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THE INSTITUTION OF
POST OFFICE ELECTRICAL ENGINEERS

"Critical Methods of Investigation as applied to the Study of Telephone Areas and Plant Lay-out."

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J. N. HILL.

A PAPER

Read before the London Centre of the Institution 14th January, 1930, and before the Eastern Centre on the 20th January, 1931.

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SYNOPSIS.

Introduction.

The investment of capital to provide a given standard of transmission and a given grade of service.

The choice of investment: comparison of Capital Costs, Annual Costs and Present Value of Annual Costs.

The effects of rate of interest and rising and falling costs on planning periods.

The period over which calculations should be made and the effect on economic planning periods.

Economics of Plant Provision.

Methods of calculation for determining economic periods for the provision of ducts and cables.

The economic use of quad type cables.

Economics of Exchange Area Lay-outs.

The machinery necessary to ensure that revisions of lay-out are formulated in sufficient time to permit of their accomplishment by the time relief is required.

Preliminary data: development summary plan: density plan: traffic distribution diagrams.

Fundamental Graphs.

Average length of lines in areas of uniform density: ratio of route length to radial length: area covered by different types of conductor: economic size of exchanges for areas of uniform density.

Application of standard curves to actual areas: equivalent density and equivalent areas.

New Exchanges.

The fundamental lay-out plan.

Comparison of alternative schemes.

The preparation of a traffic forecast : method of determining economic traffic routing : junction forecast : the determination of the practical centre.

The economic date of opening.

The Conversion of a Telephone Area from Manual to Automatic Working.

The problem of C.C.I. traffic.

The economic date for converting a manual exchange to auto working.

NOTE.—The costs used in illustrating the methods of investigation described in this paper must not be considered as applicable to any individual case. In practice, cost data are kept under constant review and suitable values are used for the particular problem under consideration.

The advances made in the technical development of telephony, together with the great expansion of the system which is already taking place, render the economic side of telephone engineering a subject of increasing importance to the engineer. The total number of direct exchange lines in London has more than doubled in the last ten years and, if the present expectations of growth are realised, the number of working lines will again be doubled within a period of eight years.

To make provision for this development, a large amount of money must be expended on engineering plant, and if this expenditure is to be reduced to a minimum, every engineering process must be organised on scientific lines and the design of plant lay-out must conform to sound economic principles.

Captain J. G. Hines, in a paper read before this Institution in November, 1923,* and in a paper read before the Institution of Electrical Engineers in January, 1929,† has described generally the economic problems with which the telephone engineer has to contend. The author, in this paper, hopes to show in some little detail some of the methods of investigation which are adopted in planning the lay-out of

* I.P.O.E.E. Paper, No. 95.

† I.E.E. Journal, No. 289, May, 1929.

a telephone area. To start from first principles, the problem set is really one of the investment of capital for the provision of an engineering structure and the necessary operating agents to provide a given standard of transmission and a given grade of service. The two standards may vary from time to time as the state of the science advances. They are, moreover, dependent to some extent on financial considerations. In other words, the object of the administration is to offer the best service and transmission that it can afford at tariffs which are sufficiently attractive to induce new business and thereby tend to the expansion of the service. As already stated, the problem is one of the investment of capital, and the choice as to the best form of investment will be governed by a comparison of costs taken over a period of years as compared with the revenue to be obtained.

As development forecasts in London are invariably made on the assumption that there is full plant availability, that intensive canvassing will be generally adopted, and that no extra mileage charges will apply, the revenue obtainable is generally assumed to be the same whatever plant lay-out is adopted, and therefore may be ignored in the calculation. In certain cases, where different rentals and call fees may be applicable, the anticipated revenue must also be computed.

Comparisons may be made of capital costs, annual costs and present value of annual costs; but, while the last named gives the only true test of economics, comparisons of capital and annual cost also assist in arriving at a conclusion where the present values do not materially differ.

The items of annual expenditure which will govern the choice of alternative schemes may be classified as under:—

(1) Interest.
(2) Depreciation.
(3) Operation cost.
(4) Maintenance.

These items can be expressed in terms of money and are generally known as reducible data, but there are many items which cannot be so computed. These are classified under the heading of irreducible data and would include such items as transmission values, interruptions of service, and risks of various kinds. The experience of the engineer alone will enable a correct judgment to be obtained when assessing the relative values of reducible and irreducible data.

The first problem which the development engineer must confront is the determination of the periods in advance of requirements for which different classes of plant should be provided. It is obvious that if any particular item of plant has the same cost per unit whether provided singly or in bulk, then no economic advantage will be obtained by providing more plant than is required to meet immediate needs. On the other hand, if the cost per unit becomes less as the number of units provided at one time is increased, then it becomes necessary to determine the most economical planning period. When plant can be economically provided in large instalments, the increased annual charges on the plant in the early years, due to plant lying idle, are offset by the reduced annual charges on plant during the later years, on account of the smaller capital costs involved by provision in bulk.

It is usual in such calculations to compare the costs over the full life of the plant, but in certain cases it is necessary to limit the calculations to a shorter period. This limitation may be due to the difficulty of forecasting for the longer period or it may be due to the necessity of correlating the debit and credit sides of the account during the early years. In a commercial concern, for example, it might be obviously unsound to incur a large capital expenditure in the early years if the annual charges thereon would greatly outweigh the revenue to be obtained for a number of years. It must also be borne in mind that where estimates of future growth are more or less speculative, it is also desirable that calculations should be limited to a shorter period; and capital expenditure should be a governing factor where the difference in the present value of annual charges is small.

In order to illustrate the effect on the planning period of shortening the period over which calculations are made, Fig. 1 has been prepared. This shows a simple case where plant could be provided in one or two instalments.

If A = capital cost of providing in one instalment
B = ,, ,, ,, the first of two instalments
C = ,, ,, ,, the second instalment
a = annual charge as a % of capital cost
n = limiting period for which it is economical to plan
x = P.V. multiplier for the full period, N years, over which costs are calculated

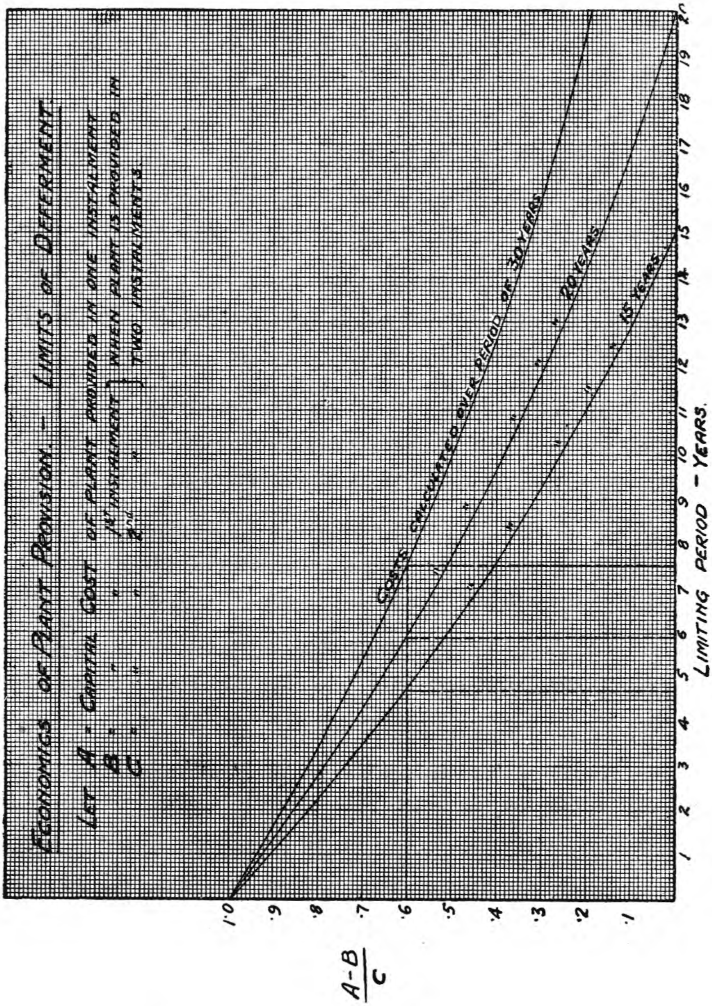


FIG. I.

y = P.V. multiplier for the second instalment, *i.e.*, for N − n years, deferred n years.

Then $axA = axB + ayC$

$$yC = x\,(A - B)$$

$$\frac{y}{x} = \frac{A - B}{C}$$

Taking values for y where N = 15, 20 and 30 years, respectively, and where n varies from 0 to 20 years, the limits of economic planning can be shown for various ratios of

$$\frac{A - B}{C}$$

As an example, let us assume that in a particular case this ratio has the value of 0.6; then, when costs are calculated over a period of 30 years, it will be economical to defer the provision of the second instalment if it will not be required for 7.5 years. On the other hand, when the comparison of costs is confined to a period of 20 years the plant should only be provided in one instalment if an increase would otherwise be necessary within 5.9 years.

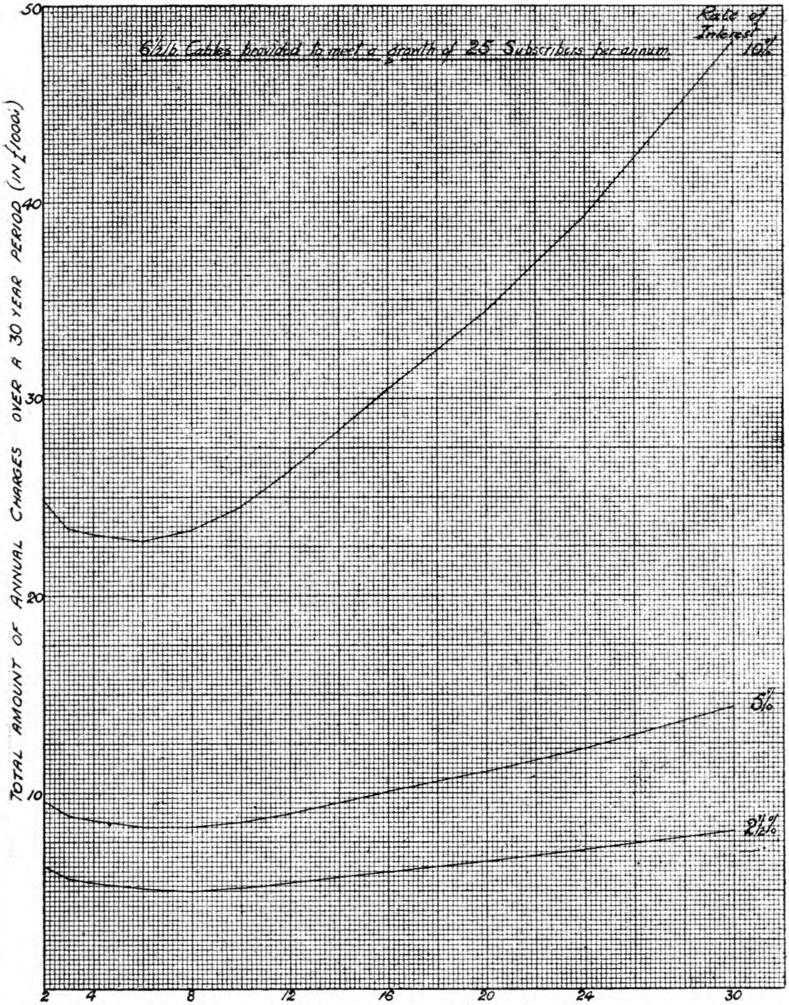
It is evident, therefore, that the economic planning period is shortened when the costs are calculated over periods less than the full life of the plant.

It is interesting also to study the effect of rates of interest on economic planning periods. It will be observed (Fig. 2) that, so long as the rate of interest is constant during the period, it does not very materially affect the planning period, although the higher interest rates will tend to shorten the period slightly. On the other hand if a rise or fall is forcast a marked effect will be noticed. The economic planning period for the first instalment will be definitely lengthened if subsequent instalments are subjected to charges at a higher rate of interest (Fig. 3), and the reverse will be the case where a fall of interest may be anticipated with regard to future instalments (Fig. 4). Similar results obtain also with regard to variations in the capital costs of instalments of plant. So long as the cost relation between different instalments of plant remains constant, the actual magnitude of the costs will not affect the planning period, but falling costs will shorten the initial planning period and rising costs increase it, the normal planning period again becoming operative as soon as stability is reached.

Fig. 5 shows a convenient method of arriving at the planning period when each instalment is of equal value.

The straight lines running diagonally across the graph represent the P.V. of £1 per annum increasing by £1 every two years, every three years and so on.

As the annual charges on any given type of plant are proportional to the capital cost, vertical lines representing the capital cost of instalments of one, two or more units can be



GRAPH ILLUSTRATING THE EFFECT OF THE RATE OF INTEREST ON PLANNING PERIODS.

FIG. 2.

shown and, by suitable calibration of the ordinates, the P.V. of annual charges can be read.

By connecting the points of intersection of the vertical lines with the diagonal lines corresponding to the period for

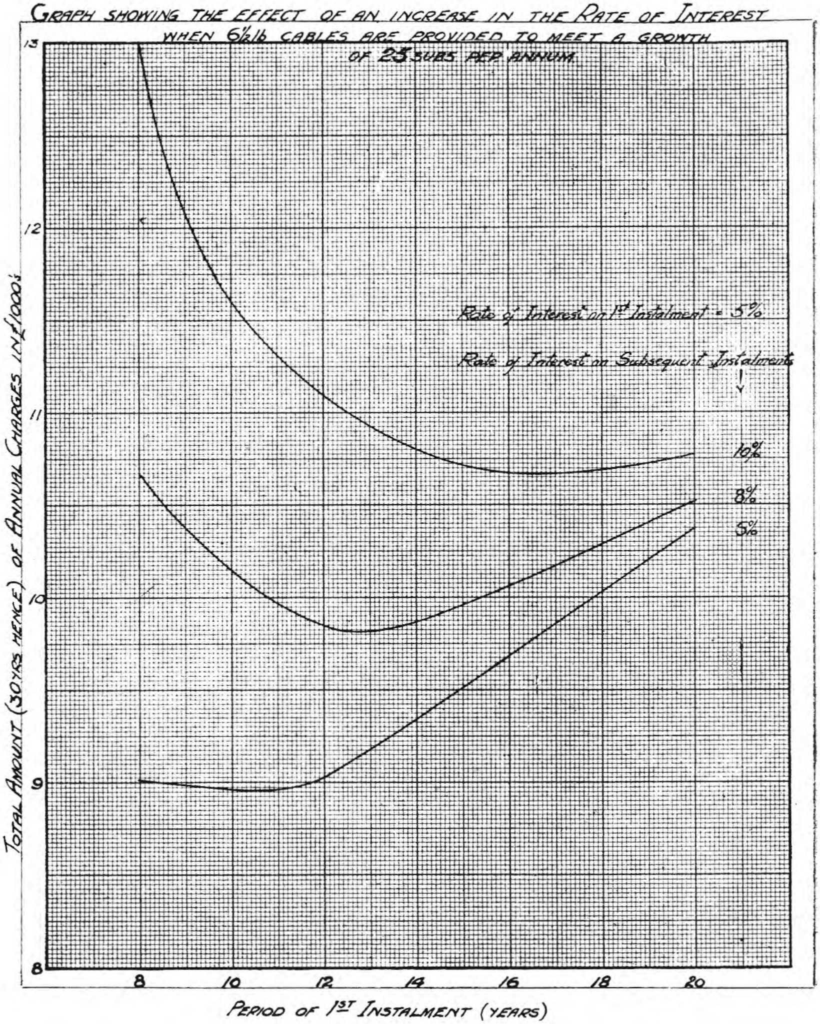


FIG. 3.

which the appropriate instalment will serve, the economic planning period can easily be seen, this being represented by the minimum point. Such a method is only suitable in its entirety where each instalment is of equal value, as in the case of duct work.

When allowance has to be made for rearrangements as

GRAPH SHOWING THE EFFECT OF A DECREASE IN THE RATE OF INTEREST WHEN $6\frac{1}{2}$ LB. CABLES ARE PROVIDED TO MEET A GROWTH OF 25 SUBS. PER ANNUM.

FIG. 4.

in the case of cables, the P.V. of the annual charges on the plant to be placed can be calculated by the use of a similar graph to that just described, the rearrangement charges being added separately. A typical example is illustrated in Fig. 6.

An interesting example of another type of investigation is illustrated in Fig. 7. It was desired to determine the con-

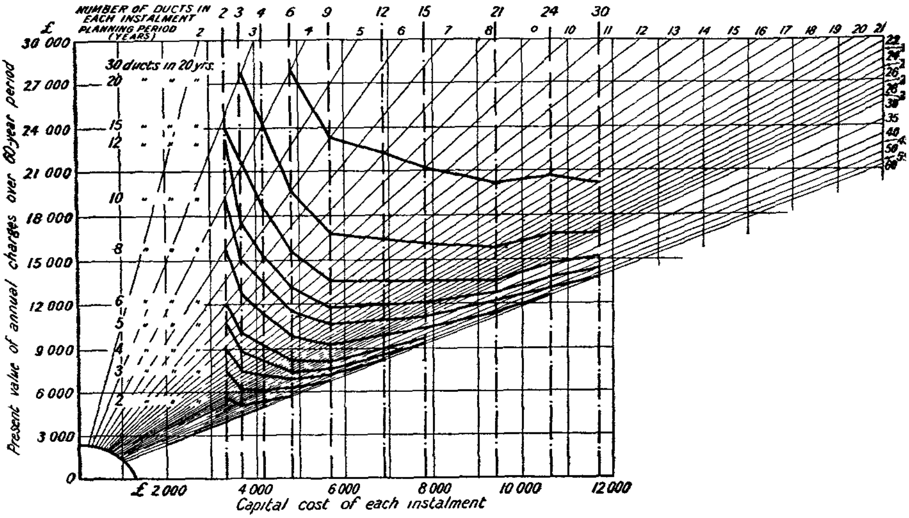


FIG. 5.

ditions under which it would be economical to use the quad type of cables when utilising the last spare duct of a nest. For example, either a 300-pair twin cable or a 504-pair quad cable could be accommodated, the use of the larger cable enabling the provision of new ducts to be deferred for a number of years.

In view of the higher cost of the 504-pair cable there obviously will be a loss on the P.V. of annual charges on cables in the earlier years which will only in part be compensated for by savings due to the deferment of subsequent instalments of 300-pair cables. If the proposal to use a 504-pair cable is to prove economical, then the nett loss on cables must be less than the savings which will accrue by the deferment of the ducts.

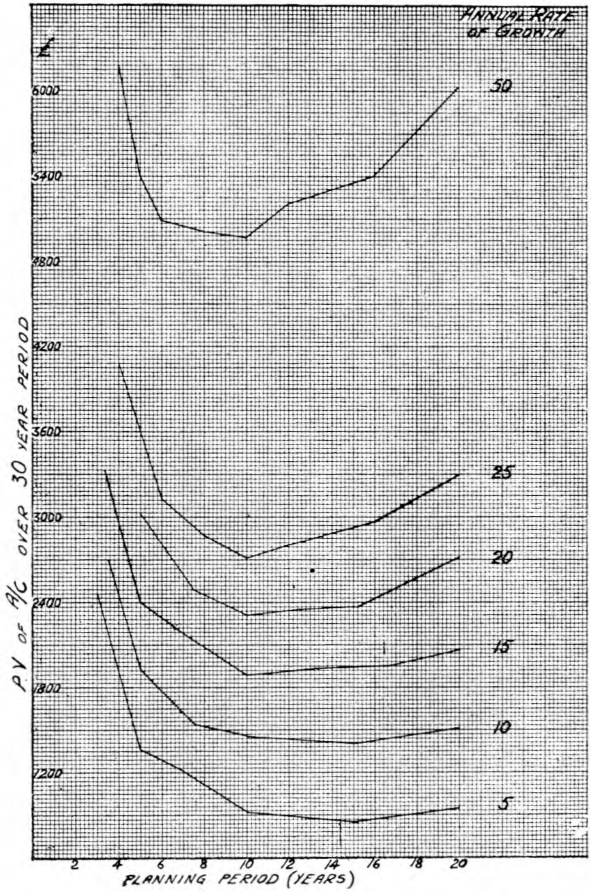
In order to find the critical values let us assume that the costs are equal and equate the savings on duct work to the losses on cabling.

Let A = capital cost of a 300-pair cable

,, $A+X$ = ,, ,, ,, ,, 504 ,, ,,

,, D = ,, ,, ,, the duct work which would be deferred.

,, N = number of years for which a 300-pair cable will meet development.



ECONOMIC PLANNING PERIOD—6½ LB. CABLES.
INCLUDING REARRANGEMENT COSTS.

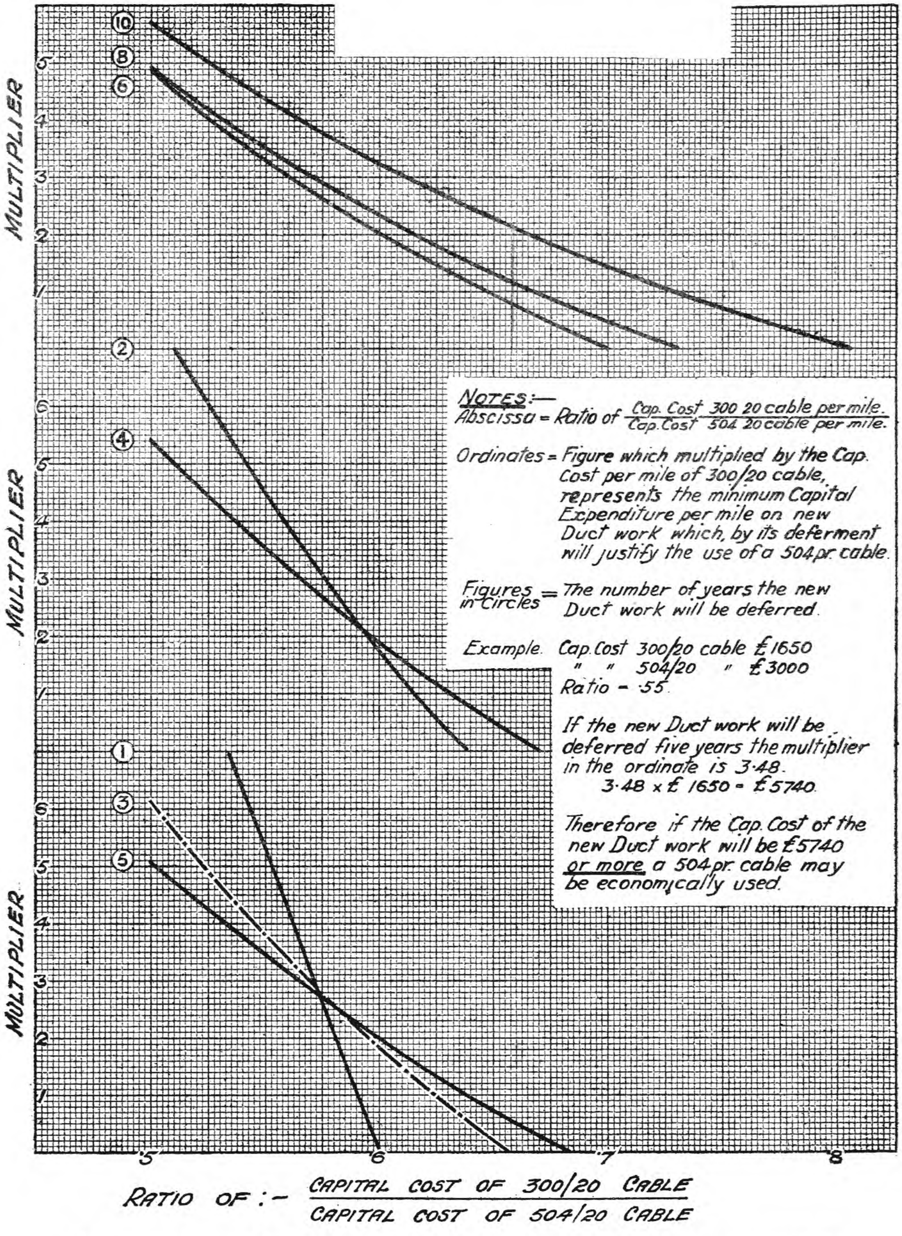
FIG. 6.

,, a = P.V. multiplier for 30 years.

,, b = ,, ,, ,, instalments made every N years, deferred N years.

,, c = P.V. multiplier for instalments made every N years, deferred 1 2/3 N years.

,, d = P.V. multiplier for 2/3 N years, deferred N years.



ECONOMICS OF PLANT PLANNING—504 PR. 20 LB. CABLE—ITS USE IN LIEU OF 300 PR. 20 LB. CABLE IN THE LAST SPARE DUCT OF AN EXISTING NEST.

FIG. 7.

11.5 = Percentage A.C. on cables

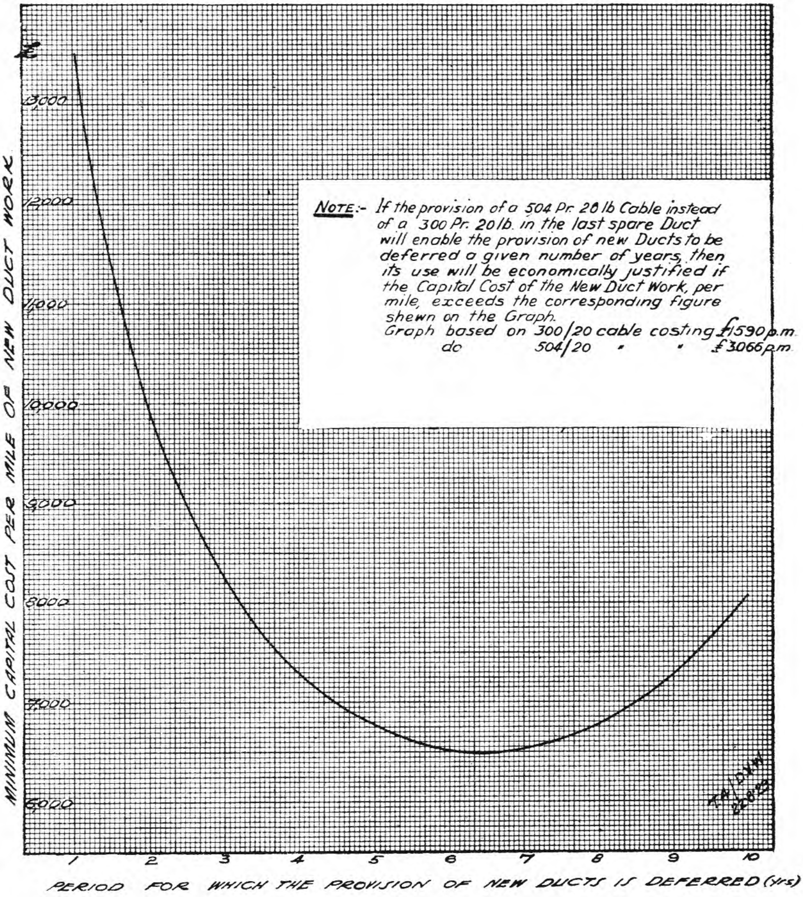
6.3 = ,, A.C. on ducts

Then $11.5\% \, (aA + bA) + 6.3\% \, dD = 11.5\% \, (aA + aX + cA)$

$$6.3\% \, dD = 11.5\% \, (aX + cA - bA)$$

$$D = \frac{11.5}{6.3}\left(\frac{aX + cA - bA}{d}\right)$$

$$= 1.825\left(\frac{aX + cA - bA}{d}\right)$$



GRAPH SHOWING CONDITIONS UNDER WHICH IT WILL PROVE ECONOMICAL TO USE A 504 PR. 20 LB. CABLE WHEN NORMAL PROVISION WOULD BE ON A 300 PR. CABLE BASIS.

FIG. 8.

By taking A as various ratios of A + X, D can be expressed in terms of A and a series of graphs plotted (Fig. 7).

Fig. 8 shows the result obtained for particular values of A and A + X. It will be seen that the use of 504-pair cable would be economically justified if it would enable duct work costing more than £6,500 to be deferred for 6 years.

One of the most interesting problems which confronts the development engineer is the lay-out of exchange areas to meet the requirements of future growth. As a period of several years must elapse between the time that a proposal to open a new exchange is first formulated and the date the exchange can be brought into service, some machinery is necessary to ensure that the whole territory is kept under review. To meet the needs of this, schedules are prepared for each exchange as shown in Fig. 9, and a graphical record is also kept. From these a priority list is prepared showing proposed reliefs already in hand and contemplated in accordance with the fundamental lay-out plan, and also the dates at which further relief is necessary but for which a scheme has not yet been formulated (Fig. 10). The need for relief to any particular exchange generally affords the opportunity for a study of surrounding territory. Each investigation usually embraces a number of exchange areas, the limits of any particular study being defined, where possible, by some natural boundary, such as a river or park land or, alternatively, by a belt of low telephone density.

Of course, before any investigation can be undertaken a development study is necessary and this is furnished by the Contract Branch of the London Telephone Service and shows the estimated development for small blocks of territory for 5, 10, 15 and 20 year periods. The result of this study will be used by the external engineer for the provision of plant, and is therefore in much greater detail than is required for the purpose now being considered. A summary plan is therefore prepared on which the distribution areas are combined to form larger areas, care being taken to combine only such areas as are of similar characteristics and which have approximately the same telephone density. This plan is usually prepared on a 6″ scale, and forms the working plan (Fig. 11). It will be evident that, when dealing with an area covering, perhaps, ten or more square miles, there may be numerous ways in which the territory could be laid out, but the problem is to determine the most economical method to cover a period

..........................EXCHANGE.

Date	T.C. of Switch Room	Limit of Appts. Room or C.C.I.	D.E.L. working	Transfers + or −	Net Annual Growth		Estimated Growth		Exhaustn. Date.	Relief proposals submitted to E. in C.					Exhaustn. date after last relief	Remarks
					3 m'thly rate	Yearly rate	Forecast	T.C. Sched.		1st	2nd	3rd	4th	5th		
1928, July																
,, Oct.																
1929 Jan.																
,, April																
,, July																
,, Oct.																
1930, Jan.																
,, April																
,, July																
,, Oct.																
1931, Jan.																
,, April																
,, July																
,, Oct.																
1932, Jan.																
,, April																
,, July																
,, Oct.																

FIG. 9.

PRIORITY LIST. SCHEDULE A.

Existing and Replacing Exchanges.	Financial Year 1929/30	1930/31	1931/32	1932/33	1933/34	1934/35	1935/36			1944/45
Cedars		T.C. 8000 Mar. 31 Beech				T.C. 8000 Sept./34 Oak				

PRIORITY LIST. SCHEDULE B.

Proposed Exchanges	1929/30	1930/31	1931/32	1932/33	1933/34	1934/35	1935/36			1944/45
Beech	Sept./30	Cedars Mar./31	Chestnut July/31							
Oak						Cedars Sept./34				

FIG. 10.

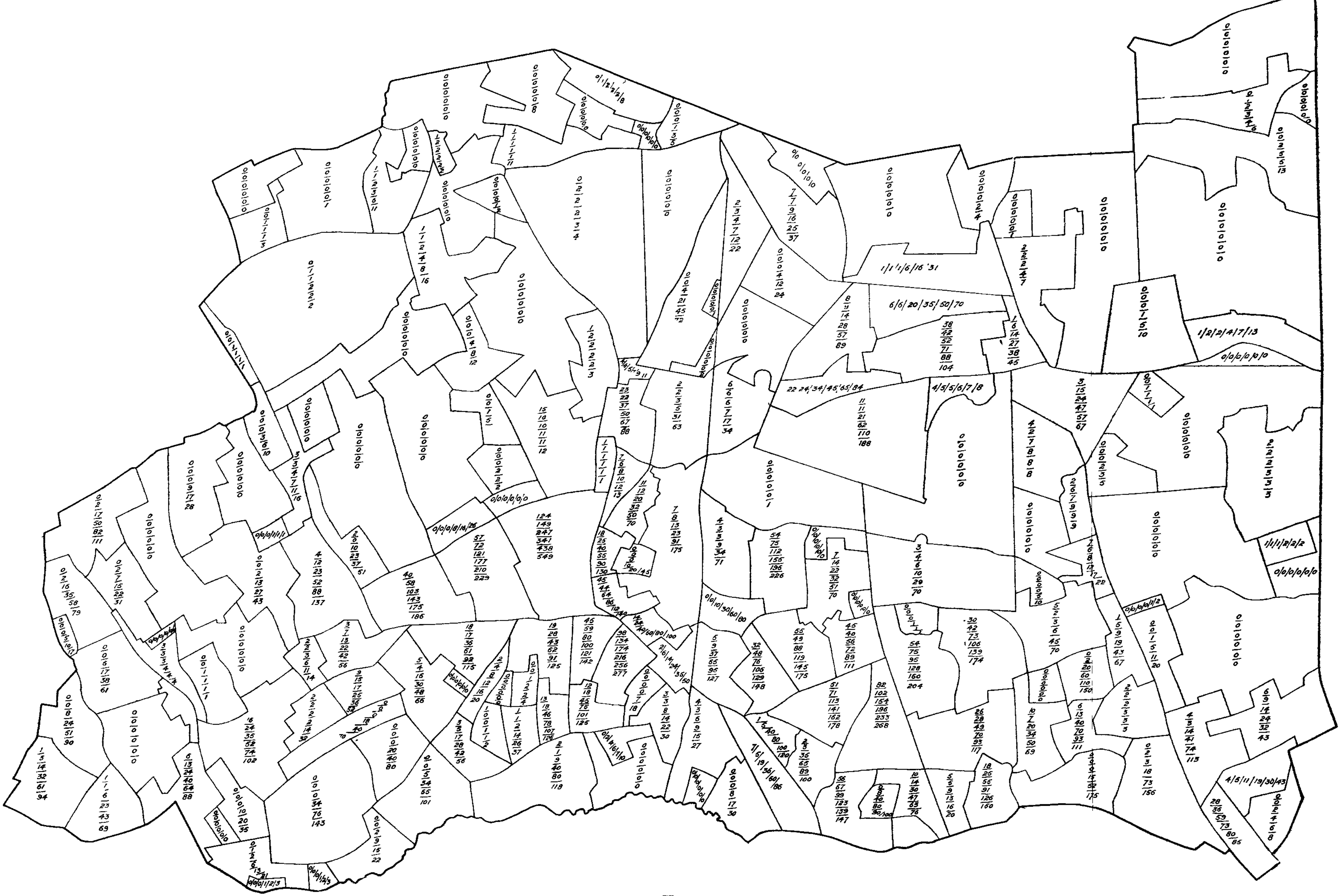


FIG. 11.


REFERENCE
Over 5000 DEL^s per square mile
4000-5000
3000-4000
2000-3000
1000-2000
0-1000
Nil

FIG. 12.

of years. It is obvious that the minimum cost of subscribers' lines will be achieved if the territory is divided so that the exchanges are situated in the areas of greatest density, for then a large number of lines will be of short length and only the less dense areas will have long lines. To facilitate the preparation of a preliminary lay-out of areas a density plan is of great assistance, and this is obtained by calculating the density per square mile for each of the development blocks on the summary plan and colouring each in accordance with a standard colour scheme. Fig. 12 gives a typical example.

In order to minimise the number of calculations which would have to be made for determining the relative merits of alternative schemes, a number of standard graphs have been prepared which assist materially in the preparation of the lay-out plan. Some of the more important of these are illustrated. Fig. 13 shows the ratio of route length to radial

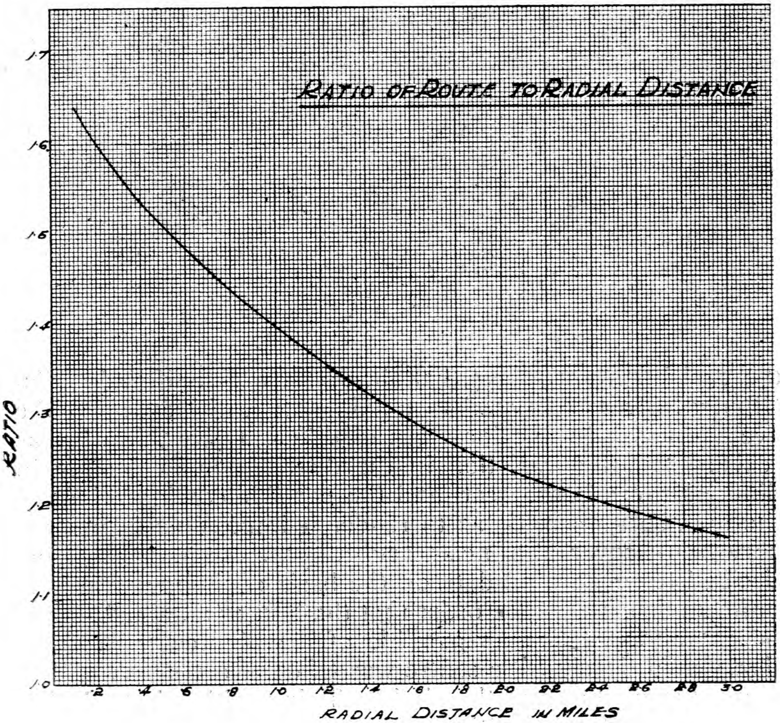


FIG. 13.

distance for lines of any length and was obtained by the analysis of a number of typical schemes. From this another graph, Fig. 14, has been derived, showing the ratio of route length to radial distance of all lines within a given radius of

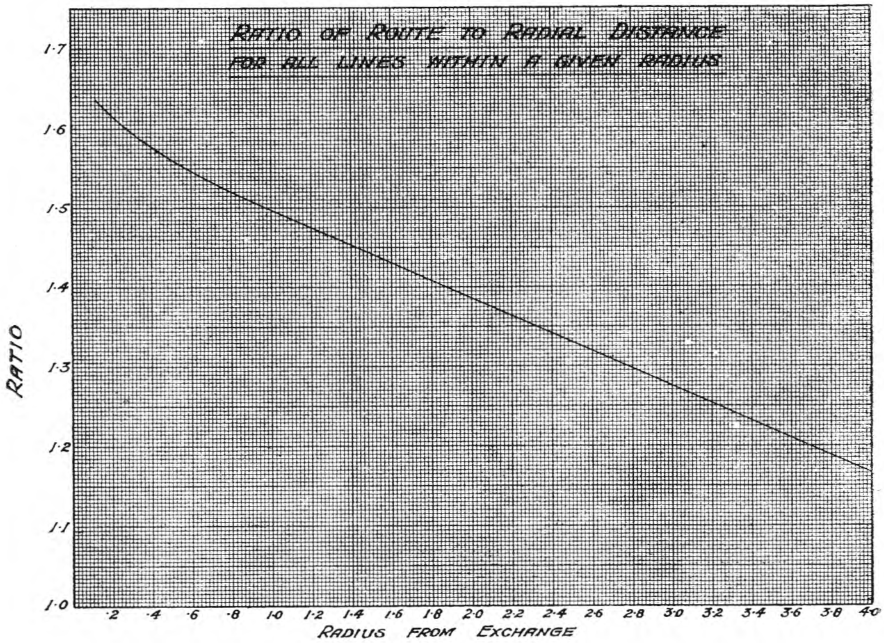


FIG. 14.

the exchange, assuming that the lines are uniformly distributed. It was desired to obtain data with regard to the average cost per line for areas of different sizes, but it was realised that the variation in the distribution of density in different areas is so great, and the possible configurations of the area so numerous, as to render it impossible to prepare curves to cover the necessary ranges. It was therefore decided to prepare all data on the basis of a circular area of uniform density, but in order that the figures obtained should be as representative as possible of actual areas of equally distributed density, the centre was taken at a point two fifths along the diameter of the circle. This position is typical of average London conditions where the pull exerted on the practical centre of the area due to the junction traffic towards

Central London is most marked. Fig. 15 shows a typical traffic distribution diagram and shows superposed on it the main junction cable routes serving the area.

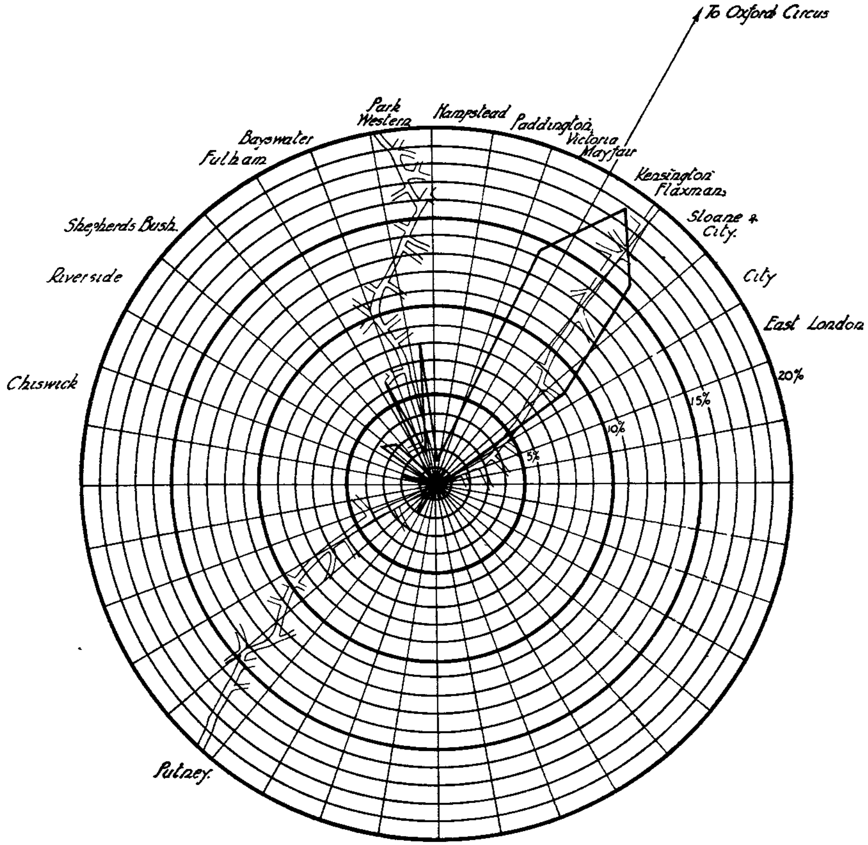


FIG. 15.

The traffic accumulated on the routes and weighted to allow for the different types of conductor is shown in the form of a vector diagram on Fig. 16. The resultant pull in the direction of Central London is clearly seen.

The average length of the lines drawn from a point two fifths along the diameter to all points within the circle may be shown mathematically to be equal to 0.686 times the radius of the circle, and using this figure in conjunction with the

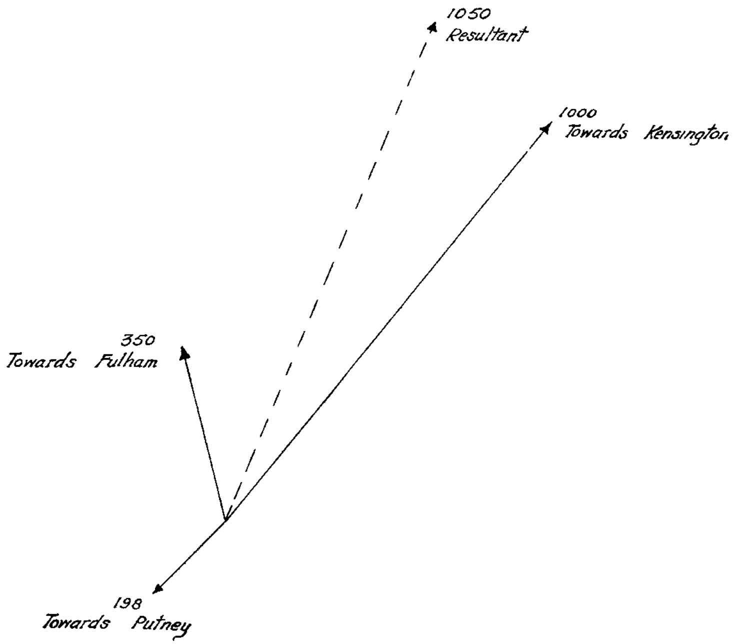


FIG. 16.

graphs already shown the average length of all lines within an exchange area of any size can be calculated. This is illustrated in Fig. 17. Another factor has, however, to be taken into account, and that is, the type of conductor necessary to give standard transmission. Assuming that it has been determined that for transmission reasons the resistance of lines should conform to a 300-ohm limit, then a certain proportion of an area may be served by each type of conductor as shown in Fig. 18.

Fig. 19 shows the average annual cost per line under similar conditions for an exchange of about 4,000 lines. It will be appreciated, however, that the cost per circuit-mile of conductors is less where development is high than where it is sparse, owing to the economic advantage to be obtained from large nests of ducts and large cables. A correcting factor has therefore been included in the graph for the purpose of adjusting the costs.

Although the cost of subscribers' line plant will be

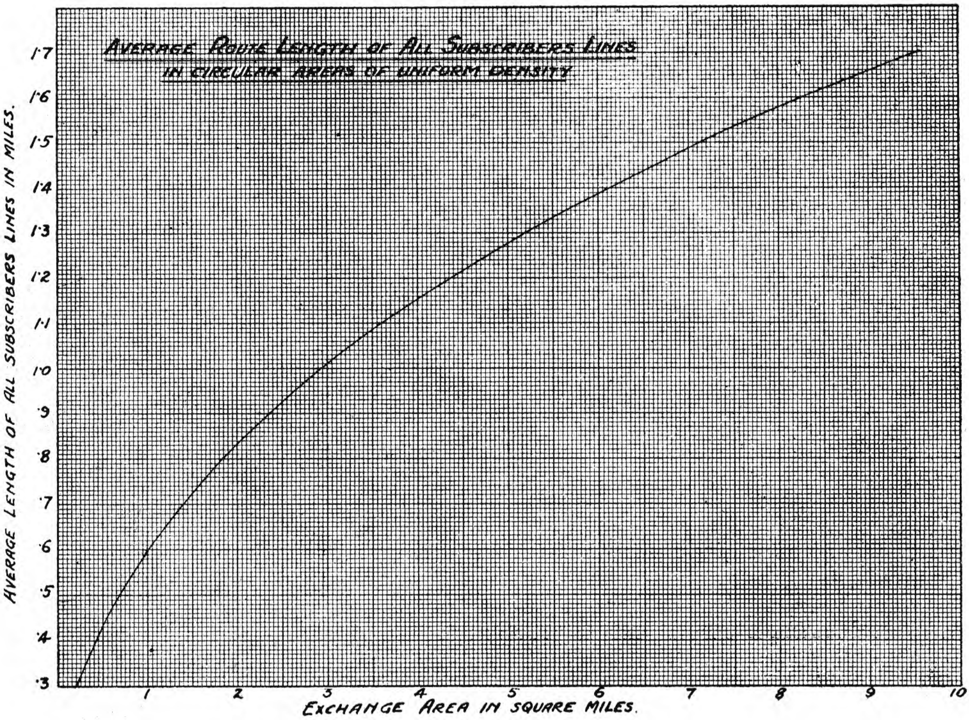
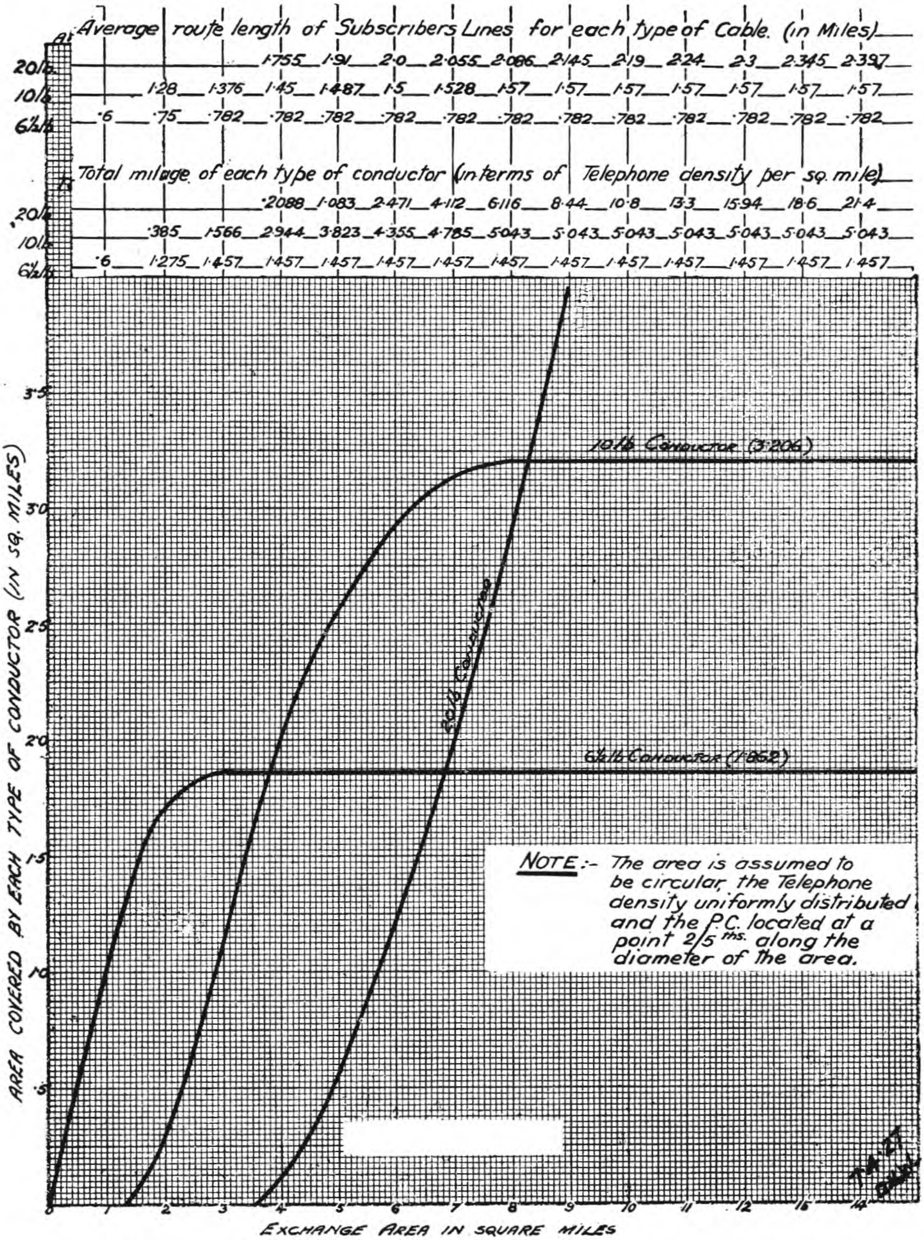


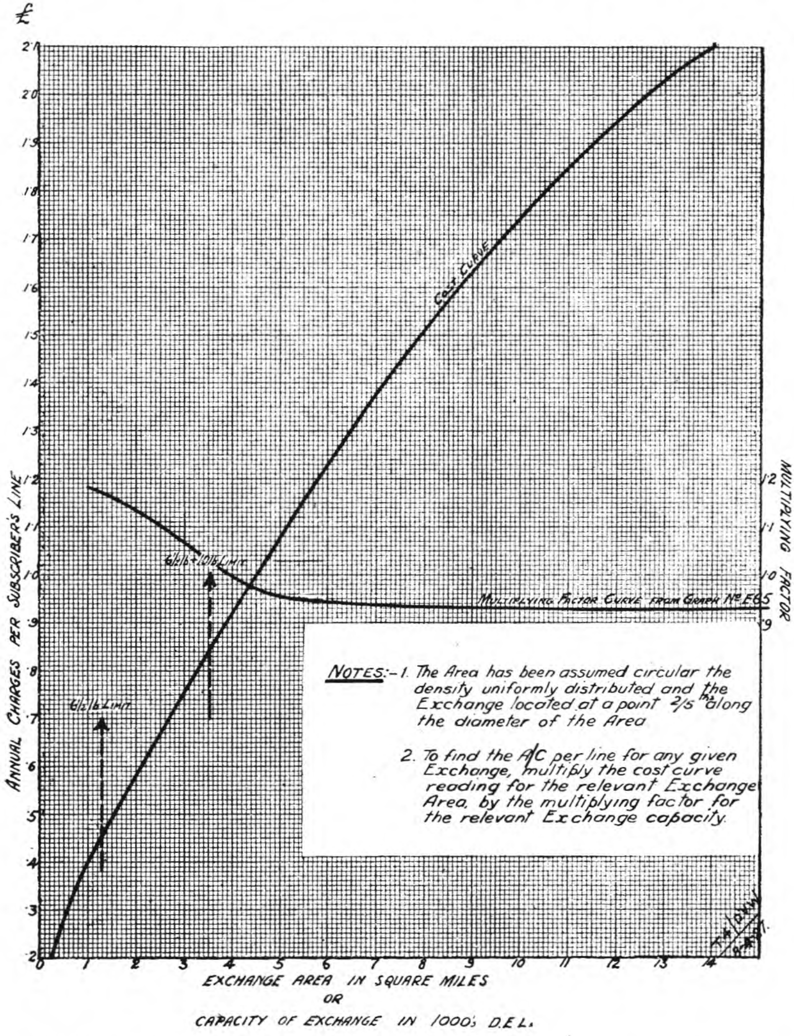
FIG. 17.

reduced by adopting small areas, site and building costs will be increased. Fig. 20 shows the average cost per direct exchange line for sites in different parts of London according to the size of the exchange. Fig. 21 shows how building costs per line increase as the size of the exchange decreases. The graph shown refers to buildings for automatic exchanges, but similar ones are prepared for manual exchanges. In both cases the size of the building is also dependent on the busy hour calling rate, and a number of graphs are therefore



GRAPH SHOWING, FOR ANY GIVEN AREA, THE SUPER AREA, COVERED BY EACH TYPE OF CONDUCTOR IN ORDER TO OBTAIN A MAXIMUM RESISTANCE OF 300Ω STROWGER 48 V. A.T. SYSTEM.

FIG. 18.



ANNUAL CHARGES PER SUBS LINE IN A.T. EXCHANGE AREAS WHERE PLANT IS PROVIDED ON A 300Ω LOOP BASIS.

FIG. 19.

shown. An increase in the number of junctions is a natural result of subdividing areas, and allowance is made for the additional junction costs incurred by converting local traffic into junction traffic. Automatic exchange equipment costs

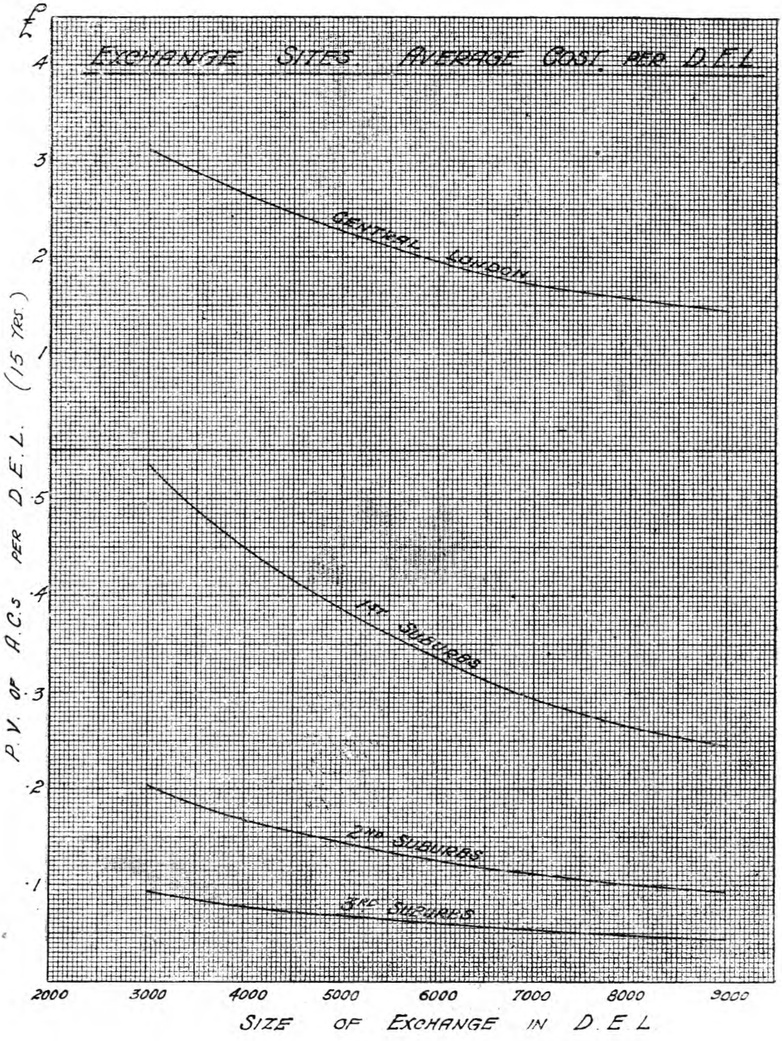


FIG. 20.

per line are also increased if the exchange is small, owing to the loss of efficiency in common apparatus and in the grouping of switches. The variable costs for these items are also calculated; and Fig. 22 shows all these variables plotted, together with a summation curve on which the minimum

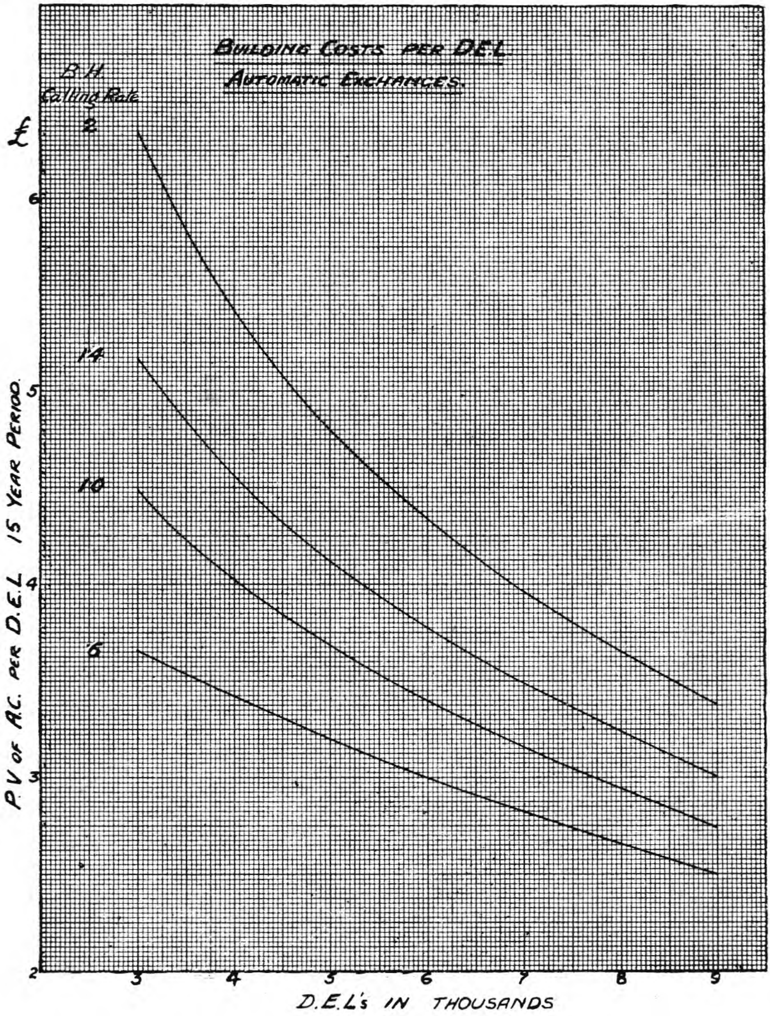


FIG. 21.

point represents the economic size of exchange for the telephone density concerned. Many of these graphs have to be plotted in order to cover the range of site costs, calling rates and densities likely to be met with in practice. Fig. 23 shows how the economic size of automatic exchange area varies with telephone density and site costs.

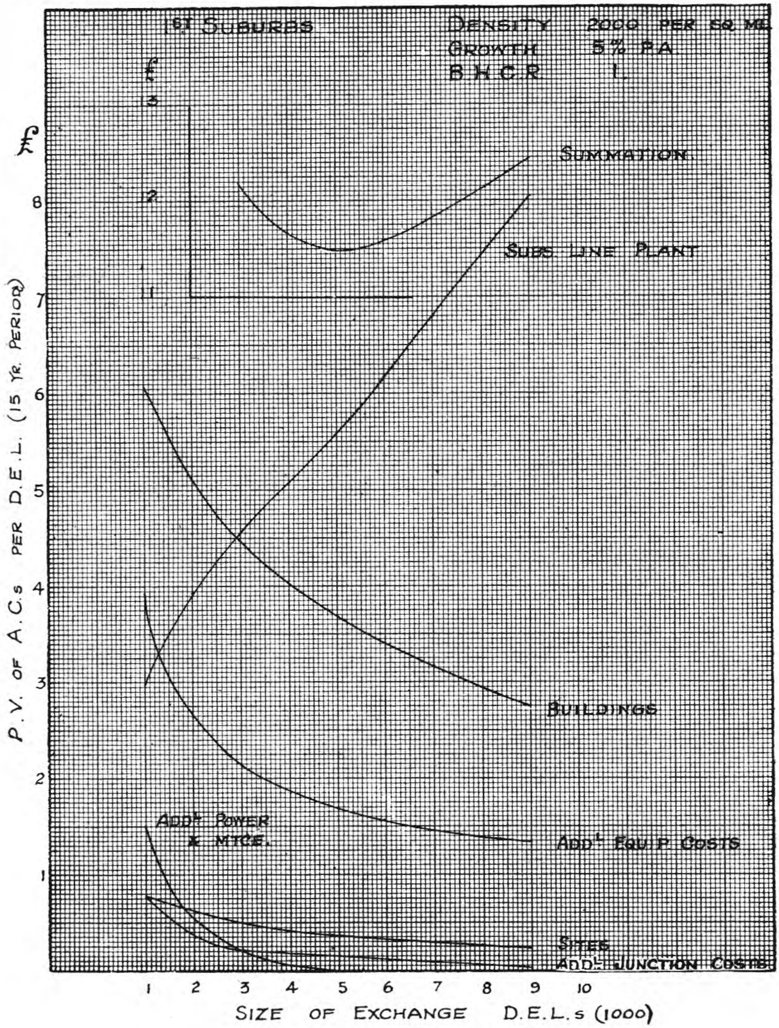


FIG. 22.

Fig. 24 shows the economic number of units to be provided in areas of high telephone density.

It now remains to consider how these curves may be used as a guide to planning when a proposed area is irregular in shape and uneven in the distribution of development.

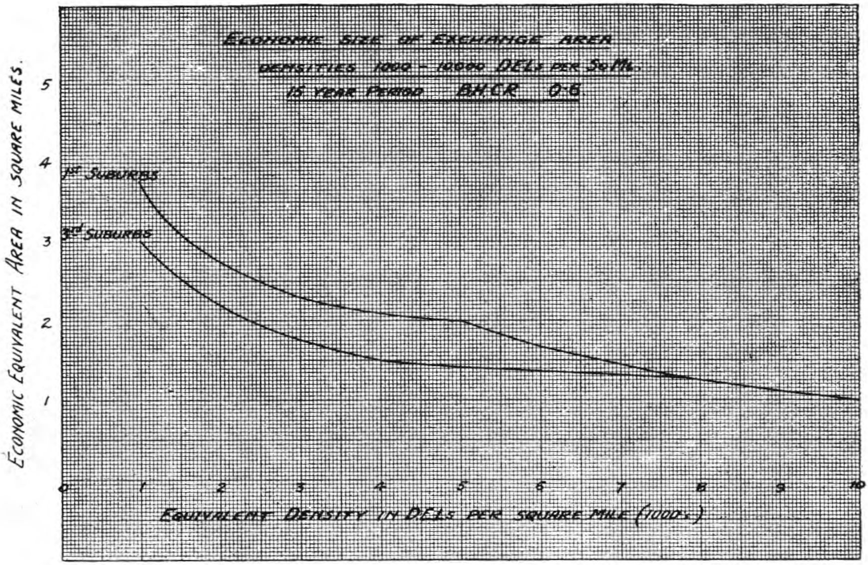


FIG. 23.

ECONOMIC SIZE OF EXCHANGES.
CENTRAL LONDON.
30 Year Period.

Equiv. Den'y D.E.L. per Sq. Mile.	Site Costs per sq. ft.				
	£1	£2	£3	£4	£5
10,000	1 unit	1 unit	1 unit	1 unit	2 unit
20,000	,,	,,	,,	2 unit	,,
30,000	,,	,,	2 unit	,,	,,
40,000	,,	,,	,,	,,	,,
50,000	,,	2 unit	,,	,,	3 unit
60,000	,,	,,	,,	,,	,,
70,000	,,	,,	,,	3 unit	,,
80,000	,,	,,	,,	,,	,,
90,000	,,	,,	3 unit	,,	,,
100,000	,,	,,	,,	,,	4 unit

FIG. 24.

To facilitate the costing of the line plant for a preliminary study, a special form of calculating rule is prepared which will enable the cost per line for groups of development at various distances from the exchange to be readily ascertained. Fig. 25 shows the method of constructing the scale. The upper portion consists of the " route to radial " curve, and to the left of the ordinate is given the annual charge per circuit for each type of conductor. By plotting this graph

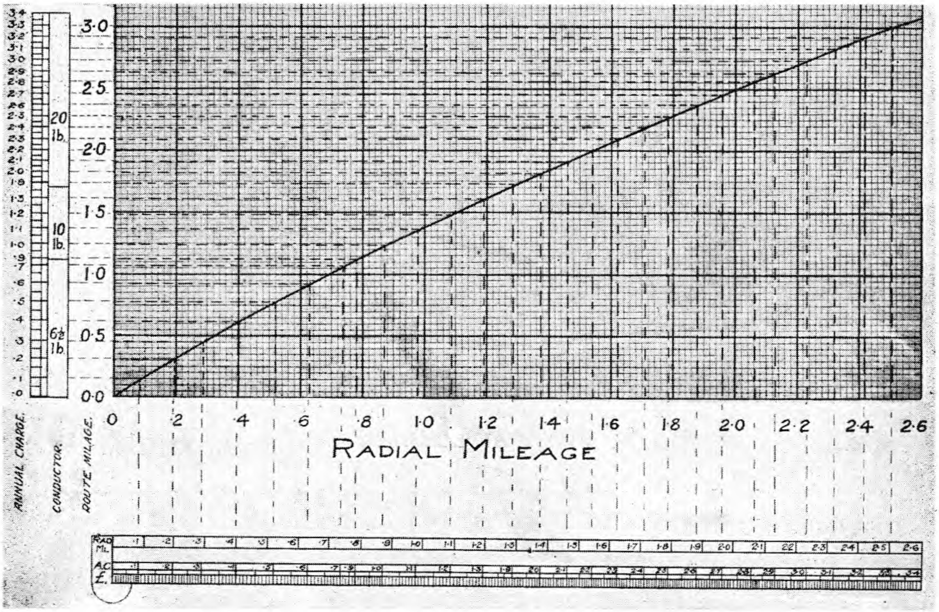


FIG. 25.

to the scale of the map to be used and by projecting the readings, a scale may be calibrated showing the annual charge per circuit for groups of development at various radial distances from the exchange. If the cost per circuit is read from the scale for each block of development on the summary plan and is multiplied by the number of subscribers per block, the cost of the line plant for serving the whole area may be readily calculated: this total, divided by the number of subscribers in the area, will give the average cost per line. Fig. 19 indicates the average cost per line for areas of different sizes when the development is uniformly distributed and, by

Actual and Equivalent Areas.

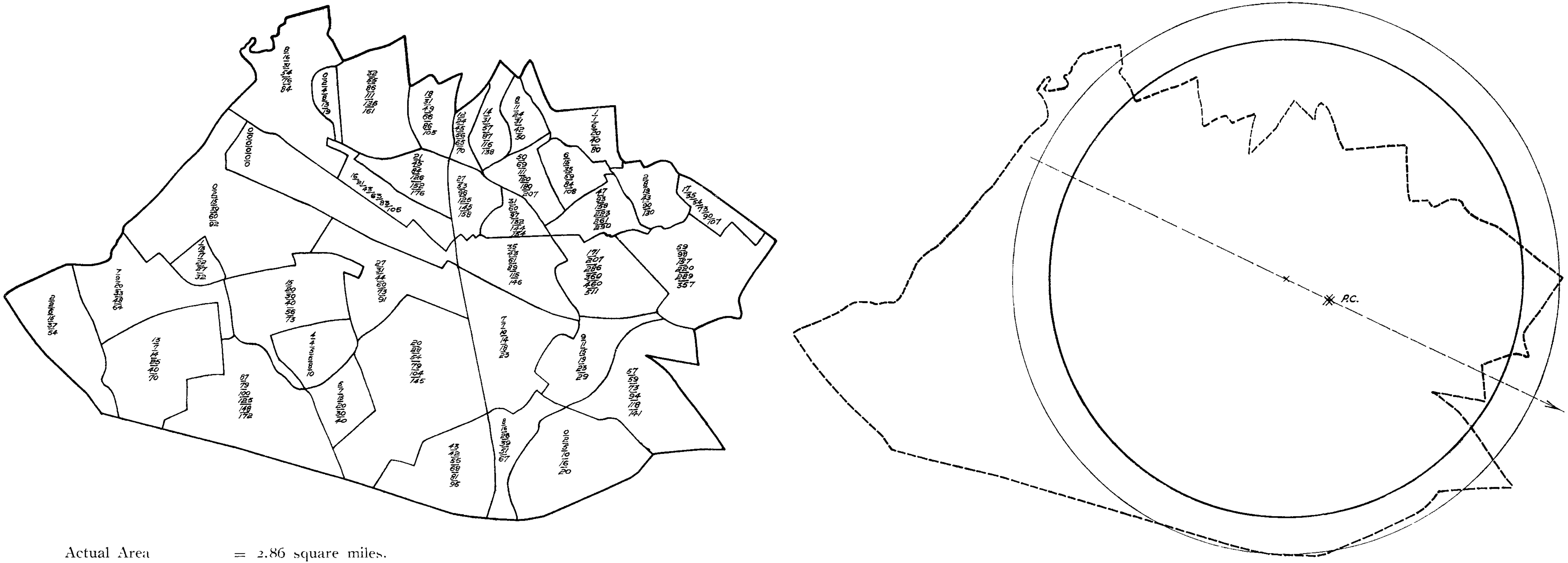


Fig. 26.

Actual Area = 2.86 square miles.
Average Density = 2400 D.E.L.s per square mile.
Average A/C per line = £.623
Equivalent Area = 2.20 square miles.
Equivalent Density = 3110 D.E.L.s per square mile.

reading in the reverse direction from this graph, the area of uniform density having a similar cost will be found. Fig. 26 shows an actual area and an area of uniform density having equal costs. If the development forecast for the area now be divided by the area as obtained from the graph, the equivalent density will be obtained, and all costs shown on the fundamental curves for areas of uniform density will be applicable. In this way an idea may be gained of the approximate size of exchange which will be economical for the portion of territory under review, and alternative schemes for serving the area may be prepared. It should be emphasized that the above method is a guide, and limits the number of methods which will require detailed investigation.

At this stage, it is necessary to determine the practical centres of the proposed areas, as defined on the alternative lay-outs, *i.e.*, the points at which line plant costs would be at a minimum. To enable this to be done a forecast of the junction requirements under each scheme will be necessary. A method of forecasting traffic has been developed by Messrs. Knight and Gadsby of the London Telephone Service, and I am indebted to them for permission to reproduce some of their diagrams. The method briefly consists of assessing, from the results of the traffic records, the acquaintance factors of every exchange to every other exchange, and then projecting the traffic to the required date in accordance with a function of the product of the growth factors of the originating and receiving exchanges. The form of this function will depend on whether it is anticipated that the average calling rate will increase, fall, or remain constant, and it may be varied from time to time as further records reveal the tendencies. Fig. 27 shows the lines of equal acquaintance for the Hampstead Exchange. The acquaintance factors for new exchanges are obtained from the acquaintance factors of existing exchanges as shown in Fig. 28.

When a forecast of the traffic has been obtained, it is necessary for the engineer to determine the most economical routing for this traffic, *i.e.*, whether the traffic should be carried direct from one exchange to another or whether it should be switched at some intermediate point. To enable this to be done, a junction route plan is prepared showing, diagrammatically, the positions of existing and proposed exchanges, together with junction links joining them. These links are drawn to scale and represent the actual route distances be-

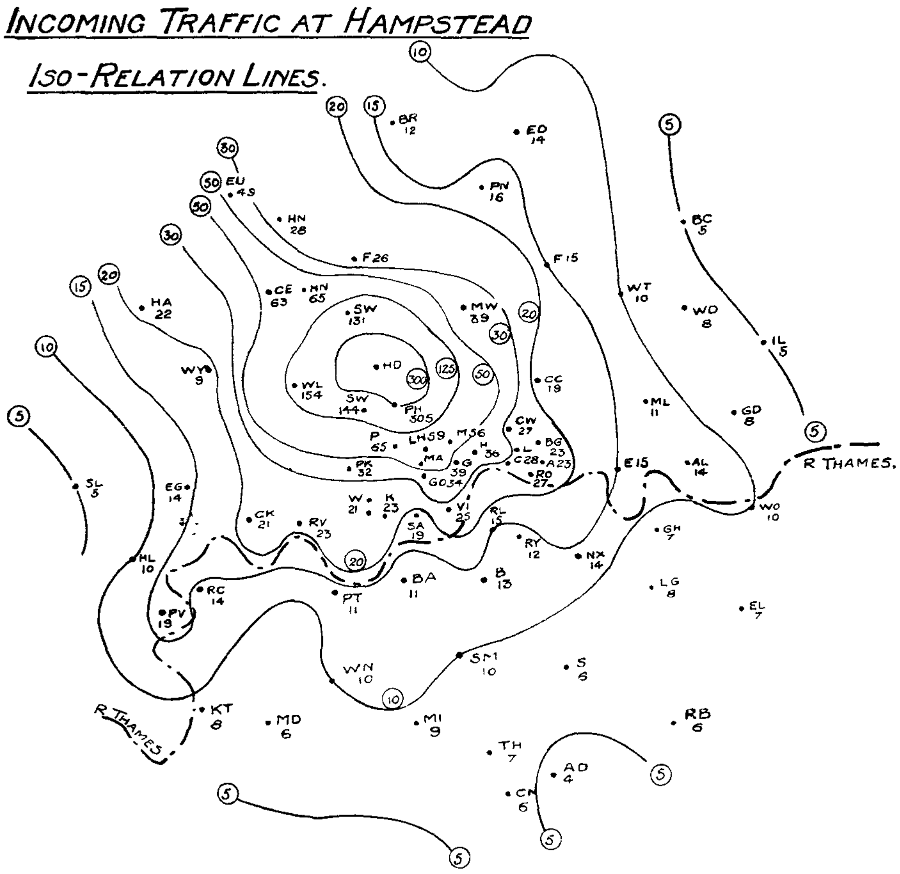


FIG. 27.

tween the exchanges. Suitable scales which indicate the type of conductor necessary and the annual charge per circuit are used in conjunction with the map which is illustrated in Fig. 29. By using these scales, the cost per circuit by alternative routings may be easily ascertained. Fig. 30 shows the number of circuits required for any number of traffic units when traffic is routed as an individual group, or when combined with other traffic to form a larger group. The product of the figure obtained by the use of the scales and the reading from the graph will give the total line plant costs for the alternative routings. It is, however, necessary

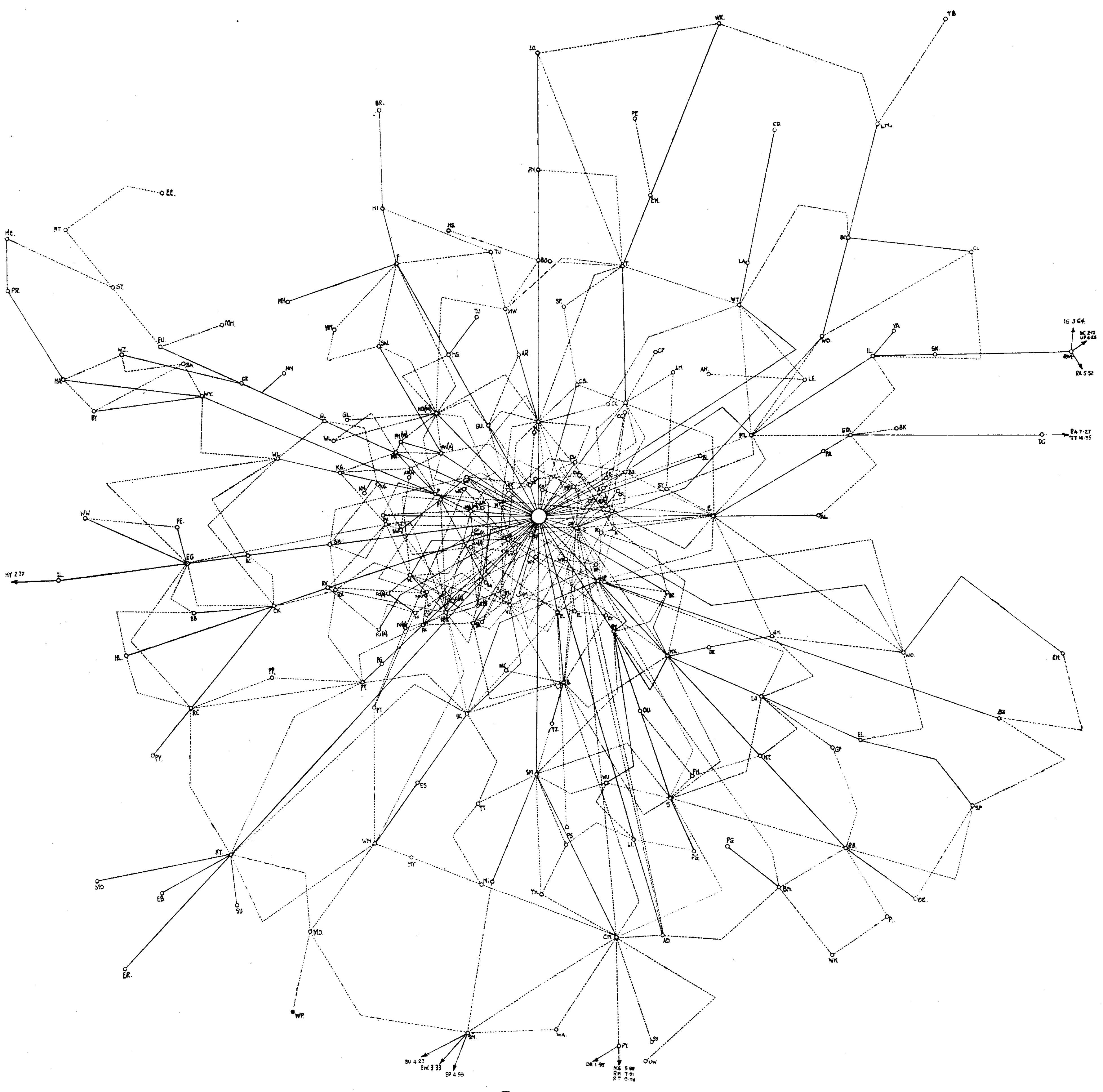


FIG. 29.

METHOD OF DETERMINING ACQUAINTANCE FACTORS FOR NEW EXCHANGES.

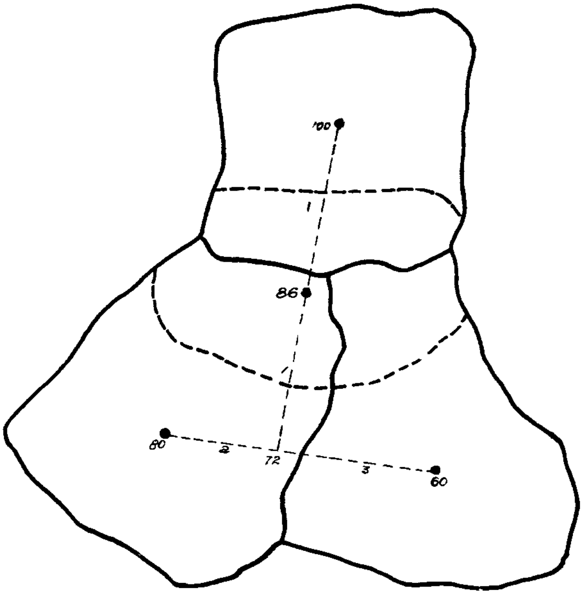


FIG. 28.

to take into account the variations in equipment costs, and Fig. 31 shows how these vary according to the number of traffic units to be routed. The combination of the two costs thus obtained will enable the most economical routing to be determined. When the total traffic on each route has been determined, the junctions necessary can be calculated from the appropriate tables and the class of conductor indicated. This information is then shown in the form illustrated in Fig. 32.

The determination of the practical centre may now be commenced. The first stage is to calculate the theoretical centre for direct exchange lines only. This is obtained in the manner which is doubtless familiar to everybody, by adding the subscribers development in vertical and horizontal columns, and by drawing lines which will divide the total development into equal portions north and south, and east and west. The point of intersection of these lines gives the

EFFICIENCY OF JUNCTION GROUPS.

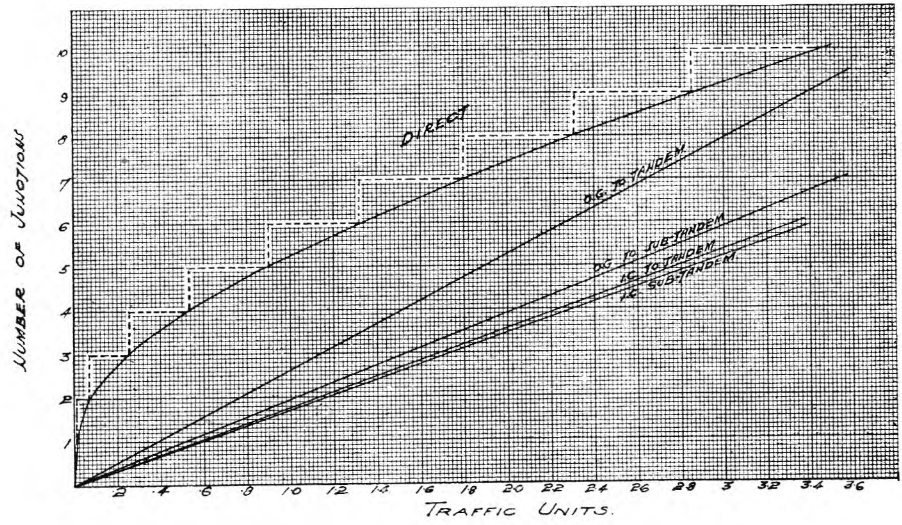


FIG. 30.

primary theoretical centre. This point is not, however, the true subscribers' centre, unless the area is small enough to be served entirely on $6\frac{1}{2}$ lb. conductor, but it will serve to define zones around it indicating the territory which can be served by each type of conductor. Weighting factors are then applied to the development figures in each zone and the theoretical centre is recalculated. The weighting factors represent the cost of the heavier conductors in terms of $6\frac{1}{2}$ lb. conductor. This centre, as now calculated, may be used as a guide to the points at which the junction plant should enter the area, and, the junction forecast having been obtained as already described, the junction pairs, duly weighted for the type of conductor concerned, can be indicated on the plan at the boundaries of the area at the appropriate points of entry. A third theoretical centre is then obtained based on the weighted subscribers and junction forecasts and this will probably be near the practical centre, which is the point at which line plant costs will be at a minimum.

To enable the practical centre to be calculated, a plan is obtained showing details of the existing line plant, and the weighted figures are collected on to routes and summated in

TRAFFIC ROUTING—AUTO TO AUTO—TANDEM V. DIRECT EQUIPMENT COSTS.

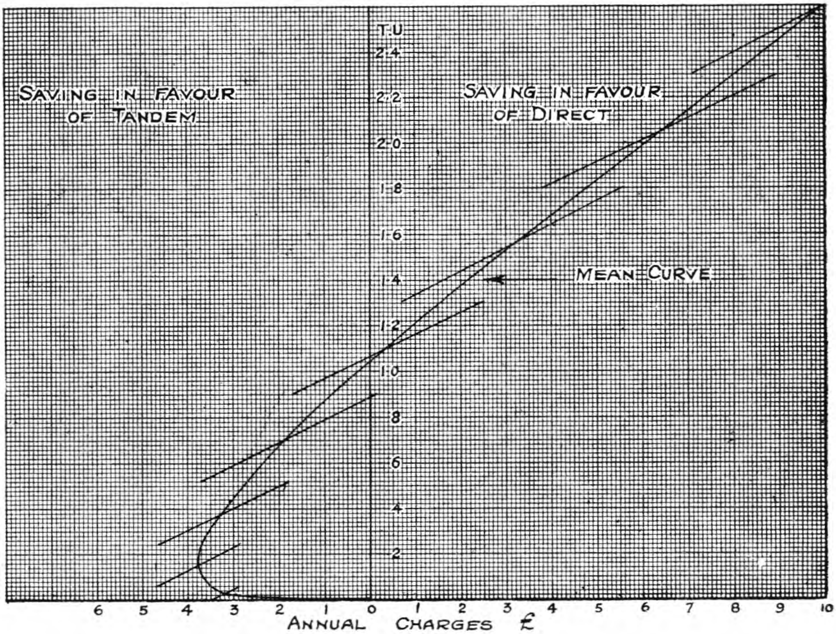


FIG. 31.

the direction of the theoretical centre, until a point is reached where the difference between the weighted figures from different directions will be at a minimum.

If there is a considerable difference between the rates of growth in various parts of the area during the period for which the exchange is to serve, it will be necessary to prepare weighted figures for an intermediate as well as the ultimate date, and to apply suitable P.V. multipliers to the figures in order to arrive at the point of minimum cost when the whole period is taken into account. Fig. 33 shows a typical case.

Practical centres having been obtained for the proposed areas under the alternative lay-outs, the two schemes may be compared.

The next stage will be to formulate a programme showing the dates at which the individual exchanges should be provided under the alternative schemes. The exhaustion

POST OFFICE ENGINEERING DEPARTMENT.

Estimate of Junction requirements for 1940 **as at** . / / 1930

Exchange CEDARS (INCOMING)

EXCHANGE	TU	DIRECT C	DIRECT No	TM	Sub TM	EXCHANGE	TU	DIRECT C	DIRECT No	TM	Sub TM	EXCHANGE	TU	DIRECT C	DIRECT No	TM	Sub TM
Abercorn	15			✓		Fulham	·39			✓		Perivale	10			✓	
Acorn	·13			✓		Gerrard	1·32				✓	Pimlico					
Addiscombe	·8				✓	Gladstone						Plashet	·18			✓	
Albert Dock	·11			✓		Grangewood	·18			✓		Pollards	7	10	5		
Ambassador						Greenwich	·54				✓	Ponders End					
Amherst	·19			✓		Grosvenor	·45				✓	Popesgrove	12			✓	
Archway	·08			✓		Grove Park						Primrose	·21			✓	
Avenue	1·2				✓	Gulliver	·21			✓		Prospect	·09			✓	
Barking						Hampstead	·32			✓		Putney	·45				✓
Barnet	06			✓		Harrow	·03			✓		Ravensbourne	1·62	10	7		
Balham						Hendon	·12			✓		Regent					
Barnhill	01			✓		Highgate						Reliance	1·0				✓
Battersea	·6			✓		Hillside	·09			✓		Richmond	09			✓	
Bayswater	15			✓		Hither Green	1·32	10	6			Riverside	·3			✓	
Beckenham	1·62	10	7			Holborn	1·14				✓	Rodney	1·0	10	6		
Beehive						Hop	1·3				✓	Royal	1 85				✓
Bermondsey	·9				✓	Hounslow	·09			✓		Shepherd's Bush	·21			✓	
Bethnal Green	09			✓		Ilford	·06			✓		Silverthorn	·03			✓	
Bishopsgate	1·02				✓	Kelvin	·06			✓		Sloane	·42				✓
Bowes Park						Kensal Green						Southfields					
Brentford						Kensington	45			✓		Southall	·09			✓	
Brixton	2·16	10	8			Kingston	·18			✓		Speedwell	1·98			✓	
Buckhurst	·09			✓		Langham	·3				✓	Stamford Hill	·18			✓	
Byron	·01			✓		Larkswood	·03			✓		Stepney					
Canonbury	·18			✓		Lee Green	2·8	10	9			Streatham	2·25	10	8		
Central	1·86				✓	Leytonstone	·09			✓		Spring Grove					
Chancery	18				✓	Livingstone	1·5	10	7			Sydenham	7·5	10	17		
Charterhouse						London Wall	1·2				✓	Talbot					
Chipping Barnet						Macaulay	09				✓	Tandem					
Chiswick	·3			✓		Maida Vale	·18			✓		Temple Bar	1·2				✓
City	1·68				✓	Malden	·12			✓		Terminus	·42				✓
Clapton						Mansion House	·6				✓	Thornton Heath	1·26	20	6		
Clerkenwell	1 2				✓	Maryland	·18			✓		Tooting					
Clissold	·45			✓		Mayfair	·36				✓	Toll	·98	40	4		
Colindale						Melina						Tottenham	·12			✓	
Concord						Merton Abbey	·06			✓		Trunks					
Croydon	·92	10	6			Metropolitan	2·75	10	9			Tudor	·17			✓	
Deptford						Mill Hill	·09			✓		Tulse Hill	1·32	10	6		
Dulwich						Minories						Valentine	·06			✓	
Ealing	·2			✓		Mitcham	·21				✓	Victoria	1·05				✓
Earlsfield						Monument	·65				✓	Walthamstow	·15			✓	
East	·36			✓		Mountview	·21			✓		Wanstead	102			✓	
Edgware						Museum	1·35				✓	Waterloo	·19				✓
Edmonton						National	2·75	10	9			Waxlow	·03			✓	
Eltham	·15				✓	New Cross	2·3	10	8			Welbeck	·3				✓
Empire						New Southgate						Wembley	·06			✓	
Enfield	·12			✓		North	·46			✓		West Dulwich					
Euston	45				✓	North Harrow						Western	·24			✓	
Fairfield	·95	10	6			Notting Hill						Westminster					
Finchley	·18			✓		Paddington	·56			✓		Whitehall	·52				✓
Fitzroy	·03				✓	Palmer's Green	·09			✓		Willesden	·45			✓	
Flaxman	1·15			✓		Park	·18			✓		Wimbledon	·21			✓	
Forest Hill						Parsons Green						Winchmore Hill					
Franklin	·91				✓	Pembroke						Woolwich	·45				✓
Frobisher	·14			✓		Penge						Wordsworth	·03			✓	
												TANDEM	12·60	40	31		
												SUB TANDEM	26·94	20	47		

FIG. 32.

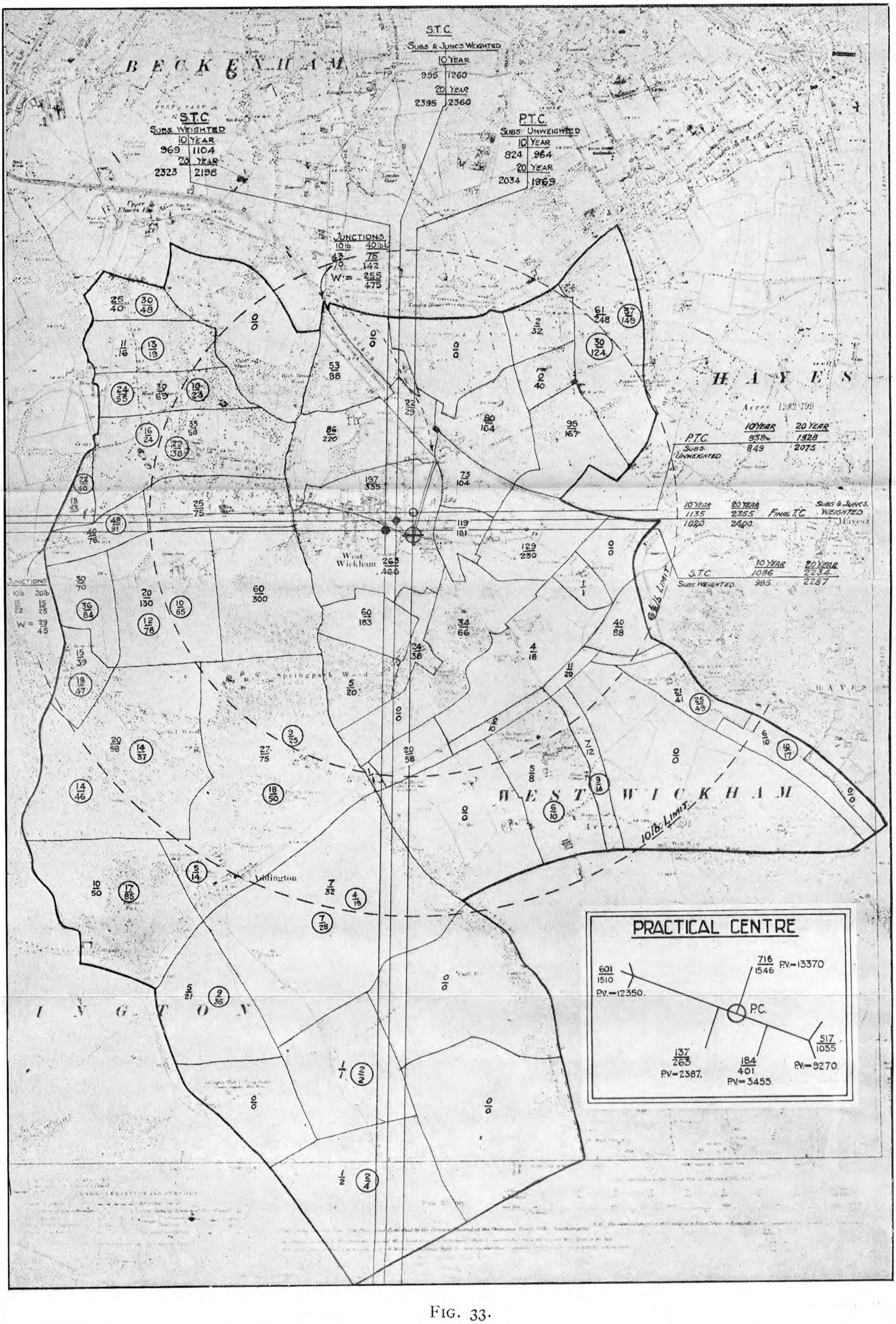

BECKENHAM
S.T.C.
Subs & Juncs Weighted
10 Year
995 1260
20 Year
2395 2360
S.T.C.
Subs. Weighted
10 Year
969 1104
20 Year
2323 2198
P.T.C.
Subs. Unweighted
10 Year
824 964
20 Year
2034 1969
Junctions
10 lb 40 lb
HAYES
P.T.C. Subs. Unweighted
10 Year 938 849
20 Year 1928 2075
Final T.C.
Subs & Juncs. Weighted
10 Year 1135 1020
20 Year 2355 2400
S.T.C. Subs Weighted
10 Year 1086 985
20 Year 2234 2287
West Wickham
Springpark Wood
WEST WICKHAM
10 lb. Limit
6½ lb Limit
Addington
Practical Centre
601/1510 P.V.—12350
716/1546 P.V.—13370
P.C.
137/263 P.V.—2387
184/401 P.V.—3455
517/1035 P.V.—9270

Fig. 33.

dates of the exchange capacity will in many cases automatically decide the priority of relieving exchanges, but it may happen that one exchange could conveniently serve two areas for a period of years. A separate investigation is then necessary to determine the economic date for opening the second exchange.

Fig. 34 shows a typical cost statement indicating the P.V. of annual charges on all variable items of plant when the additional exchange is opened at various dates. These dates are usually taken at intervals of five years and a graph is plotted (Fig. 35). The minimum point of this curve will indicate the approximate date at which the exchange should be opened in order to realise the maximum economies. A tentative programme is now prepared for each of the alternative lay-outs, and a financial statement is compiled to show a comparison of the P.V. of annual charges for the planning period. All the necessary detailed information relative to the individual problem is at this stage taken into account. A proposal for the revision of the lay-out can then be formulated, and Fig. 36 shows a typical example.

Similar methods are used in determining the lay-out under manual conditions, but the additional factor of operating costs has to be included in the financial statement. If a given manual area is divided into two exchange areas, then additional annual charges will be incurred due to the increase in junction traffic and to the loss of efficiency in staffing. Fig. 37 shows a typical curve for determining the economic date of opening for a relieving manual exchange in the outer London zone.

The gradual conversion of London to automatic working has introduced an interesting problem in connection with the replacement of manual exchanges. Fig. 38 shows (*a*) the number of lines working on automatic and manual exchanges at the present time within the automatic zone, and (*b*) the estimated number of lines at the 1st January in each of the next few years in accordance with the present programme with a projection to 1940. Fig. 39 shows the same information in the form of a percentage. Under the system of working adopted in London it is well known that all calls from automatic to manual subscribers are routed *via* Coder Call Indicator positions at the manual exchanges: Fig. 40 shows the number of calls to be so routed year by year, and is a measure of the total C.C.I. equipment necessary. By assum-

ECONONOMIC OPENING DATE FOR SECOND AUTOMATIC EXCHANGE.

Opening Date.	1935				1940				1945				1950			
Item.	Period.	A.C.	P.V. Mult.	P.V. of A.C.	Period.	A.C.	P.V. Mult.	P.V. of A.C.	Period.	A.C.	P.V. Mult.	P.V. of A.C.	Period.	A.C.	P.V. Mult.	P.V. of A.C.
		£		£		£		£		£		£		£		£
EXCH. A.																
Site	1935/55	206	12.46	2,565	1935/55	206	12.46	2,565	1935/55	206	12.46	2,565	1935/55	215	12.46	2,680
Building	1935/55	2312	12.46	28,800	1935/55	2532	12.46	31,500	1935/55	2673	12.46	33,300	1935/55	2937	12.46	36,600
,, extension	1950/55	495	2.08	1,030	1950/55	275	2.08	572	1950/55	—	—	—	1950/55	—	—	—
Variable equipt.	1935/55	1600	12.46	19,900	1935/55	1600	12.46	19,900	1935/55	1600	12.46	19,900	1935/55	1600	12.46	19,900
EXCH. B.																
Site	1935/55	198	12.46	2,465	1940/55	203	8.13	1,650	1945/55	208	4.74	985	1950/55	212	2.08	441
Building	1935/55	1834	12.46	22,850	1940/55	2040	8.13	16,600	1945/55	2230	4.74	10,600	1950/55	2383	2.08	4,960
,, extension	1950/55	529	2.08	1,100		—		—				—		—		—
Variable equipt.	1935/55	1600	12.46	19,900	1940/55	1600	8.13	13,000	1945/55	1600	4.74	7,590	1950/55	1600	2.08	3,325
Additional Line Plant					1935/40	1222	4.33	5,300	1935/45	1222	7.72	9,430	1935/50	1222	10.38	12,700
									1940/45	1222	3.39	4,150	1940/50	1222	6.05	7.400
													1945/50	1222	2.60	3,250
Wastage on ditto.					1940/55	691	8.13	5,620	1945/55	1382	4.74	6.550	1950/55	2073	2.08	4,310
				98,610				96,707				95,070				95,566

FIG. 34.

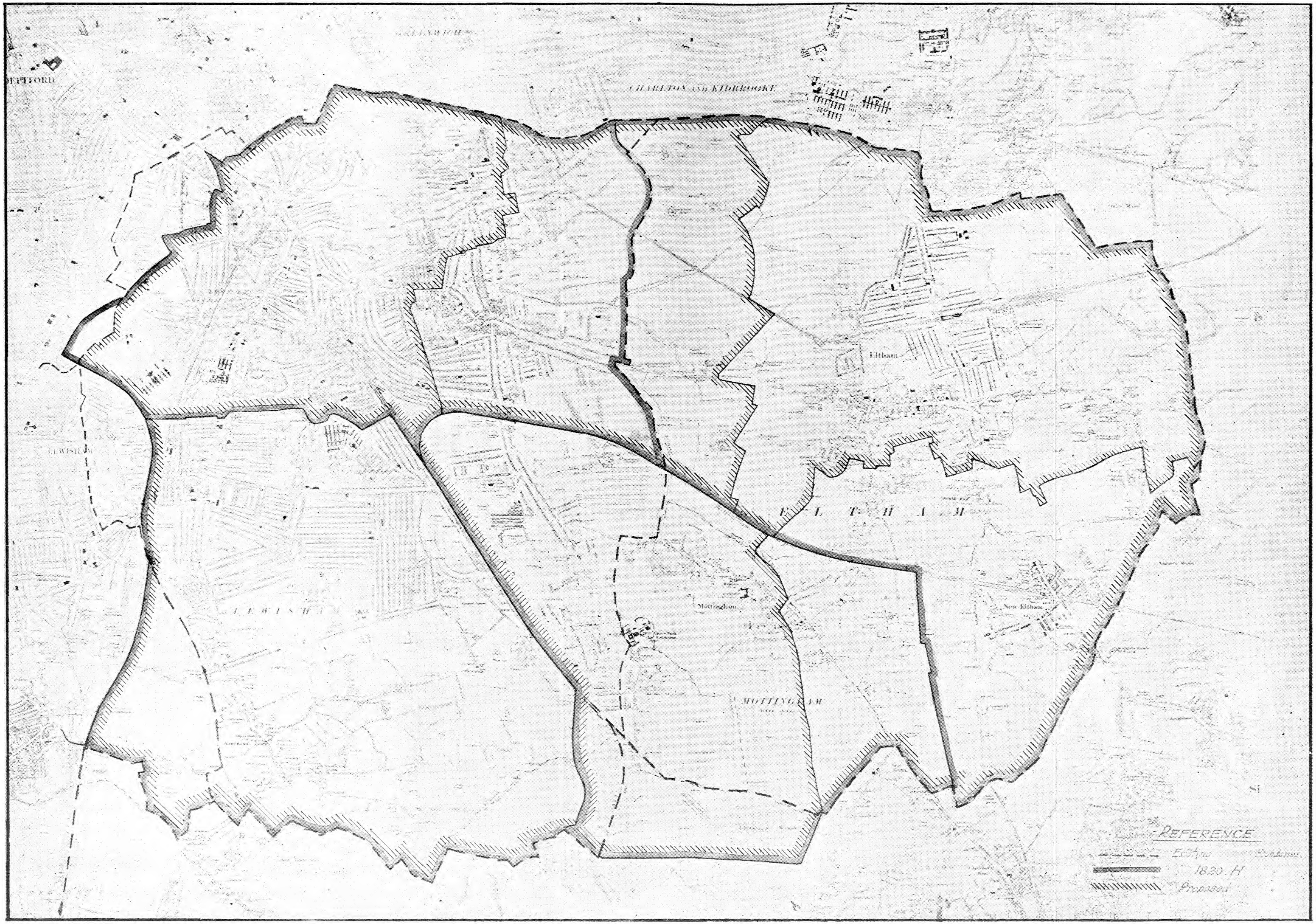

DEPTFORD
CHARLTON AND KIDBROOKE
LEWISHAM
Eltham
E L T H A M
Mottingham
New Eltham
MOTTINGHAM
REFERENCE
Existing Boundaries
1820. H
Proposed

FIG. 36.

ECONOMIC OPENING DATE OF 2ND AUTO. EXCHANGE.

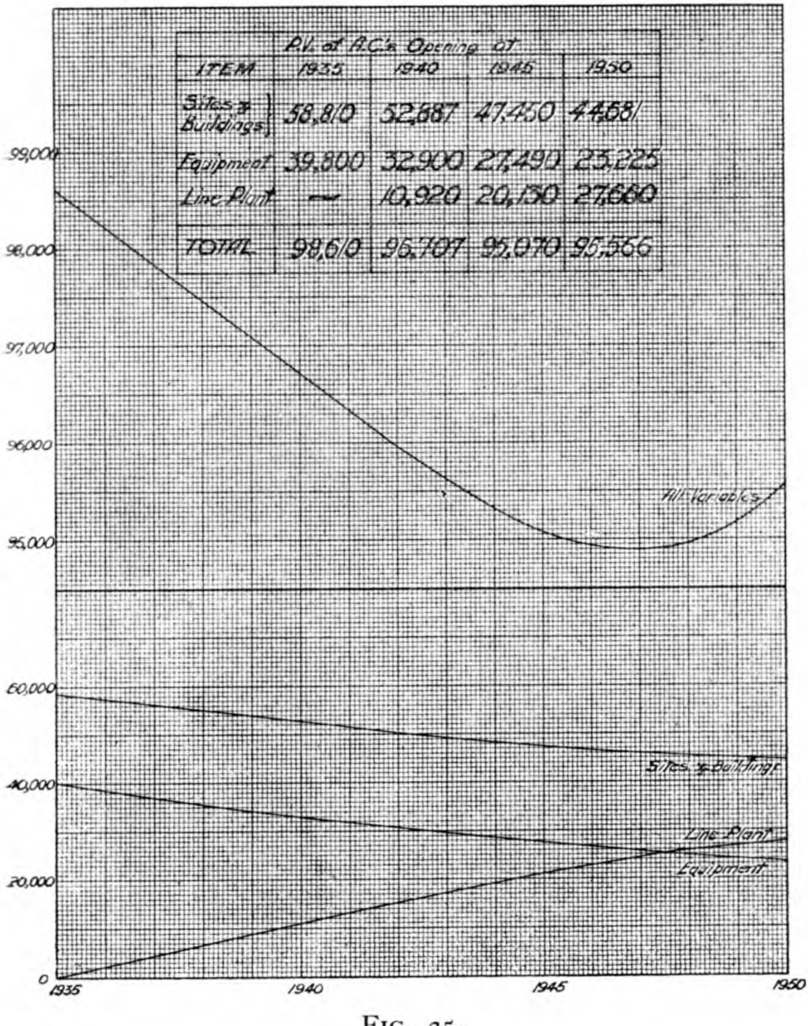
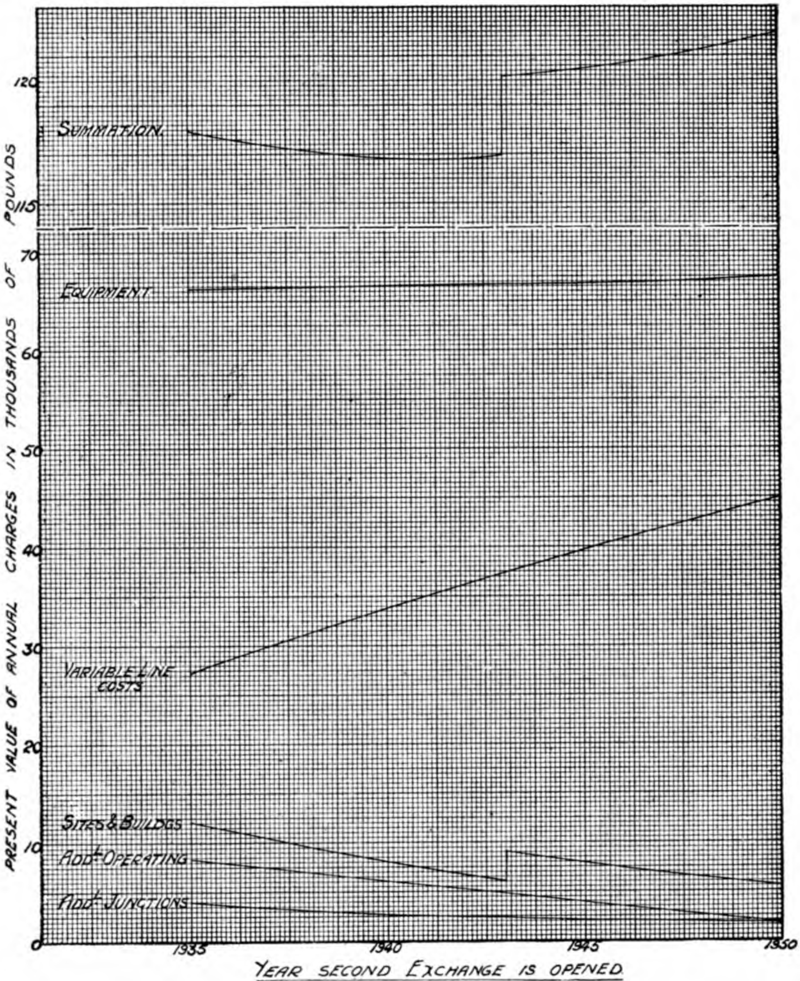


FIG. 35.

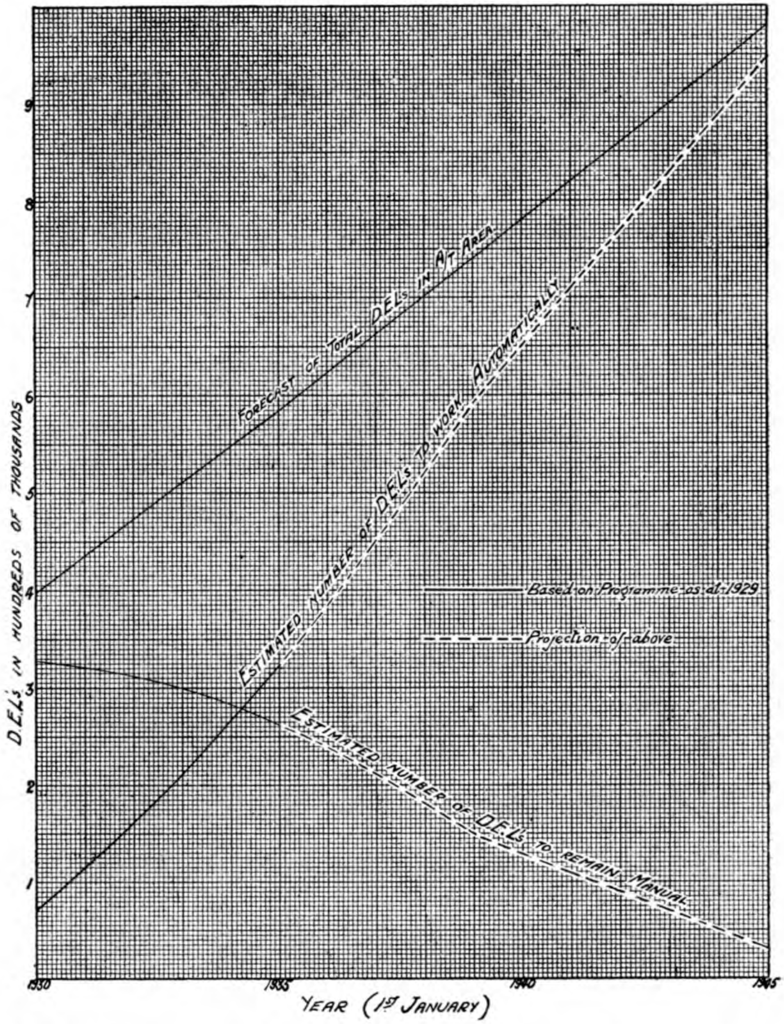
ing, for the moment, that the programme of conversion beyond 1935 follows the same rate as that up to 1935, the traffic curve when extended shows a peak of C.C.I. traffic at 1936, and a rapid falling away beyond that date. It is interesting to note the effect on the position and magnitude of the



ECONOMIC DATE OF OPENING MANUAL EXCHANGES.

FIG. 37.

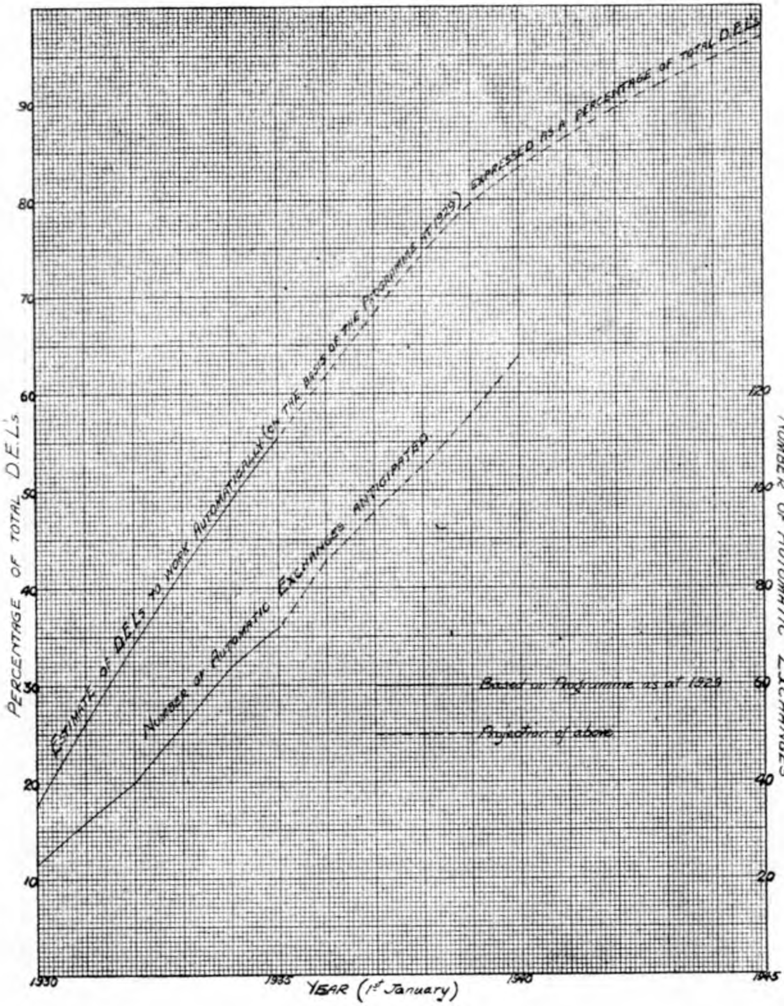
peak of increasing the rate of conversion. If, for example, it were possible to increase by 10% the number of lines to be working automatically each year according to the present programme then the peak of C.C.I. traffic would be advanced and at the same time reduced in magnitude. Now it is obviously possible to increase the number of lines working



ESTIMATE OF THE NUMBER OF D.E.L's WITHIN THE LONDON AUTO. AREA WHICH WILL BE CONNECTED TO AUTOMATIC AND MANUAL EXCHANGES RESPECTIVELY ACCORDING TO THE PROGRAMME AT 1929.

FIG. 38.

automatically by converting more existing manual exchanges to automatic working or, alternatively, by relieving manual exchanges by additional transfers to existing or proposed



ESTIMATE OF THE NUMBER OF AUTOMATIC EXCHANGES TO BE WORKING IN LONDON AND THE PERCENTAGE OF TOTAL DEVELOPMENT CONNECTED TO THEM ACCORDING TO PROGRAMME AS AT 1929.

FIG. 39.

automatic exchanges. The lower curves show the average C.C.I. traffic per exchange if the increase in automatic lines

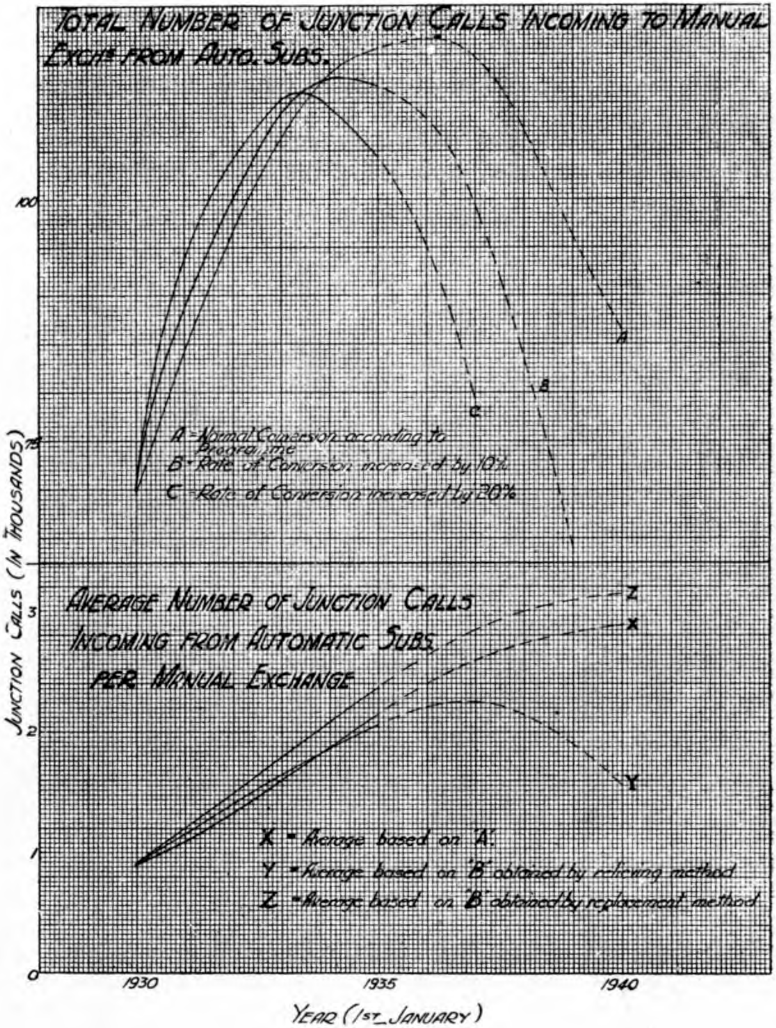


FIG. 40.

is obtained in each of the alternative ways. It would appear that, generally, the greatest economy in C.C.I. positions would be achieved by adopting the relieving method rather than the replacement method, as by so doing the difficulties arising in finding space for increases of C.C.I. apparatus racks will be reduced, and the cost of removal of equipment from one exchange to another will be avoided.

Fig. 41 illustrates how the C.C.I. equipment at a manual exchange may be kept constant by the removal of territory to adjacent exchanges, the traffic capacity of the manual exchange being steadily reduced as the C.C.I. traffic per line is increased.

CEDARS MANUAL EXCHANGE.

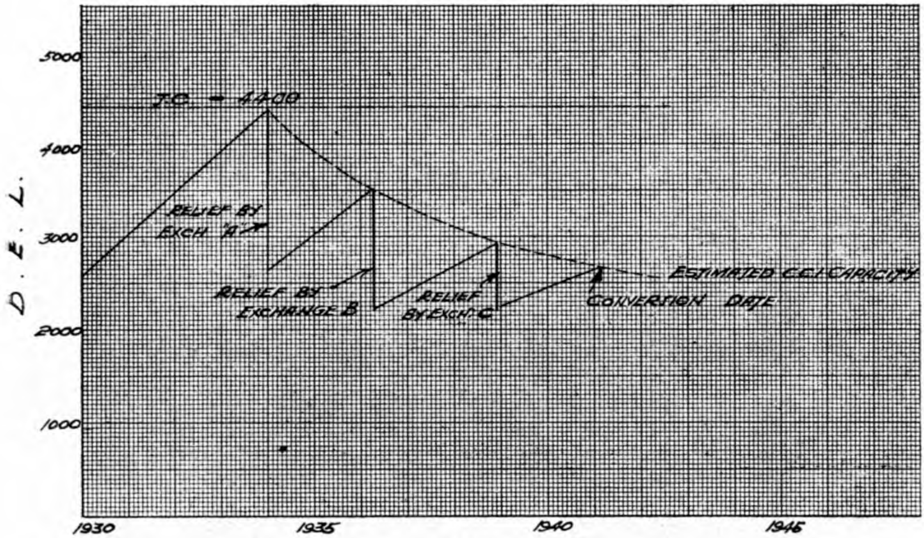


FIG. 41.

It must not be assumed that this conclusion is of general application, and each case must be considered on its merits. There is, moreover, a limit imposed on the amount of relief which can be afforded to an existing area by the provision of additional adjacent exchanges, and that limit is reached when the area has been reduced to its economic size for future automatic working. In such cases it may be economical to convert an exchange to automatic working a considerable number of years before the physical life of the manual equipment has been reached. It is, of course, well known that, when an exchange is recovered before the end of its life, wastage is incurred, and it is an interesting problem to determine the date at which the wastage is at a minimum. If the whole of the equipment were installed at the same time then obviously the minimum point would be at the end of the life of the equipment, but, generally speaking, equipment is provided in instalments from time to time and the wastage incurred by keeping the exchange in service for a few more years may be increased instead of reduced, if the provision of additional equipment is necessary in order to obtain the increased life.

Fig. 42 affords an example, and illustrates how the wastage is increased by the installation of additional equipment at 1934.

EFFECT OF EXTENSION OF EQUIPMENT ON WASTAGE.

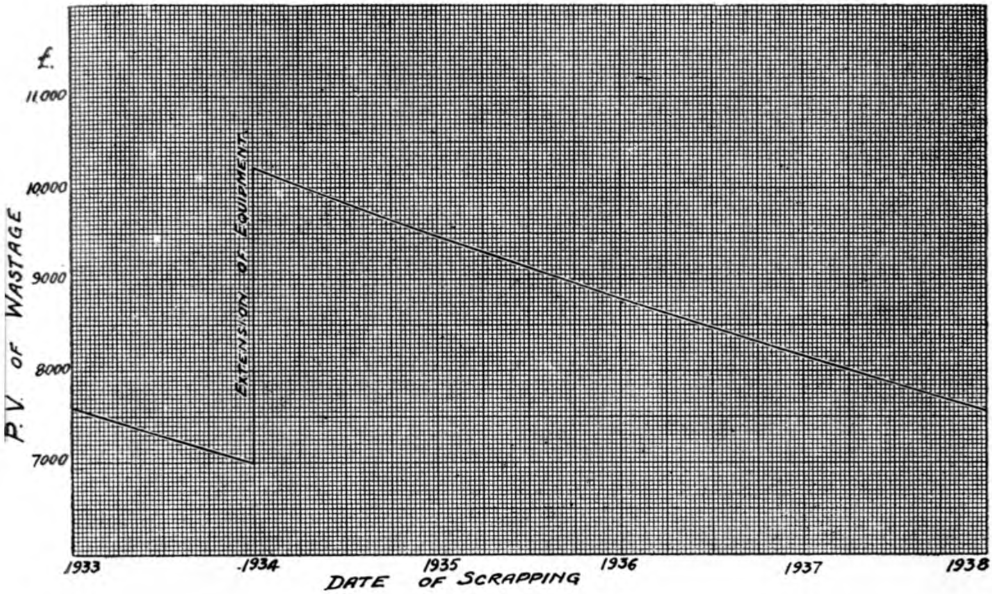


FIG. 42.

Fig. 43 shows an example of the comparison of all variable costs, and illustrates the fact that in this case conversion to automatic working could be justified at an early date in preference to the continuance of manual working.

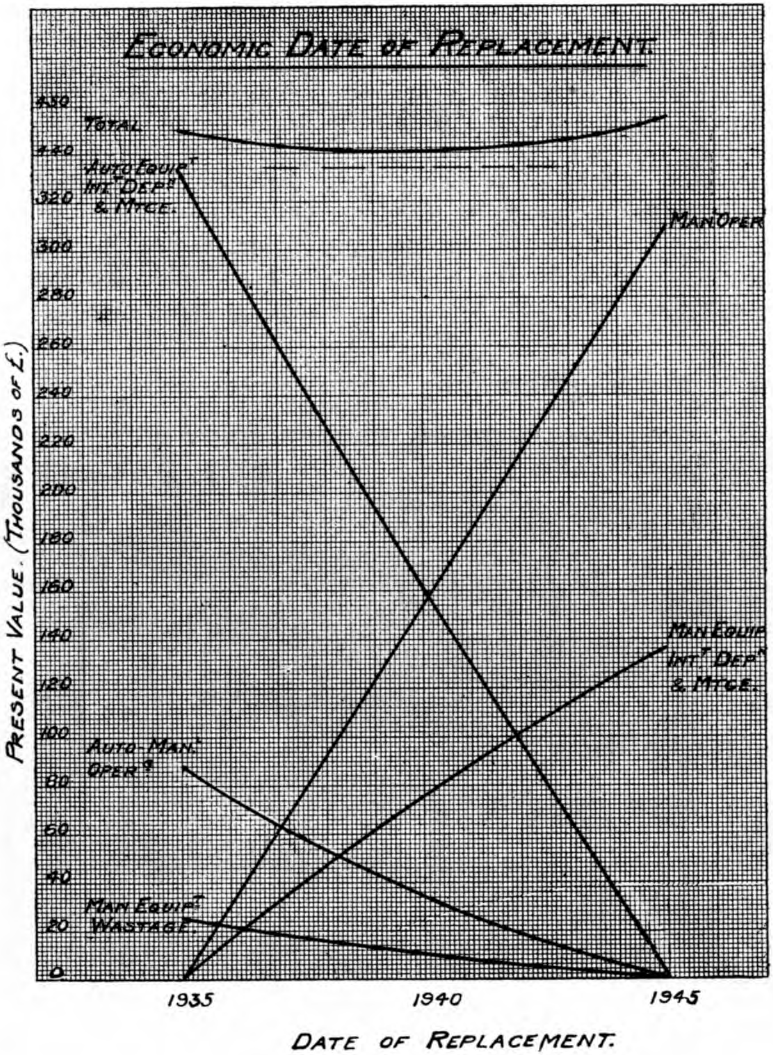


FIG. 43.

In conclusion, I wish to thank numerous colleagues for their assistance in supplying data and especially Mr. D. V. Wilton and Mr. S. I. Brett for their work in helping to devise methods and in carrying out the detailed calculations involved in the investigations.

APPENDIX I.

FORMULÆ.

Let P = Principal

i = Rate of interest

A = Amount

n = Number of years

a = Amount of £1 for year, *i.e.*, $1 + \frac{i}{100}$

Amount of P in n years = A = Pa^n

Present value of A = $P = \frac{A}{a^n}$

*Amount of an annuity £x per annum for n years $= x\left(\frac{a^n - 1}{a - 1}\right)$

*P.V. of an annuity of £x per annum for n years $= x\left(\frac{a^n - 1}{a_n(a - 1)}\right) = x\left(\frac{1 - a^{-n}}{a - 1}\right)$

*P.V. of an annuity of £x per annum deferred m years and continuing for n years $=\left(\frac{x}{a - 1}\right)(a^{-m} - a^{-m-n})$

* NOTE.—The payments are assumed to be made at the end of the year.

APPENDIX II.

PRESENT VALUE TABLE.
RATE OF INTEREST 5%.

No. of years.	P.V. of £1.	P.V. of £1 p.a.	P.V. of £1 p.a., starting at any given year and continuing to the 20th year.	P.V. of £1 p.a., starting at any given year and continuing to the 30th year.	P.V. of £1 p.a. increasing by £1 p.a.
1	·952	·952	12.462	15·372	·952
2	·907	1.859	11.506	14·414	2.767
3	.864	2.723	10.602	13·512	5·358
4	.823	3·546	9·741	12.651	8.648
5	·783	4·329	8.919	11.83	12·57
6	·746	5·076	8.128	11.036	17·05
7	·711	5·786	7·385	10.293	22.02
8	.677	6.463	6.679	9·59	27·43
9	.645	7·108	6.000	8.91	33·23
10	.614	7·722	5·358	8.27	39·38
11	·585	8.306	4·741	7·651	45·8
12	·557	8.863	4.159	7·07	52·49
13	·530	9·394	3·600	6.511	59·38
14	·505	9·899	3·067	5·975	66.45
15	·481	10.380	2.563	5·473	73·66
16	·458	10.838	2.082	5·000	80.99
17	·436	11.274	1.624	4·534	88.41
18	·415	11.690	1.187	4·096	95·89
19	·396	12.085	·773	3·678	103·4
20	·377	12.462	·377	3·29	111.
21	·359	12.821		2.911	118.486
22	·341	13·163		2·551	126.01
23	·324	13·488		2.203	133·485
24	·309	13·798		1.875	140.925
25	.295	14.094		1.568	148.32
26	.281	14·375		1.277	155·63
27	.268	14.643		·996	163.867
28	·255	14.898		·730	170.
29	·243	15·141		·474	177·054
30	·231	15·372		·231	184.

NOTE.—The payments are assumed to be made at the end of the year.

APPENDIX III.

PRESENT VALUE OF £1 P.A. INCREASING BY £1 AT INTERVALS OF 2, 3, 4 YEARS, ETC.

Interval in years.	P.V. of £1 p.a. increasing at intervals over 60 years.	P.V. of £1 p.a. increasing at intervals over 30 years.
2	171.6	95.9
3	117.5	66.6
4	90.8	52.1
5	74.8	43.2
6	63.9	37.4
7	56.2	33.5
8	50.5	30.4
9	46.1	28.0
10	42.6	25.9
11	39.8	24.6
12	37.6	23.5
13	35.4	22.3
14	33.7	21.3
15	32.2	20.4
16	31.0	19.9
17	29.9	19.5
18	28.9	19.1
19	28.0	18.7
20	27.1	18.3
21	26.5	17.9
22	25.9	17.6
23	25.3	17.3
24	24.8	16.9
25	24.4	16.6
26	23.9	16.4
27	23.5	16.1
28	23.1	15.8
29	22.7	15.6
30	22.5	15.4

APPENDIX IV.

List of multipliers which give the present value of annual charges for operating over a period of 20 years.

It is desired to know the present value of annual charges for operating due to having one or two exchanges serving the same area.

Let *a, b, c, d* and *e* represent the annual charges at five yearly periods, for operating the one exchange, and A, B, C, D and E the annual charges at the same dates for operating the two exchanges (*i.e.*, the A/C for each exchange added together).

OPERATING COSTS.

Second exchange opened now.	P.V. of A/C over 20 years =	A × 1.82 B × 3.932 C × 3.084 D × 2.417 E × 1.209
Second exchange deferred 5 years.	do.	*a* × 1.82 *b* × 2.514 B × 1.418 C × 3.084 D × 2.417 E × 1.209
Second exchange deferred 10 years.	do.	*a* × 1.82 *b* × 3.932 *c* × 1.968 C × 1.115 D × 2.417 E × 1.209
Second exchange deferred 15 years.	do.	*a* × 1.82 *b* × 3.932 *c* × 3.084 *d* × 1.544 D × .873 E × 1.209
Second exchange deferred 20 years.	do.	*a* × 1.82 *b* × 3.932 *c* × 3.084 *d* × 2.417 *e* × 1.209