Thus a main exchange situated at a group centre would be accorded a higher " local loss " rating than would (say) a minor or dependent exchange, and lighter-gauge conductors would be used for the subscribers' lines.

6.1.2 *Junction Lines.*

The C.C.I.F. has recognised the importance of the higher speech frequencies for good articulation, and the upper limit of frequencies to be transmitted on international calls has been raised to 3,400 c/s. It may be desirable, therefore, in the author's view to reconsider the basis on which short junction cables are provided at present, *i.e.*, by unloaded cables up to 40-lb. gauge. The transmission losses at various speech frequencies on an unloaded cable of 4.5 db. loss (at 800 c/s.) are given in Fig. **12**. It will be seen that considerable improvement in articulation efficiency would result from the use of lighter-gauge loaded conductors. Support is given to the foregoing suggestion when the performance of unloaded junction cables is viewed from an " effective transmission " basis. It may be taken that, on this basis, the calculated attenuation of 20-lb. cable at 1,600 c/s. would serve for practical purposes in the same way as the attenuation at 800 c/s. now used for volume efficiency. Nevertheless for 10-lb. cable, the above figure is reduced to about 1,200 c/s., whilst for 40-lb. cable a frequency of 1,850 c/s. is approximately correct for the assessment of effective transmission loss.



LOOP MILEAGE OF CABLE WITH T.E. OF 4·5db. AT 800 C/S.			
CONDUCTOR	MILEAGE UNLOADED	MILEAGE LOADED 44/1·136	MILEAGE LOADED 88/1·136
6½ LB.	2·32	3·29	4·16
10 LB.	2·88	4·64	6·17
20 LB.	4·45	9·18	12·15
40 LB.	6·43	17·31	23·10

Fig. 12.—Transmission Losses on Cable at various Frequencies.

6.1.3 *Relation between Transmission and Economic Design.*

It is difficult to dissociate the problem of local line transmission from that of new methods of line plant provision such as are discussed in the present paper. The additional attenuation losses introduced by teeing for flexibility purposes, the simplification in cable layout design and construction by the avoidance of mixed gauges of conductors, the need for overcoming the practical difficulties in the provision of external extensions, and the high cost of ductwork, all point to the need for obtaining the fullest advantage of any new basis of transmission standard which allows for an increase in local line resistance limits or reduced conductor gauges.

6.2 Local Line Signalling.

Reference has been made in the foregoing to expedients which permit signalling over high-resistance exchange lines, but it may be desirable to mention two facilities which, with the present methods of provision, cannot be catered for economically in subscribers' local line layouts.

6.2.1 *External Extensions.*

These circuits cause considerable trouble both as regards signalling and transmission, and very often the amount of plant used is grossly out of proportion to the revenue earned. For instance, it is possible that an external extension of small radial distance must be routed via the exchange on account of the plant layout. On normal one-pair circuits the permissible resistance for signalling is probably exceeded, so to reduce this figure two cable-pairs are " bunched " on one or more sections of route. This results in degradation of transmission[5], and a layout which is costly both to provide and to maintain. It is suggested that the provision of extension facilities should be based on economic considerations.

6.2.2 *Private Branch Exchanges.*

These form a considerable source of trouble and expenditure on account of the condition at present applicable to all extensions, *i.e.*, that the extension must be able to obtain, when connected to the exchange, full exchange-line facilities. Under these conditions the over-all resistance from the most distant extension to the exchange must not exceed the maximum permissible loop resistance. This condition often involves transmission difficulties, as in the case of External Extensions. To overcome these difficulties it is the author's view that P.B.X.s should be redesigned on the same basis as public exchanges, *i.e.*, to provide, at the P.B.X.,

(*a*) power for speaking and signalling,
(*b*) full control of all exchange calls.

Some slight transmission loss on receiving would result from the introduction of an additional transmission bridge, but there would, however, be an improvement on sending. In those cases where it was previously found necessary to resort to " bunching," to keep the line resistance within specified limits, the foregoing modifications would obviate the need for " bunched " conductors, with a consequent improvement in transmission.

(5) See Bibliography.

7. SUGGESTED POST-WAR DESIGN OF LINE PLANT NETWORKS.

In the report of the Subscribers' Distribution Committee issued shortly before the war, it was made clear that finality on the selection of the most suitable method for future application could be reached only after considerable further investigation, taking into account the results of the trial schemes already referred to. The further consideration which has been given to the problem at Headquarters during the past few months appears to indicate the desirability, not so much of adopting one or another of the various methods, as of employing a combination which would utilise the best features of each. The matter is still under review, but the indications are that a very profitable course of inquiry would be towards the development of a system which employs multiple teeing and cross-connexion frames and Australian pillars, the Australian pillars being used in the distribution network in order that 50 pairs (say five 10-pair D.P.s) may be grouped together to form one large D.P. for flexibility purposes, the small distribution cables connected to each pillar being provided on the most liberal basis although not necessarily all laid at the outset. The branch cables connected to each pillar would be multipled as in the American system in such a way that provision would only be required for, say, 10 years with a reinforcement cable at the relief period. Six or eight of these pillars would be grouped on each branch cable and, at the junction between the branch cable and the main cable, a cross-connexion cabinet would be placed, the capacity of which would provide for the ultimate requirements of the branch cable area. The main cable feed to each cabinet area would also be provided on the American system of multipling on the assumption that relief might be required at more frequent intervals, thus effecting the major economies in the main cable and duct track. Probably it would be desirable with such a scheme to arrange for a block of main cable pairs to be provided on a non-teed basis to each cabinet, and perhaps a similar block of a smaller number of pairs to each pillar. Advantages would be gained in fault location and in providing for miscellaneous circuits. A scheme of this kind has decided merits, but much further thought will have to be given to the problem before a conclusion can be arrived at.

Consideration which has been given by the Construction Branch of the Engineer-in-Chief's Office to the difficulties in the use of cross-connexion frames, has led to the development of an airtight cabinet, inside which are fitted metal pockets containing silica gel. A novel terminal assembly permits a large proportion of the circuits to be joined through by means of short bare wires, while insulation on the necessary jumpers is maintained by utilising wire covered with polyvinyl chloride. The theoretical study of conditions of humidity likely to be experienced in this country, reveals that insulation difficulties may not be experienced in practice with a cabinet of the above design, but trials are being made in selected localities to gain further information.

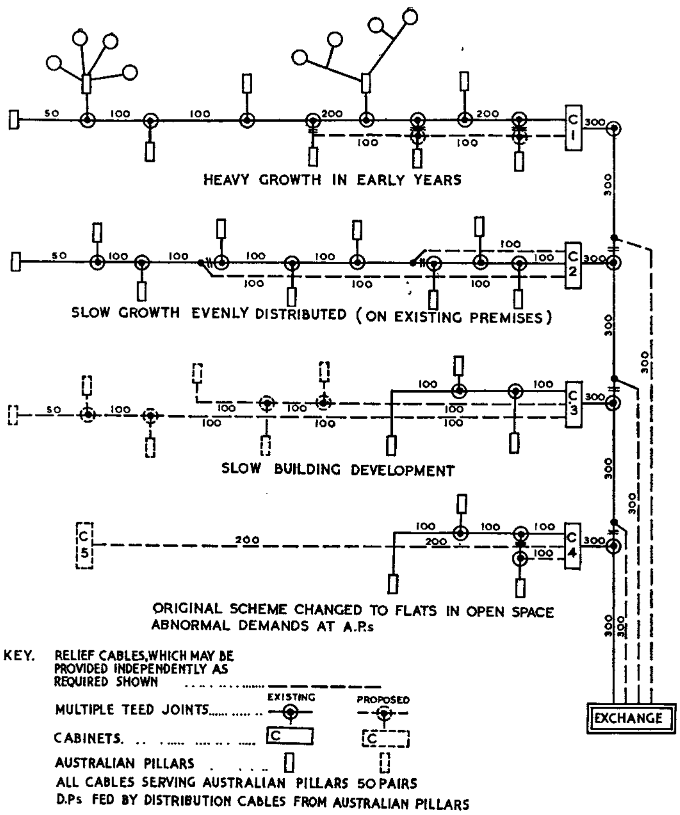


FIG. 13.—SUGGESTED POST-WAR LINE PLANT LAYOUT.

It has been borne in mind that, having regard to post-war conditions, the essential features of an efficient new method of subscribers' line plant provision can be summarized as follows:—

(*a*) Reduction in the number of stock sizes of cables, in order to effect economies in manufacture and in construction;

(*b*) The utmost flexibility that can be secured, not only between individual D.P.s but between individual branch cables and individual branch cable areas;

(*c*) Simplicity in periodic augmentation rearrangements;

(*d*) Simplicity in records, and facilities for controlling the possible influence on records by maintenance and construction field force;

(*e*) The employment of special types of cable to enable construction and jointing economies to be fully obtained;

(*f*) Facilities for transferring blocks of territory bodily to new exchanges involving reversal of feed;

(*g*) Economies in conduit and jointing chamber provision by eliminating unnecessary jointing points and enabling duct provision to be co-ordinated with post-war roadway reconstruction;

(*h*) Rapidity in the connexion of new orders;

(*i*) Simplification in fault location, and facilities for effecting speedy repairs;

(*j*) Facilities for connexion of miscellaneous circuits with minimum wire mileage and transmission difficulties;

(*k*) Facilities for conversion to a fully underground scheme at minimum cost;

(*l*) Best possible quality of transmission within economic limits.

Naturally all these desirable features cannot be incorporated in any one method, and a choice must be made of the most important ones which should be obtained and a scheme adopted which will provide for these even though at the expense of other desirable features which cannot be included. Fig. **13** gives an indication of such a combined scheme.

8. IMMEDIATE POST-WAR REQUIREMENTS.

8.1 Provision of service to waiting applicants.

The demands made on the Post Office in the early post-war period will be so great that any question of long-term plant provision must be subordinated to the need for an intensive campaign to provide for immediate requirements mainly by the utilization of such spare plant as may exist in the present cable network. Even in the pre-war years, the provision of spare plant had not kept pace with the demands for service, and, many years before the war, a waiting list of applicants existed (Fig. **14**). During the war

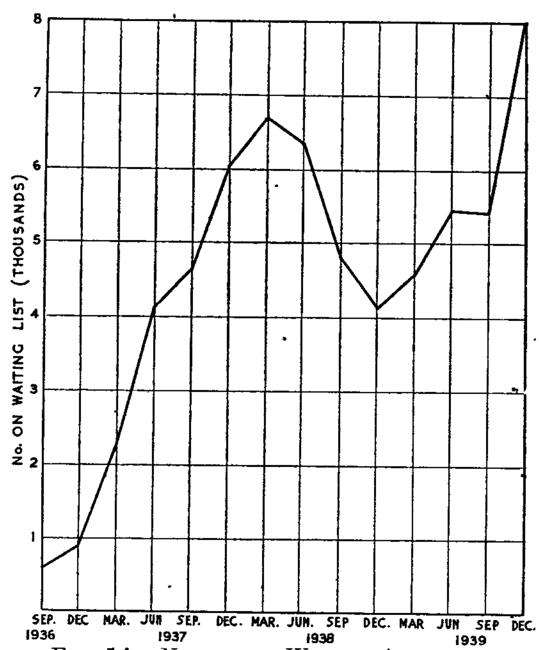


FIG. 14.—NUMBER OF WAITING APPLICANTS (PRE-WAR).

this waiting list has naturally expanded very considerably, and the position is indicated in Fig. **15**. There is no doubt that the first efforts of the Post Office staff will be to provide service to these waiting applicants. A proportion of these can probably be connected without material difficulty as spare plant exists, and the allocation of the applicants concerned to the waiting list has been for reasons other than the availability of line or equipment spares. A large proportion of the waiting list, however, cannot be provided for without plant extensions involving new cable provision, and a good deal of the resources of the available local staff both in planning and construction

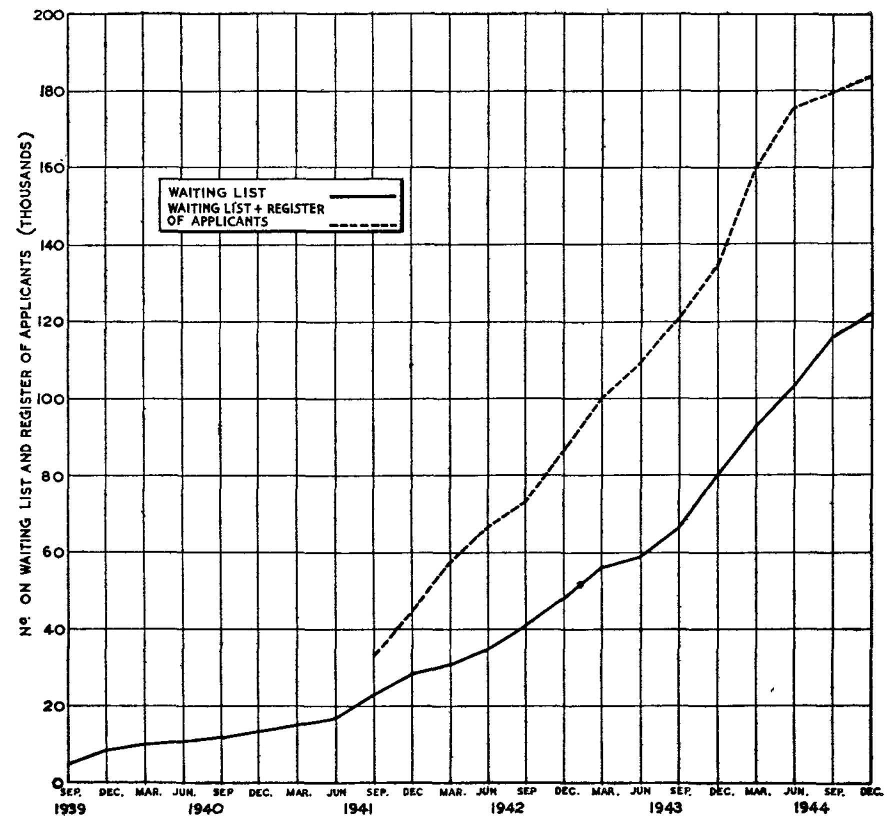


FIG. 15.—GROWTH IN OF NUMBER OF WAITING APPLICANTS DURING WAR.

will be absorbed in extensive relief measures which may have to be undertaken regardless of whether or not the work fits in with long-term plant provision. The typical layout shown in Fig. 16 indicates the nature of relief that may be necessary, which would comprise the introduction of flexibility in branch cables where such flexibility does not exist, the extending of blocks of dead spares by bridging-over bottle necks, etc., in order to convert unusable dead wire into revenue-earning plant, the provision of additional cables in order that new D.P.s can be opened up and where duct-space is available for cable to be drawn-in. Fig. 17 shows the further measures of relief which can be provided.

8.2 Provision of Ducts.

Another matter which will call for immediate post-war action will be the provision of additional conduit capacity. Inquiries have shown that, before the war, spare duct-space was generally very limited. Further, the spare pair position has in general reached a dangerous point, and there will be many cases where the only possible relief measures will involve additions to the cable network and the requisite associated duct provision. It will naturally be desirable for plant provision of such a character to fit in with any contemplated changes in long-term method, but the urgency of the problem may necessitate steps being taken without the desirable sound basis being available. In this connexion one has to bear in mind that the arrears of road construction and improvements by local authorities throughout the country will presumably be dealt with in a similar intensive way, and it will be necessary for the Post Office to take advantage of the economies in reinstatement provided under a co-ordination scheme. For this reason, it is considered that an important early post-war plan should take the form of fundamental planning for conduit provision.

8.3 New Exchange Building Programme.

A further feature is the co-ordination required between line plant provision and new exchange building programmes. It is known that the building position throughout the country is likely to be extremely difficult in the early post-war years, so much so that the Post Office is unlikely to be able to meet its requirements for new buildings or building extensions. There may be many cases where, because of building limitations, line plant provision however desirable may have to be deferred.

8.4 Combination of New and Existing Line Plant.

Even when a firm decision has been arrived at as to the method of long-term plant provision, a major problem will arise in the grafting of the new plant into the existing network without appreciable wastage or rearrangements, and the question of relative economy of providing long-term plant in the post-war

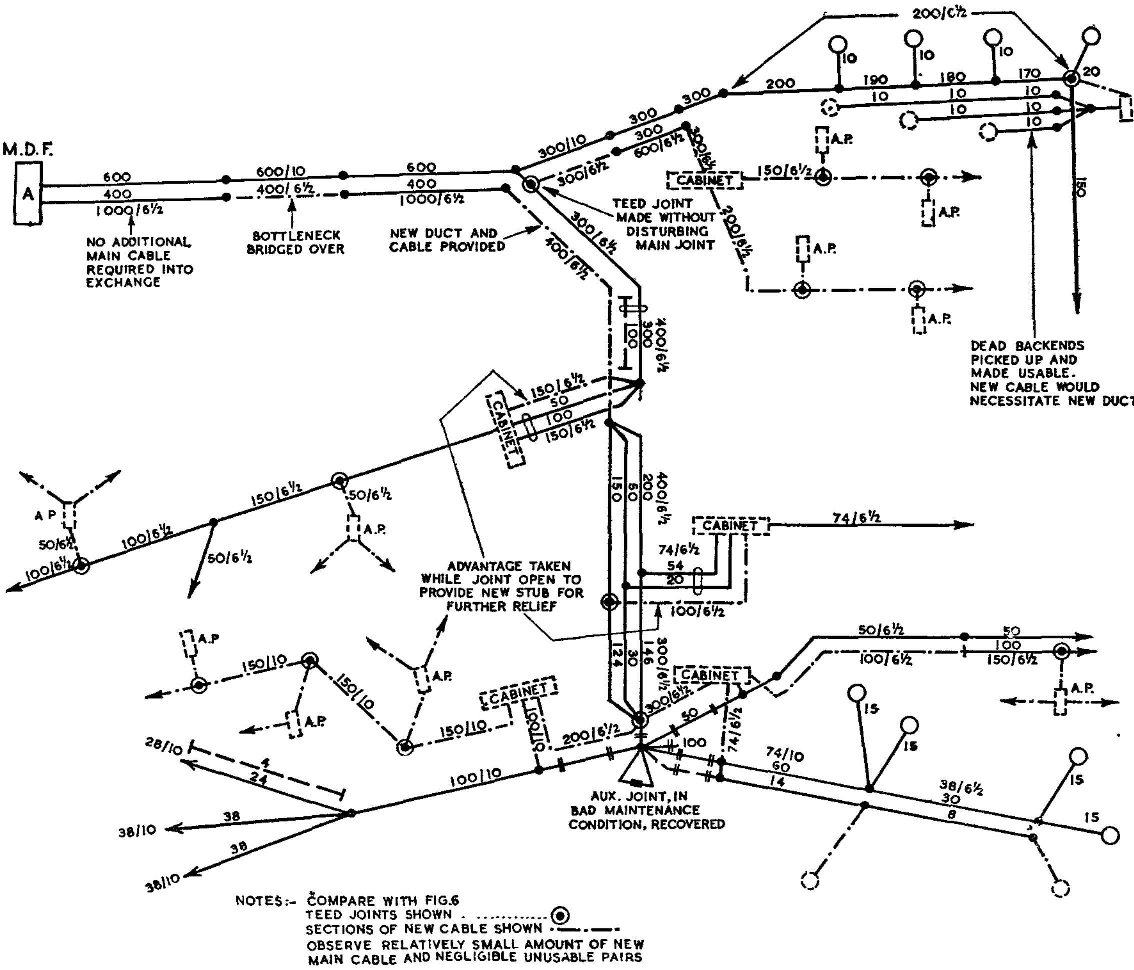


Fig 16.—Typical Scheme for Provision of Relief Plant (First Relief).

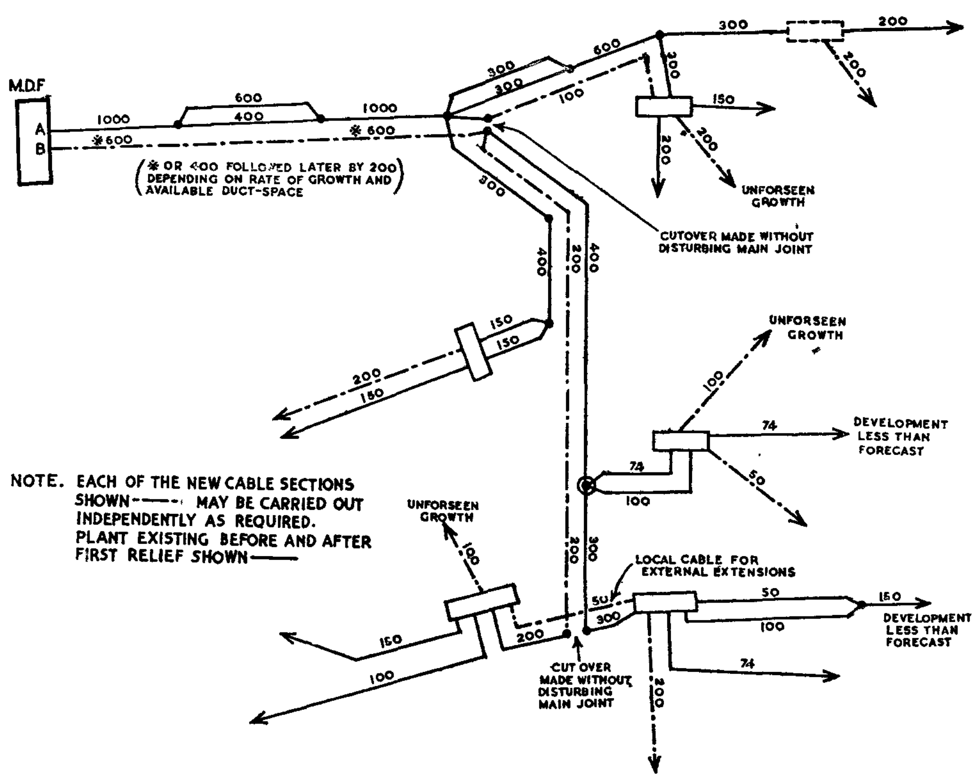


Fig. 17.—Typical Subsequent Relief Schemes.

years parallel with the existing network or, alternatively, rearranging the existing network so that it can fit in with the new plant provision, is being fully explored.

9. LINE PLANT RECORDS.

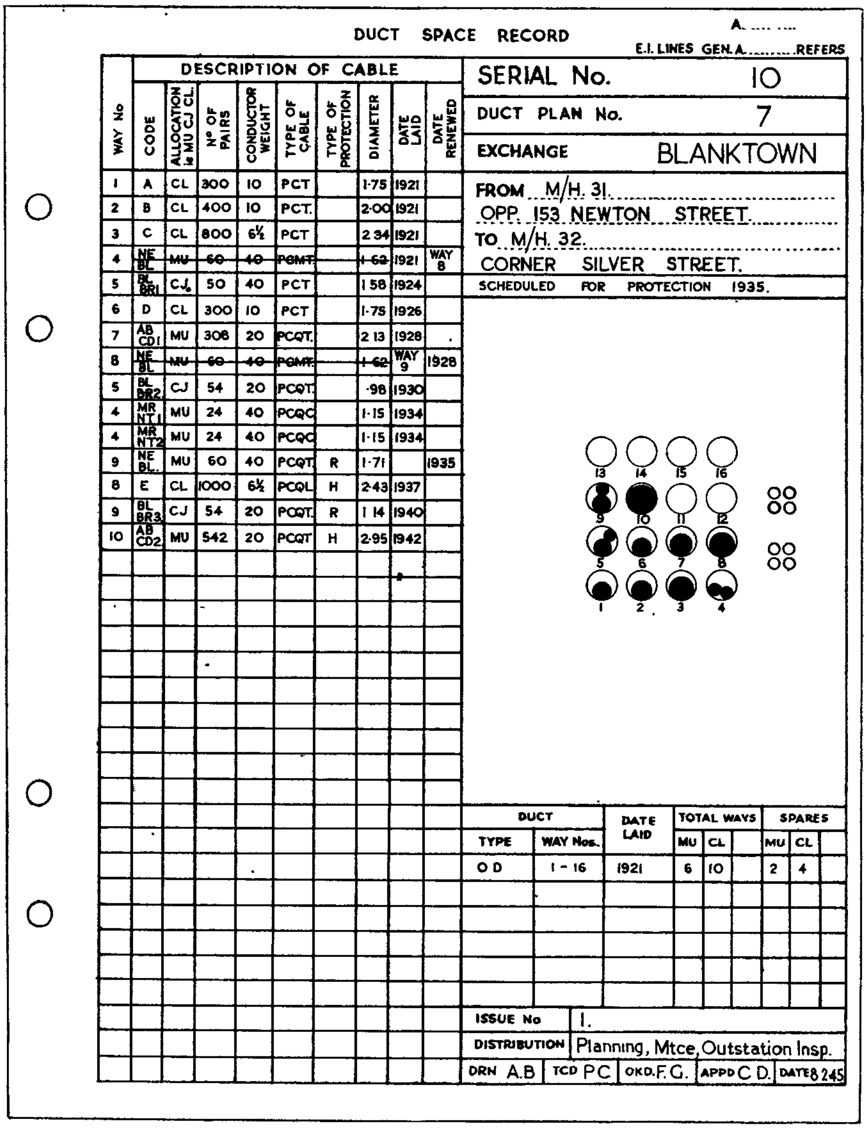
9.1 Relation to the general efficiency of the system.

Perhaps the key to the efficient and economic use of plant of any description is the maintenance of clear, concise, and accurate records. Nowhere is this more true than when applied to subscribers' local line plant. Speed of reference is essential and, in considering the form that records should take, simplicity should be the aim both in their preparation and use, since accuracy is more likely to be ensured thereby.

It is not clear that the present methods of recording subscribers' line plant are free from defects that would prejudice the maintenance and use of plant and its post-war expansion, and accordingly the Engineer-in-Chief has set up a Line Plant Records Committee to examine the question thoroughly. This Committee has as its prime object, the simplification of records and the avoidance of duplication of information where this will not interfere with the usefulness of the records.

9.2 New and Revised Records.

Certain deficiencies in the records, resulting in the uneconomic use of plant, have been detected and this factor will, in a few instances, lead to the introduction of new records and some modification of existing ones. For instance, there is ample evidence to show that the existing records do not assist materially in the economic use of ducts or the ready identification of spare duct-space. This latter item is often determined only after costly surveys. To overcome these deficiencies it is most probable that a new record, known as the Duct Space Record (Fig. **18**) will be introduced. The Committee will endeavour, also, so to combine information on plans that the seeking



DUCT SPACE RECORD

A. ....

E.I. LINES GEN. A. .... REFERS

SERIAL No. 10

DUCT PLAN No. 7

EXCHANGE BLANKTOWN

FROM M/H. 31.

OPP. 153 NEWTON STREET.

TO M/H. 32.

CORNER SILVER STREET.

SCHEDULED FOR PROTECTION 1935.

WAY No	DESCRIPTION OF CABLE: CODE	ALLOCATION i.e. MU CJ CL.	No. OF PAIRS	CONDUCTOR WEIGHT	TYPE OF CABLE	TYPE OF PROTECTION	DIAMETER	DATE LAID	DATE RENEWED
1	A	CL	300	10	PCT		1·75	1921	
2	B	CL	400	10	PCT.		2·00	1921	
3	C	CL	800	6½	PCT		2·34	1921	
4	~~NE BL~~	~~MU~~	~~60~~	~~40~~	~~PCMT.~~		~~1·62~~	1921	WAY 8
5	BL BR1	CJ.	50	40	PCT		1·58	1924	
6	D	CL	300	10	PCT		1·75	1926	
7	AB CD1	MU	308	20	PCQT.		2·13	1928	
8	~~NE BL~~	~~MU~~	~~60~~	~~40~~	~~PCMT.~~		~~1·62~~	WAY 9	1928
5	BL BR2	CJ	54	20	PCQT.		·98	1930	
4	MR NT1	MU	24	40	PCQC		1·15	1934	
4	MR NT2	MU	24	40	PCQC		1·15	1934	
9	NE BL.	MU	60	40	PCQT.	R	1·71		1935
8	E	CL	1000	6½	PCQL	H	2·43	1937	
9	BL BR3	CJ	54	20	PCQT.	R	1·14	1940	
10	AB CD2	MU	542	20	PCQT	H	2·95	1942	

DUCT: TYPE	WAY Nos.	DATE LAID	TOTAL WAYS: MU	CL		SPARES: MU	CL	
O D	1 - 16	1921	6	10		2	4	

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FIG. 18.—PROPOSED DUCT SPACE RECORD FORM.

of information will entail reference to the minimum number of records. With this end in view, it is possible that the simplification of cable layouts in the post-war years may render unnecessary the costly Cable Pair Distribution Diagram. Again the Duct Plan (or Conduit Diagram as it is now called) will become so simplified that a single plan showing all the information now shewn on three plans might well be the future standard.

9.3 Ordnance Maps.

After the war there will be a considerable revision of the basis of preparation and printing of Ordnance Maps as the result of the recommendations of a Committee on Ordnance Survey set up a few years prior to the war. The main revisions involve the introduction of a National Grid scheme for map reference, and the reduction of the standard area for survey purposes to a kilometre square. Maps will normally be published square in shape, and in convenient multiples of the above area. Two new maps will be introduced, one to a scale of $\frac{1}{25,000}$ or approx. $2\frac{1}{2}''$ to one mile; and in addition all urban areas will be surveyed, and maps published to a scale of $\frac{1}{1,250}$ or approx. $50''$ to one mile. This latter map should be of material assistance in planning and recording Post Office works. The National Grid scheme (which will displace the present County reference basis) should simplify the filing and identification of maps and other plan records.

9.4 Control of Records.

It is hoped that the foregoing gives some idea of the scheme envisaged for post-war adoption, but no matter how simple any operation can be made, there exists always the possibility of human error. Experience has shown that errors arise which remain undetected for a considerable time on account of the lack of any form of systematic checking. It will perhaps be of interest to state that the Committee will recommend the setting-up of a machinery for the control of recording and the systematic checking of all records, in the anticipation of an over-all saving as compared with present conditions.

10. STAFF TRAINING.

It is clear that, with the radical changes envisaged and particularly the need for intensive action, new line plant provision will involve a very high degree of staff training in order to cope with requirements.

A few years prior to the war, the problem of adequate training in Line Plant Development had been given full consideration and training courses were established at the Central Training School, through which passed a large proportion of the development planning personnel. Quite recently the subject has come under review, and arrangements are being made for an intensive campaign of training to be put in hand. This training will include instruction in any new method likely to be introduced, and will undoubtedly have an appreciable effect on post-war plant provision. Indeed, one cannot under-estimate the value of training in local line plant development because the result of inadequate training may involve very considerable economic loss to the Post Office, especially in view of the high proportion of the value of this plant to that of the entire telephone system. It is intended that the training should cover not only the practical application of economic methods but also the basis of economic considerations. The telephone service must be a financially sound undertaking, and at the same time its cost to the public must be as low as practicable. These factors necessitate studying every problem, not only from its practical but also from its economic aspect. Sir Frank Gill makes this point clear in his Foreword to the new Abridged Version of Inwood's Tables of Interest:—

> "Engineers must be trained so that engineering does not merely consist in the ability to apply technical knowledge to works, but that they must with equal competence give economic consideration to their problems. While it is obvious that a technical solution cannot be put into practice if it is too expensive, it is not always realized that engineers must make alternative plans for filling the requirements of any project and use economic analyses to help in deciding which of the alternative plans to select."

For this reason a considerable amount of the training will be devoted to the fundamentals of economics in relation to Post Office work, and will cover the methods of weighing-up alternative schemes not only in line plant provision but in the determination of the associated problems of size of exchange area and location of exchange centres. This is necessary because during the next 10 years or so, particularly if there is an impetus in telephone penetration due either to tariff reductions or increasing popularity of the telephone service, important questions affecting the establishment of new exchanges and variations in the sizes of exchanges will undoubtedly become an important problem in line plant provision.

11. CONCLUSION.

The author wishes to offer grateful thanks to the many kind and energetic colleagues who have assisted in the presentation of this paper, including the compilation of data, checking of proofs, and in obtaining photographs and slides. In particular the author is indebted to Mr. Harvey Smith, who was appointed by the Engineer-in-Chief to carry out many of the special investigations referred to in this paper, for his valuable contribution. Thanks are due also to Mr. Barnes, of the Research Branch, who has kindly assisted with the section on Transmission. Finally, grateful thanks are due to Sir Frank Gill for his kind permission to quote the extract from the foreword to Inwood's "Tables of Interest — Abridged Version" (Technical Press Ltd.). In the author's opinion the extract sums up admirably the purpose of this paper.

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" The anticipation of Demand, and the Economic Selection, Provision and Layout of Plant," by Capt. J. G. Hines, M.I.E.E. Journal I.E.E., Vol. 67, No. 389 (May, 1929).

TABLE 1.

Local line resistance to give a grade of Effective Transmission equal to that given by a Telephone No. 162 on a 50-volt, 200 + 200-ohm feeding bridge with a 450-ohm local line of 10-lb. cable.

Telephone	Local Line	Feeding Bridge							
		22-Volt C.B.		40-Volt C.B.		50-Volt (200 + 200 Ω)		50-Volt (Ballast)	
		Ohms	Miles	Ohms	Miles	Ohms	Miles	Ohms	Miles
No. 150 and Bell-set (or Tele. No. 121)	6½ lb.	350	1.3	360	1.3	315	1.2	320	1.2
	10 lb.	190	1.1	200	1.15	175	1.0	185	1.05
	20 lb.	100	1.15	105	1.2	90	1.0	105	1.2
No. 162	6½ lb.	420	1.55	465	1.7	560	2.05	660	2.45
	10 lb.	355	2.0	380	2.15	450	2.55	410	2.35
	20 lb.	285	3.25	270	3.05	215	2.45	205	2.35
No. 332 or 232 (Coils Induc., Nos. 22 and 24)	6½ lb.	540	2.0	650	2.4	745	2.75	820	3.05
	10 lb.	465	2.65	535	3.05	570	3.2	565	3.2
	20 lb.	365	4.15	330	3.75	315	3.6	315	3.6
No. 232 (Coil, Induc., No. 20)	6½ lb.	570	2.1	700	2.6	790	2.9	890	3.3
	10 lb.	480	2.75	580	3.3	655	3.7	740	4.2
	20 lb.	375	4.25	430	4.9	435	4.95	430	4.9
Long-line tele. (Experimental sample)	6½ lb.	825	3.05	1075	3.95	1115	4.1	1130	4.2
	10 lb.	690	3.9	900	5.1	940	5.3	985	5.6
	20 lb.	465	5.3	625	7.1	635	7.2	670	7.6
L.B. non-A.S.T.I.C. Tele. No. 196, Bell-set No. 21 (or 31) and 3 cells	6½ lb.	580	2.15	715	2.65	715	2.65	750	2.75
	10 lb.	510	2.9	595	3.4	595	3.4	635	3.6
	20 lb.	370	4.2	440	5.0	440	5.0	465	5.25
L.B. A.S.T.I.C. Tele. No. 196, Bell-set No. 38 and 3 cells	6½ lb.	815	3.0	865	3.2	865	3.2	910	3.35
	10 lb.	630	3.6	670	3.8	670	3.8	690	3.9
	20 lb.	470	5.35	495	5.6	495	5.6	505	5.7
No. 332 or 232 with Coil, Induc., No. 27	6½ lb.	530	1.95	670	2.48	755	2.8	845	3.15
	10 lb.	480	2.7	585	3.3	660	3.75	750	4.25
	20 lb.	395	4.5	450	5.1	505	5.75	570	6.45

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