STANDARDS FOR THE ECONOMIC PROVISION OF DIRECT ROUTES

Robert B. Leigh
United Kingdom Post Office
London, UK

ABSTRACT
This paper describes the system used by the UK Post Office to assess the economic justification of direct trunk routes. The method used is simple and although it involves a number of generalisations is considered to give an acceptable answer in the majority of cases.

INTRODUCTION
1 The provision of plant in a commercial undertaking must be governed in the long run by economic considerations. In such an environment precise theoretical concepts are unlikely to be adopted unless they meet this end or can be adapted to do so making due allowance for sacrifices in precision which practical considerations so often dictate. The method outlined in this paper attempts to reconcile the theoretical and practical in the field of its application. It was developed with the aim of providing a simplified system which, whilst involving a number of generalisations, was sufficiently accurate to give a basis for direct route provision over the network as a whole.

NETWORK CONFIGURATION
2 There are over 6000 local exchanges in the UK, each of which is directly connected for the control and disposal of trunk calls to a group switching centre (GSC) of which there are about 400. In turn, each GSC is connected to one of 36 transit switching centres (TSC) of which 27 are district switching centres (DSC) and 9 are fully interconnected main switching centres (MSC). The network thus follows a normal hierarchical pattern and is illustrated in Figure 1 overleaf.

3 To ensure that any call can be connected over a maximum of 5 trunk (ie routes between GSCs or higher order centres) plus 2 local routes in tandem, basic (mandatory) routes are provided as an operational requirement between:
   a. the local exchange and the GSC which serves it;
   b. the GSC and the TSC which serves it. This may be either a DSC or MSC;
   c. the DSC and a nominated MSC;
   d. MSCs, ie, MSCs are fully interconnected.

4 Other routes (eg between GSCs) termed auxiliary routes, which enable the number of routes involved on a call to be reduced, are provided only where these can be justified economically, ie when it is cheaper to connect traffic over the auxiliary route than use two or more existing routes. It is the justification of these auxiliary routes with which this paper is concerned.

GRADES OF SERVICE
5 Basic routes (see paragraph 3) are circuited to give a grade of service of one lost call in 25 when the normal traffic is increased by 10%. This type of circuiting is adopted to give a degree of protection against overload and to provide an improvement in the grade of service with the size of group at normal traffic loading (see reference 1).

6 Auxiliary routes (see paragraph 4) are circuited to a lesser grade of service of one lost call in 15 when the normal traffic is increased by 10%. A lesser grade of service is used because calls passing over such routes generally involve fewer links than those passing over the basic network.
A new route will be economically justified when the ratio

\[
\text{Cost of (direct) auxiliary route} = \frac{\text{Cost of indirect (tandem) routing}}{\text{Cost of (direct) auxiliary route}}
\]

must all be taken into account in assessing this ratio.

The cost of connecting a call via a given routing depends on:

- the length, and types, of line used;
- the number of, and cost of, intermediate switching points;
- the cost of terminating the route;
- the efficiency of the routes concerned, which will depend upon the average traffic carried per circuit. This, in turn, depends on the grade of service, the size of the route and the method of access to it.

The ideal of detailed cost studies for every individual case would be so complicated that their ready application would not be possible. Not only would a disproportionate amount of time and effort be involved, but the information necessary might be difficult to obtain or be unreliable particularly in a dynamic changing situation. National average figures for the various types of circuits and equipment currently being provided are, therefore, used.

**COST FACTORS**

10. We need only be concerned with cost ratios and can, therefore, employ a simplified system using cost factors derived from the annual charges of plant currently being provided. Three main cost factors arise in considering the economics of direct route provision. These are the line, switching and provision costs.

11. Costs, of course, are constantly changing either on account of changes in the basic price for the materials or due to changes in the methods of circuit provision. The cost factors are, therefore, reviewed every 3 years and new factors derived from current present value of annual charge values. However, as we are primarily concerned with cost ratios, and most costs seem to be moving in the same direction, the overall effect of price changes tends to be insignificant in this context.

12. **LINE COSTS** depend on the length and type of line plant used. They comprise two main parts, one relating to the cost of cable and intermediate repeater equipment which is proportional to the length of a route, and the other to the cost of terminal equipment which is independent of the length of route. The current factors used are shown in Table 1.

<table>
<thead>
<tr>
<th>Type of circuit</th>
<th>Line factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDM (1MHz and 12MHz)</td>
<td>0.2 + 0.6 + 0.5</td>
</tr>
<tr>
<td>PCM (24 or 30 channel)</td>
<td>0.5 + 0.3 + 0.53</td>
</tr>
<tr>
<td>Audio amplified</td>
<td>0.7 + 0.34</td>
</tr>
</tbody>
</table>

\[ r = \text{radial distance in kilometres} \]

The radial distance in kilometres between the nodes concerned is used when applying the table. This, of course, is an approximation. In assessing the factors allowance has been made for the generally longer physical routing of the circuits involved using national average figures. Determination of the actual physical routing to be used would be very difficult owing to the number of possible variables.

The cost advantage of using FDM for the longer distance routes, PCM for the middle distance and audio amplified circuits for the short routes can readily be appreciated from Table 1. It should, however, be emphasised that the balance could change significantly owing to technological developments in the various fields concerned.

13. **SWITCHING AND TERMINAL COSTS.** The provision of new direct auxiliary routes may affect costs at the terminal and intermediate switching points involved. Although some terminal costs may be common to both routes, they must still be taken into account as the method depends upon cost ratios. Table 2 gives the factors currently in use.

<table>
<thead>
<tr>
<th>Switching stages</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct route, Outgoing terminal switching</td>
<td>1.2</td>
</tr>
<tr>
<td>Tandem routing, Outgoing terminal switching</td>
<td>3.4</td>
</tr>
<tr>
<td>Tandem routing, Intermediate G.S.C switching</td>
<td>3.4</td>
</tr>
<tr>
<td>Incoming terminal switching</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 2 - Switching and Terminal Factors
REARRANGEMENT COSTS. Until recently we took no account of the rearrangement costs involved in providing a new route as we considered these to be "once only" costs and relatively small. We have, however, become increasingly conscious that apart from the direct labour cost of bringing the route into service, a number of hidden costs may be involved. Plant will have to be duplicated up to the time the new route comes into service, and for a considerable time afterwards the plant on the old routing may be under-utilised. Because of the difficulty in precisely determining the traffic to be diverted to the new route there may be a degree of over-provision on both routings. Unfortunately, there is a regrettable, but natural, tendency to cater for traffic on the new route without making a corresponding reduction on the old (losing) routes. The forecasting problems are accentuated; there are difficulties in determining the respective route growth rates and much information has to be exchanged to enable the necessary adjustments to be carried out.

To cover all these problems we have assessed their cost effect, in similar terms to those used for the line and switching factors, in the form of a rearrangement factor which will normally be added to the costs of the direct route although in certain circumstances, where rearrangements must be carried out whether the new route is provided or not, (eg, in considering the routes to be provided from a new exchange) it might be added also to the tandem costs or omitted altogether depending on these circumstances.

It will be appreciated that such a factor is not easy to assess as it is dependent upon a number of highly variable factors, but by making a number of assumptions based on our experience, we have arrived at a current rearrangement factor of 65.

BASIS OF METHOD

15 For practical purposes, although we are setting out to compare the cost of direct against tandem routing, we really want to know the limiting traffic quantity (in erlangs) between the two exchanges concerned for economic route justification. To establish a relationship between cost and traffic carried per circuit, let us consider the following arrangement.

Extra outgoing terminal switching on direct route

Incoming terminal switching

Direct route

Outgoing terminal switching

Tandem Route

Intermediate switching on tandem routing

Let:

- **A** = traffic between collecting areas (in erlangs)
- **d** = average loading per circuit on direct route
- **t** = average loading per circuit saved on tandem routing
- **D** = annual charges per circuit on direct route (line costs)
- **C_1, C_2** = annual charges per circuit saved on tandem routing
- **S** = annual charges per circuit of intermediate switching on tandem route
- **T_1** = annual charges per circuit of outgoing terminal switching on tandem route
- **T_2** = annual charges per circuit of outgoing terminal switching on direct route
- **T_3** = annual charges per circuit incoming terminal switching
- **R** = annual charges per circuit for rearranging

Then:

- Number of circuits on direct route = **A**
- Number of circuits saved on the tandem route = **A**

Annual charges on direct route =

\[
\frac{AD}{d} + \frac{A}{d} \left( T_2 + T_3 \right) + \frac{AR}{d}
\]

(line) (terminal switching)

Annual charges saved on the tandem route =

\[
\frac{A}{d} \left( C_1 + C_2 \right) + \frac{A}{d} \left( T_1 + T_3 \right) + \frac{AS}{d}
\]

(line) (intermediate switching)

:: To justify provision of the direct route

\[
\frac{A}{d} \left( D + T_2 + T_3 + R \right) \leq \frac{A}{d} \left( C_1 + C_2 + T_1 + T_3 + S \right)
\]

and

\[
\frac{A}{d} \geq \frac{C_1 + C_2 + T_1 + T_3 + S}{D + T_2 + T_3 + R}
\]

In this equation d/A is a ratio of the traffic carrying capacity of each circuit on the direct and tandem routes, whilst the right-hand side of the equation is a ratio of the costs per circuit on the direct and tandem routes.

If the d/A ratio equals or exceeds the cost then the route is justified.

CIRCUIT LOAD RATIO

16 The average load per circuit differs with size of route and its position in the network. The circuit efficiency on each routing must, therefore, be taken into account when considering the provision of any new direct auxiliary route. Whilst it would be possible to consider the precise loading on each link involved, in practice, so far as the existing (tandem) links are concerned a standard figure of 0.82 erlangs per circuit is used which is the average load carried by each circuit added to the existing basic network.

Now if:

- **A** = traffic in erlangs between collecting Areas (see paragraph 21)
- **N** = number of circuits on direct route
- **d** = average load per circuit on direct route = **A**
- **t** = average load per circuit saved on tandem route

then

\[
\frac{A}{d} = \frac{A}{N} \quad \text{and since } t = 0.82 \quad \frac{A}{d} = \frac{A}{0.82} = \frac{A}{N}
\]

Thus for any circuit provision table values of 0.82A can be determined and tables of minimum traffic A for corresponding values of d/N easily produced for use by field staff. Table 3 (overleaf) is a typical table.
Typical tandem routes

<table>
<thead>
<tr>
<th>d/t</th>
<th>Unidirectional Routes</th>
<th>Partially Divided Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum erlangs</td>
<td>Minimum erlangs</td>
</tr>
<tr>
<td>0.68 or less</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>0.70</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>0.72</td>
<td>6.0</td>
<td>7.4</td>
</tr>
<tr>
<td>0.74</td>
<td>6.8</td>
<td>8.5</td>
</tr>
<tr>
<td>0.76</td>
<td>7.7</td>
<td>9.6</td>
</tr>
<tr>
<td>0.78</td>
<td>8.6</td>
<td>11.1</td>
</tr>
<tr>
<td>0.80</td>
<td>9.8</td>
<td>12.8</td>
</tr>
<tr>
<td>0.82</td>
<td>11.2</td>
<td>14.8</td>
</tr>
<tr>
<td>0.84</td>
<td>13.4</td>
<td>15.8</td>
</tr>
<tr>
<td>0.86</td>
<td>16.4</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 - Typical Direct route justification Table

17 Reverting now to the formula in paragraph 15 for any particular case the cost per circuit provided on the direct route can be determined using the cost factors set out in paragraphs 12 to 14. Thus, from the other side of the equation this represents the d/t value to be used in determining the minimum traffic A for economic direct route provision and Table 3 can readily be applied.

17.1 Example Let us consider provision of a new direct route between A and B in the arrangement illustrated. The existing routing is via C.

 Proposed route - 100 km - FDM

A

Existing link
150km - FDM

B

Existing link
60km-FDM

d - direct route cost:

Line cost (see para 12) = (0.2h x 100) + 8h = 108
Terminal switching cost (para 13) = h2 + 12 = 2h
Rearrangement cost (para 14) = 65

Direct route cost d = 227

t - tandem routing cost:

Line cost - 1st link = (0.2h x 150) + 8h = 120
- 2nd link = (0.5 x 60) + 53 = 83
Terminal switching cost = 3h + 12 = 5h
Intermediate switching cost = 3h
Tandem routing cost t = 283

\[ \frac{d}{t} = \frac{227}{283} = 0.80 \]

From Table 3 it will be seen that 9.8 erlangs of traffic are necessary to justify the route if it is to be unidirectional or 12.8 erlangs if it is to be partially divided.

HIGH USAGE ROUTES

18 The average load carried by each circuit on the direct route can be increased by limiting the number of circuits on that route, such that traffic is forced to overflow to a tandem routing. Improving the overall circuit efficiency in this way does not necessarily save money however. Even if we assume that the facility is available, and this is not always the case, particularly in a Strowger environment, the cost of any circuits saved may be offset by the intermediate switching costs and the increased line length on the tandem routing.

19 The high usage principle has, of course, been used with great success by many administrations but, in the UK, the following factors have tended to limit its application:

a. A predominantly Strowger environment with restricted alternative routing facilities; in fact the facility is only currently available on routes to and from TSCs (see para 2). Such routes carry less than 6% of the total trunk traffic.

b. The high cost of switching via a TSC.

c. The relatively short route distances involved - the average trunk route is 84km radial length.

d. The absence of time zones to give a spread of the busy hours and so enable the receiving route to be more fully exploited.

20 To enable full benefit to be gained from high usage working, it is essential that the dimensioning of the routes involved be optimised using such methods as those postulated by Mr Yang (see reference 2). Such optimisation and the degree to which forecasting errors can be accommodated is very dependent upon the relative cost of the direct and tandem routings. The higher the costs on the tandem route compared with the direct route, the less the advantage of high usage working, and the greater the danger of departing from the principles of optimisation on the grounds that increasing the circuit loading on the direct route must be more efficient. Although in the UK 85% of the cases considered for High Usage working would appear to pay, only in 15% of them would any practical degree of dimensioning error be permissible. We are very conscious that the very nature of high usage working renders it less likely that forecasting errors could be identified and for these reasons we are proceeding very carefully in extending its use.

OPERATIONAL FACTORS

21 An important decision to be made concerns traffic to be taken into account when considering the direct route, should this traffic be terminal between, eg GSCs concerned, or should transit traffic also be taken into account. This decision will be affected by practical considerations, some of which may prevent the use of a terminal advantage, eg restrictions on access imposed by restricted equipment facilities. Others may render the route to be operationally desirable, eg the need to by-pass large congested centres. All these things being equal, we tend to favour that only the terminal traffic should be considered unless provision of the route would enable a large block of traffic to be transferred from another routing.

22 Realism is required. The need for new routes must be forecast for some years ahead for efficient planning. One must be quite sure that when the route comes into operation, all the traffic which it is expected to carry, will be transferred to it; as already mentioned, there is a regrettable tendency to cater for traffic on new routes without making a corresponding reduction on the old (losing) routes. The provision of new routes brings many forecasting difficulties; adjustments have to be made throughout the Network, increasing the risk of forecasting errors; the plant has to be adjusted. For these reasons it is desirable that changes be restricted so far as possible so that there be stability and continuity in planning.

23 It must also be borne in mind that the provision of line transmission equipment is modular, at present it is based on a basic group of 12 channels and the proportion of this group utilised will affect the economics. So far as possible we attempt to utilise groups to their full extent and, bearing in mind this and the other operational factors referred to above, we have considered it prudent to add an overriding condition that any new unidirectional route must justify a minimum 9 circuits. This minimum
requirement must be justified by the new route terminal to terminal traffic, together with transit traffic (is traffic that will use the new route as part of a multi-link routing) whose transfer to the new route can be guaranteed.

CEASING EXISTING ROUTES

24 Owing to the opening of more new routes, changing traffic distribution patterns, etc, the traffic on an existing route might fall to such a level that the need for its continuance may be called into question. In considering whether to cease the route the method outlined in this paper may be used, treating it as though it were under consideration for provision. There would be one important difference; its cessation would have similar repercussions on planning and the cost penalties would militate against cessation so justifying retention of the route at an appreciably lower traffic level than would have been needed for its initial provision.

25 Thus in the case of a route under consideration for cessation, we again repeat the d/t calculation, but this time adding the rearrangement cost factor to the tandem routing instead of the direct routing. This gives slightly more bias to retention of the route than our calculations justify but makes some allowance for further growth of the remaining traffic. In the example quoted in paragraph 17.1 the effect, if we were considering the route for cessation, would be to reduce the d/t factor from 0.80 to 0.47. It would not be ceased unless the traffic fell below 1.4 erlangs (this figure was obtained from an extension to Table 3 not published in this paper for space reasons) as compared with the 9.8 erlangs required for its initial provision.

THE FUTURE

26 We are about to move into a digital era. With digital working the basic route module is likely to increase in size to 30 channels. This suggests that the justification of auxiliary routes will be much more difficult and, indeed, we are already considering that the minimum size of a dedicated route between nodes/multiplexing points should be 25 circuits, thus giving a reasonable module fill. The technique of overflowing traffic from one route to another might prove very useful in minimising the effects of the larger modular provision.

27 Studies into the long term planning of the UK Trunk Telecommunications Network (see reference 3) have recognised the continued need for a routing hierarchy and the need to relate digital nodes to that hierarchy. In establishing these nodes, there is a need to draw more closely together physical routing, traffic circuit routing and network switching. There is also a need to consider the integration of switching and transmission plant, overall system security and thus physical diversity. It is possible that new systems will be developed, eg, waveguide, which will lead to very wide-band high capacity carrying systems. This leads to the possible concept of a National grid giving high channel concentration and a strong basic network - or grids to take account of alternative physical paths. Much thought will have to be given to ways in which a digital system can develop from nothing at present to such high capacity systems.

28 The precise definition of a route in such an environment is subject to interpretation and will depend on the engineering arrangements to be adopted. It will be necessary, for example, to decide whether channels are dedicated to a particular destination. Non-dedicated channels would enable maximum advantage to be taken of digital working by ensuring full utilisation, and this would involve a quite different route concept than envisaged in the rest of this paper. At this stage, however, in looking at the possible development of the digital network we are proposing to assume dedicated channels, but recognise as the system develops, this situation could well change.

ACKNOWLEDGMENTS

29 The author wishes to thank his colleagues for their assistance in compiling this paper.

REFERENCES

1 H A LONGLEY: On the determination of the number of circuits. 3rd ITC