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Traffic Engineering Techniques for Determining Trunk Requirements in Alternate Routing Trunk Networks

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In 1945 the Bell System embarked on an extensive study with the purpose of developing a program for operator toll dialing on a nationwide basis. Operator toll dialing had been done, of course, on a limited scale in various parts of the country for many years, but the concept of this program was one of nationwide proportions carried on with a uniform numbering plan arrangement and a completely integrated trunking system which would handle traffic at a high speed between any two points in the United States and Canada, even in the busier hours of the day.*

Implementation of this program required the development of new switching mechanisms and the exploitation of carrier transmission potentialities to a degree never before achieved. Great strides had already been made in these fields, resulting in the practical development of the coaxial cable system and the first toll crossbar switching office installed at Philadelphia in 1943. But the very core of the nationwide dialing plan was the proposal to revolutionize the method of traffic distribution so as to combine high speed handling over the intertoll trunk network with a highly efficient use of facilities. The method of accomplishing is called "engineered alternate routing"

* W. H. Nunn, Nationwide Numbering Plan, Communication and Electronics, **2,** Sept., 1952 and B. S. T. J., **31,** Sept., 1952.

The capacity of this particular grade is precisely 334 CCS and its efficiency is 16.7 CCS per trunk or only 12 per cent below the single trunk group efficiency. Here the common trunks serve as an alternate route for such portions of the loads a, b, and c, respectively, as can not be handled by the five trunks which are individual to each. Because it is not likely that a, b, and c will overflow equal amounts of traffic at the same time, the common trunks are kept busy by a more or less complementary pattern of greater and lesser overflows at any given moment, emerging from the three subgroups. It is this action of the overflows, amply substantiated by experience, which accounts for the efficiency of graded multiples. Looked at another way, it may be said that all trunks above five in each subgroup of the split-multiple case have been pooled for the common use of all subgroups and that in so doing, it is possible to reduce the number of pooled trunks from 9.9 to five without

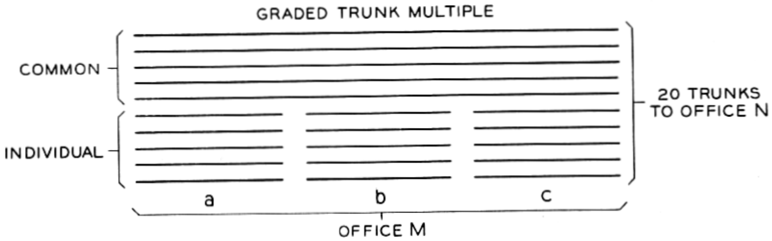

FIG. 1 — Typical graded arrangement of 20 trunks on 10 terminals.

impairing the speed of service. This very brief discussion of graded multiples serves merely to point out by familiar example, some of the potentialities of the alternate routing principle in the economical handling of telephone traffic.

ALTERNATE ROUTING IN LOCAL INTEROFFICE TRUNK NETWORKS

The effectiveness of alternate routing as illustrated by its action in graded multiples suggests the possibility of improving the efficiency of trunking between central offices by arranging the offices themselves in a sort of grade. Let us carry the analogy as far as practicable and assume that the loads a, b, and c in Fig. 1 are now emanating from central offices A, B, and C and still destined for office N. Let us assume that A, B, and C are typical offices in a multi-office city which has a tandem office, T, and further, that every office in the city has a group to and a group incoming from the tandem office. Fig. 2 illustrates these conditions with respect to offices A, B, C, and N and for simplicity indicates carrying the load from the originating office to each distant office would be at a minimum. This required some means of determining how much load would be carried by the direct trunks when offered a given load and consequently how much of that load would be overflowed to the alternate route. For this purpose, a formula* known as the Erlang B "lost-calls-cleared" assumption was used. This formula states for a given random offered load, the amount of load which will be carried by each of a number of trunks, n, tested in succession provided that the calls failing to be carried on the first attempt (the lost calls) *are not reoffered within the hour during which the first offering took place*. The condition italicized is extremely important to the problem since it requires that calls lost on the direct high usage group, i.e., the calls overflowed to the

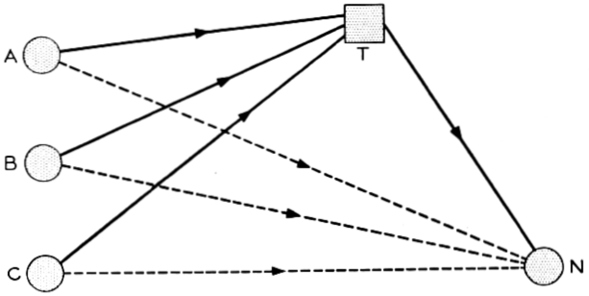

FIG. 2 — Illustration of simple interlocal trunk network arranged for alternate routing.

alternate route, must be disposed of without delay on the alternate route or routes. In the New York City trials it was assumed that the then current basis of provision of trunks in each leg of the alternate route (final groups AT and TN, Fig. 2) namely, with a probability of delay of one per cent. (P.01) would, as a practical matter, satisfy the condition that calls overflowing from AN should be cleared. It should be mentioned in passing that the results of the trials substantiated the reasonableness of this assumption.

A typical Erlang B distribution is shown in Fig. 3, Curve A wherein the load carried by each of n=14 trunks is shown for the condition of 240 offered CCS. Thus, assuming the load to be offered in succession to trunks 1, 2, 3, etc., in that order, it will be seen that the first trunk carries the most load, the second trunk somewhat less, the third still less until the fourteenth trunk carries about 0.5 per cent of the total. By

* A. K. Erlang, Solution of Some Problems in the Theory of Probabilities of Significance in Automatic Telephone Exchanges, Post Office Electrical Engineers' Journal, **10,** 1917.

is a function of the number of trunks provided to handle a given load on a lost-calls-cleared basis.

Referring once more to Fig. 2, let us assume that the ratio of the cost of an incremental path in ATN to the cost of an incremental path in AN is 1.4. It may then be stated that it costs 1.4 times as much to handle traffic on the alternate route as on the direct route. The cost ratio is computed on the basis of values of incremental trunks because the ultimate question in the economical separation of load between a direct and an alternate route is whether one more trunk should be added to the direct route or should more trunk capacity be provided in the alternate route to handle a marginal portion of the total load. Let us assume further that the offered load, A to N, is 240 CCS and that the efficiency of incremental trunks in the alternate route is 28 CCS per trunk.

With these three factors, the offered load, the cost ratio and the efficiency of incremental trunks in the alternate route, the most economical arrangement of trunks for carrying traffic from A to N may now be determined. The first step is to make sure that any trunk in the direct (HU) group will carry load at a cost per CCS equal to or less than the cost per CCS which is characteristic of the incremental trunks in the alternate route. Since the last trunk in a high usage group carries the least traffic, as previously discussed, the significant comparison is the ratio of the load carried by a trunk added to the alternate route to the load carried by the last trunk in the high usage group. The numerator of that ratio is 28 (CCS) and the denominator could be any one of 14 values shown on Curve A of Fig. 3, depending upon the number of trunks provided. If that ratio is made equal to the cost ratio (ATN/AN) there will be determined a value of load to be carried by a last trunk which in turn will determine the most economical number of trunks for the direct high usage group. This value is referred to as the "economic CCS" of the problem and is determined as follows:

$$\text{Cost ratio } \frac{1.4}{1.0} = \text{Efficiency ratio } \frac{28}{X}$$

$$X = 20, \text{ the economic CCS}$$

On Curve A it will be seen that the sixth trunk will carry 22.5, the seventh, 19.6 and the eighth, 16.4 CCS. Since the loading of the seventh trunk is closest to the economic CCS just computed, the conclusion is that seven trunks should be provided in the high usage group for the minimum overall cost of handling traffic from A to N. Since the seven trunks as a group will carry 185 CCS (Curve B), there will be 55 CCS value of 1.12. With the latter ratio the economic CCS would be (28 ÷ 1.12) or 25. On Curve A of Fig. 3 it will be seen that trunk No. 5 (the last trunk of a 5-trunk group) carries 25 CCS. So, if the lower cost ratio had been used instead of the correct one, the effect upon overall trunking costs would have been 1 per cent in excess of the most economical arrangement. Had a cost ratio of 1.25 been used, six trunks would have been provided in the HU group and no cost penalty would have been incurred. On the other side of the optimum point an eight trunk HU group would meet the requirements of a cost ratio as high as 2.0 with a resulting cost penalty of about 2 per cent. As can be seen from Table I, the cost penalties mount more rapidly when more than the optimum number of high usage trunks are provided than when less are provided.

The principles of alternate routing and certain of the techniques used by traffic engineers in determining quantities and arrangements of interoffice trunks have just been described with particular reference to the trials that have been carried on in New York City. The latter were very extensive undertakings in which not only single alternate routes were provided but for a majority of items, multiple alternate routes. This was possible because New York City had two tandem systems each with a completing field to all city offices as well as other tandem systems (office selector tandems) each with a completing field to about 20 offices. Thus it was possible in many cases for an originating office to test a direct

Table I — Comparative Costs of Alternate Routing System for Various Assumptions as to Number of HU Trunks

Given: Offered load in CCS 240
Efficiency of trunks added to alternate route 28
Cost ratio, alternate to direct (HU) route 1.4

No. of HU Trunks	Nominal Costs					% Deviation from Optimum
	HU trunks		Alternate trunks		All trunks	
	Per trunk	Total	Per trunk	Total added*		
3	1.0	3	1.4	7.50	10.50	7.70
4	1.0	4	1.4	6.10	10.10	3.59
5	1.0	5	1.4	4.85	9.85	1.03
6	1.0	6	1.4	3.75	9.75	0.00
7	1.0	7	1.4	2.75	9.75	0.00
8	1.0	8	1.4	1.95	9.95	2.05
9	1.0	9	1.4	1.30	10.30	5.64
10	1.0	10	1.4	.80	10.80	10.75

* $\frac{\text{Overflow CCS from HU Group} \times 1.4}{28}$

of more than two million items of traffic between toll offices, would need to be devised.

Over the years since 1945 practical solutions to the problems raised by the conditions have been attained by Bell System engineers and the fruits of their efforts will be put to the test in 1954 during which year the first practical application of "engineered" alternate routing in the intertoll network will be undertaken.

The remainder of this paper will be devoted to the more important aspects of the traffic engineering techniques used in determining the arrangement and numbers of intertoll trunks required in a multi-alternate routing system.

GENERAL TOLL SWITCHING PLAN

A brief description of the General Toll Switching Plan* will be appropriate here since any discussion of the alternate routing methods necessarily presumes an understanding of the basic pattern for routing traffic.

The plan under which transmission had been designed and traffic routings determined since 1930 comprehended a maximum connection of 5 intertoll trunks in tandem. Early studies of the alternate routing possibilities in toll networks led to the conclusion that a total of 8 intertoll

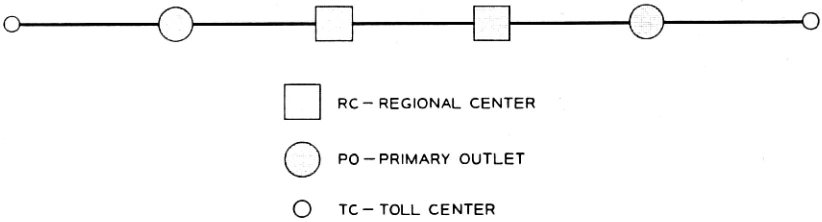

FIG. 4 — Illustration of present basic intertoll network showing maximum intertoll trunk linkage.

links would provide a more economical arrangement of trunks by shortening some very long final groups that would otherwise be required. Fig. 4 illustrates schematically the arrangement of switching centers in a maximum connection currently in use.

Fig. 5 shows a schematic of the proposed General Toll Switching Plan in which a connection involving 8 links is possible between TC1 and TC2. Such a route would constitute the final route between those TC's and each group in the route would be a low delay final group similar to

* J. J. Pilliod, Fundamental Plans for Toll Telephone Plant, Communications and Electronics, No. 2, Sept., 1952 and B. S. T. J., **31**, Sept., 1952.

Each regional center (RC) homes on, ie., has a final group to the NC, and has one or more sectional centers homing upon it;

Each sectional center (SC) homes on an RC (or the NC) and has one or more primary outlets homing upon it;

Each primary outlet (PO) homes on an RC, NC or SC and has one or more ordinary toll centers homing upon it; and

Each ordinary toll center (TC) is so called because it performs no through switching function but merely serves as the connecting point between the intertoll network and local central offices or tributaries.

Thus each toll center (and in the generic sense this phrase includes all CSP's as well as ordinary toll centers) was classified with respect to the area served: the TC serving a group of local offices or tributaries, the PO serving a group of TC's, the SC serving a group of PO's, the RC serving a group of SC's and lastly the NC serving all the RC's. Under this arrangement any toll center could home on another of higher rank or classification. Thus a TC or PO, for example, could home upon an RC if so dictated by geographic and economic considerations. Before proceeding with a detailed study of trunk requirements the classification of toll centers and the homing relationships had first to be established. This was done in a manner which reflected the known densities and flow of traffic between the larger cities and the relative cost of final routes which in turn reflected the differences in lengths of haul to one CSP as opposed to another, etc. With the classification and homing of each toll center established it was possible to trace the final route, the route of last resort, between any two toll centers in the entire system. Thus was the stage set for determining the location of and number of trunks to be provided in high usage groups whose function would be to move traffic more economically by direct connection between points than could be done by following the final route.

It is apparent at once from the illustration in Fig. 5 that the problem of determining the most economical alternate for a given HU group is different from that encountered in the interlocal situation of Fig. 2 inasmuch as the latter had only one intermediate switching point in each final route. A further difference not specifically indicated is that intertoll trunk groups handle traffic in both directions whereas interlocal trunk groups handle traffic in only one direction, i.e., there are separate outward and inward groups between any pair of local offices. There are special circumstances under which one-way intertoll groups also are established but these may be ignored for purposes of our discussion.

While this paper is not specifically concerned with the transmission aspects of an alternate routing network some mention should be made costs of the direct and alternate routes are controlling. Since load carried by a high usage group is a function of the load offered, under the Erlang B assumption, it is apparent that the size of the load between any two toll centers will also limit the possible range of economic CCS values which can be realized. In other words a high usage group to exist at all must have at least one trunk and that one trunk must carry not less than the economic number of CCS required by the cost ratio applying to the case. For example, if a busy-hour load of 60 CCS is to be carried between offices A and B and the cost ratio indicates an economic CCS of 25 it can be shown that when one trunk is offered 60 CCS it will carry only 23 of the 60 CCS with the balance 37 CCS being overflowed. Under these conditions no direct (HU) group could be economically established since the efficiency of even the first trunk of such a group would fail to meet the requirement of the case.

This immediately suggests that a prime requirement in determining whether or not there should be a direct group of any size between two toll centers is a level of load at and above which a group will prove in and below which, of course, it will fail to prove in. As previously stated the cost ratio between the alternate route and the potential direct group is also a controlling factor. Thus, to determine the economic propriety of establishing a direct (HU) group it is necessary to know the following:

Cost of path in the alternate route;

Cost of path in the direct route;

Efficiency of trunks added to the alternate route; and

Load offered between toll centers.

The last three of these items were available to the engineer but the first item could not be known in all cases because the groups comprising the logical alternate routes in some cases were themselves hypothetical. For example, a high usage group between TC1 and TC2 in Fig. 5 might have an alternate route via P01 or via P02 which routes in turn would depend upon the existence of groups P01-TC2 and TC1-P02, respectively. Therefore, it was necessary to "cut-and-try" in the process of locating high usage groups. This was accomplished by choosing an average cost ratio (and hence an average economic CCS value) which could be used with the known offered loads between toll centers to test the feasibility of at least one high usage trunk. With this tentative pattern of high usage groups the potentially available alternate routes could then be identified. For each high usage-alternate route triangle thus tentatively selected the test of relative costs was applied to verify the economy of the case. Some proposed high usage groups failed to prove in under such test in which cases the uneconomic high usage groups were load offered to the PO1-PO2 group is composed in part of the overflow traffic from TC1-PO2. It is likewise clear that the final group TC1-PO1 will be offered overflow traffic from both TC1-TC2, TC1-PO2 and TC1-SC and hence the final group can not be engineered until the overflows from all high usage groups terminating at TC1 have been determined. This transfer of load from group to group with each succeeding high usage group serving as the base of a new triangle in orderly procession from TC to RC is the essence of the multi-alternate routing system and, therefore, a precise order of group load computation was necessary to assure proper accounting of the load offered to each group. In practice the order of group load computation requires that all TC-TC high usage groups be established first, then TC-PO groups, TC-SC and so on. The process involves selecting a particular TC as a "reference" and examining all traffic involving that TC to determine what (if any) high usage groups should terminate there.

The second rule, affecting the concentration of switched traffic, is related to the order of group load computation in that it postulates a starting point for the process of examining HU group possibilities. The need for such a rule may be best explained by reference to Fig. 7 representing a simple intertoll network in which PO, a CSP serving four TC's, homes on SC, another CSP, serving four other TC's. The question, answered by the second rule, is which of the eight TC's should be used as the first reference TC. The choice will determine the sizes of, i.e., the number of trunk terminations to be provided at, PO and SC, respectively. Let us examine the reason for this. Assume the TC's homing on PO are to be used as the first set of reference TC's (it makes no difference which TC is first chosen). Assume that the investigation showed an economical HU group between TC2 and SC but that no HU groups proved into any of the TC's (5, 6, 7, and 8) dependent upon SC. The load offered

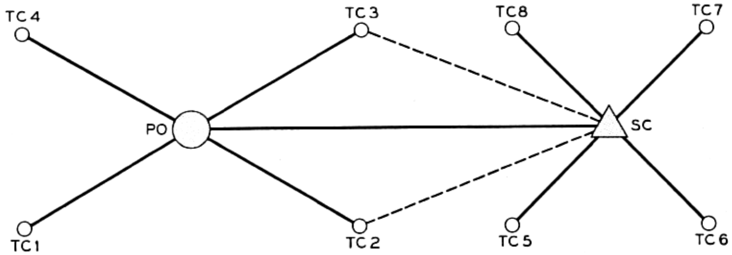

FIG. 7.

administration and engineering have been obtained with that end in view. However, in alternate-routing networks the significant level of a trunk group load is not that which is characteristic of its own busy hour but rather that which is characteristic of the hour in which all trunk groups in a given network are collectively carrying the greatest aggregate traffic volume. For each group the former level is referred to as the group busy-hour (GBH) load and the latter, for convenience, as the office busy-hour (OBH) load.

The reason for using office busy-hour loads between toll centers rather than group busy-hour may be explained with reference to Fig. 8. Here is a represented part of an intertoll trunk network showing 4 HU groups connecting TC with four other toll offices a, b, c and d. TC homes on SC and for simplicity it may be assumed that the alternate route of each such group is the final group to SC.

In the hour during which the greatest volume of traffic is leaving and entering TC, i.e., the office busy-hour, the demand for trunk capacity in the TC-SC group will also be greatest since by design the final group to the home CSP of any TC is the route of last resort for all traffic to and from the TC. Thus the group busy-hour of the TC-SC group coincides with the busy-hour of TC as a whole.

The group busy hours of the respective HU groups (TC-a, TC-b, etc.) may occur outside of the office busy-hour for TC and during such hours the amount of traffic offered to and hence overflowed by each of the HU groups is greater on the average than that occurring in the office busy-hour. But at any other hour than the office busy-hour there is less total load on the network and hence there is some spare capacity in the final group available for handling the group busy-hour overflow of one or more of the high usage groups. By properly evaluating the average ratio between any given toll center-toll center load in its group busy-hour and its value in the office busy-hour it would be practicable to start with basic data in group busy-hour terms and convert it to equivalent office busy-hour levels before undertaking the procedures for separating loads between direct (HU) and alternate routes.

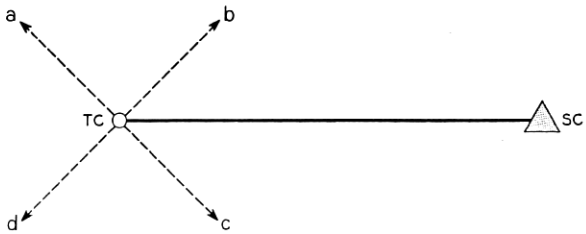

FIG. 8.

loads was arrived at through an averaging process. The ratio values are conservative, i.e., there was some evidence that in large toll offices the higher ratio values apply to larger loads than indicated by the curve. However, no attempt was made to develop separate sets of ratios for offices of different size since the use of the common set of values would tend merely to increase slightly the number of HU trunks required in a relatively few groups. The elimination of this small distortion did not appear to warrant the effort required to achieve it. The study data also showed that for a given toll office the sum of the respective group busy-hour loads for all groups was approximately 10–14 per cent greater than the sum of their respective loads in the office busy-hour.

The significance of this difference in the GBH and OBH aggregates is at once apparent. The intertoll trunk network designed on the alternate routing principle is required to handle from 10–14 per cent less busy-hour traffic than is required under the arrangement in which each toll center-toll center load stands alone and must be trunked for its own busy-hour. It is the pooling of trunk group capacities during the hour of maximum traffic flow for a given office plus the increased efficiency due to larger size of final groups that result in a requirement of fewer trunks in the network as a whole than would be required with any non-alternate routing trunking system of comparable service characteristics. The alternate routing system will enable the handling of normal busy-hour traffic on virtually a no-delay basis in so far as trunk provision may be controlling. The matter of speed of service potentialities and relative costs of alternate routing versus non-alternate routing systems will be treated later.

SOME UNANSWERED QUESTIONS

There are three questions upon the answers to which depend ultimate judgment of the adequacy and economy of a nationwide toll dialing network constructed upon the principles and with the techniques already described. These are:

1. What will be the effect upon trunk requirements of a proper evaluation of the non-random characteristic of lost calls, i.e., of the calls overflowed from high usage groups to other high usage or to final groups?

2. What will be the effect upon trunk requirements of a proper evaluation of the effect of non-coincidence of busy hours and busy seasons among the various toll centers?

3. What are the relative net costs of a nationwide intertoll dialing system engineered for multi-alternate routing and one designed without engineered alternate routing?

Non-coincidence of Busy Hours and Busy Seasons

With respect to the second question involving the non-coincidence of busy hours among toll centers it should be noted first that trunk requirements estimated in the nationwide alternate routing trunk study were predicated on a common busy season and a common office busy hour for all toll offices and all intertoll groups. This premise resulted in system-wide requirements which were patently incorrect since it is known that different toll centers have different busy hours and that the busy season for toll traffic in New England for example is in the summer while that for Florida is in the winter. While it was possible to identify the busy season and the average busy hour of each toll center the statistical problem of incorporating such information for some 2,500 toll centers in a completely integrated nationwide study appeared insuperable.

The seriousness of the error introduced by the above premise is not as great as might at first appear since the New England Company should know the requirements for the busy season of its territory and the Southern Bell Company is equally interested in the busy season requirements for Florida. It is only in the trunks required for handling traffic between these two areas that a distortion of requirements could be readily demonstrated as a result of assuming the two busy seasons to be coincidental when in fact they are months apart. The example cited is an extreme case which serves to point up the problem. While no evaluation has been made of this distortion, and none seems statistically practicable, it is evident that the direction of distortion is toward over-estimation of trunk requirements.*

Thus it may be confidently stated that the general effect of assuming premise regarding the coincidence of busy seasons and busy hours upon the network as a whole was to compute trunk requirements in some groups more liberally than a precise evaluation of all significant factors would indicate as adequate. Proper evaluation of the effect of non-coincidence of busy seasons and busy hours will likely await the findings of field experience.

Costs — Alternate Routing Versus No Alternate Routing

In planning extensive and radical changes in the methods of handling toll traffic on a nationwide basis it was necessary to explore the economic

* In the New York City studies previously discussed, a similar assumption was made with respect to the coincidence of busy hours and busy seasons of the local offices. Due to the homogeneity of intra-office traffic the degree of distortion in individual trunk group requirements was considered, except for a very few cases, to be insignificant.

levels can and do change with the years for a variety of reasons thus automatically changing the cost comparison.

In spite of the difficulties in obtaining a true and stable comparison of the overall costs of the two methods the weight of evidence indicated the desirability of proceeding with the plans for achieving an ultimate goal of nationwide toll dialing employing the techniques of multi-alternate routing in the design of the intertoll trunk network.

With the completion of the study of the various intertoll trunk requirements for nationwide operator toll dialing there was established for the first time a bench-mark against which many of the assumptions, theories and procedures which went into its making could be measured for accuracy and practicability. Among these was the early question regarding the cost of operator toll dialing with engineered alternate routing compared to its cost without alternate routing. To arrive at a complete answer it would be necessary to restudy the entire network on the current basis of trunking, compare costs of dial switching equipment without CSP features with the cost of CSP switching equipment, evaluate changes in the location and types of trunk facilities and so on. The undertaking of a study and analysis of this scope would require a larger expenditure of engineering time and effort than would seem justified by the usefulness of the results. It should be noted, however, that analysis of the alternate routing trunk study indicated that the original premise as to trunk economies to be expected were substantially correct. In any event the advent of customer toll dialing with its peremptory requirement for high speed trunking has rendered the original question of the relative costs of operator toll dialing, with and without engineered alternate routing, somewhat academic. It can be safely assumed that a high speed intertoll trunking system suitable for customer dialing and engineered without alternate routing would be prohibitive in cost.

CONCLUSION

The transition from ringdown (wholly manual) handling of long haul toll traffic to operator dialing of such traffic has been proceeding for many years and at an increasingly greater rate during the last five years until now some 45 per cent of such traffic is dialed by operators. This has been accomplished almost exclusively on trunk networks operated without benefit of engineered alternate routing. Along with this, increasing use of dialing by destination code has been achieved as various cities and areas have converted to the nationwide numbering plan.

The second phase of the transition, now under way, involves the change from non-alternate routing to alternate routing trunking. With