ESTIMATION OF REFERENCE LOAD FROM DAILY TRAFFIC DISTRIBUTIONS

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ABSTRACT

This paper postulates the criteria for selecting an appropriate method of reference traffic load estimation from traffic measurements, reviews the principal methods currently in use, and proposes a new distribution-based method. This method is compared with the most widely used reference traffic definitions and is shown to possess a number of advantages. The comparison is illustrated by data from the Australian Telecommunications network.

1. INTRODUCTION

Telecommunications networks are designed and dimensioned to provide the required inter-communication facilities at minimum cost consistent with some specified standard of service. The grade of service is usually defined as the proportion of the offered traffic that may be lost or delayed during the busy hour because insufficient number of circuits has been provided. The provision of circuits in the various parts of the network, i.e., network dimensioning, is thus based on the estimated traffic loads and the specified design grade of service. This paper is concerned with the estimation of representative reference traffic from traffic load measurements, but will also include some comments about the grade of service standards, since these two aspects of network dimensioning cannot be considered in isolation.

Several different definitions of the reference traffic (or the traffic base) are used by different administrations and further formulations for this important design parameter have been proposed. Probably the best known and most widely used definition is the average time-consistent busy-hour (ATCBH) traffic of a selected number of busy days in the year. The choice of days included in the reference traffic calculation varies from administration to administration, thus resulting in a number of ATCBH traffic base variants. The CCITT recommended method of reference traffic calculation (Recommendation E500) is also in this category. Its definition of normal traffic load is the ATCBH traffic of the 5 highest traffic days in the same period. Another frequently used method is to estimate reference traffic load from the busiest hour traffic of selected days (e.g., the busy month, 4 consecutive busiest weeks, etc), regardless of when the busy hour occurs in the days selected.

For many years now the practice of the Australian telecommunications administrations has been to use the ATCBH traffic during the busy season as the reference load for all design and planning purposes. The busy season is currently defined as the 4 consecutive busiest working weeks of the financial year (1 July to 30 June). In exchanges where traffic is recorded outside the busy season, the recorded traffics are adjusted by seasonal correction factors, based on continuous daily measurements of total originating and terminating traffics.

While on the whole the ATCBH traffic of selected number of working days has given a reasonably satisfactory estimate of the reference load, a great deal of empirical evidence has accumulated in recent years which suggests that in a significant proportion of cases this method does not produce a fair representation of the underlying traffic load. Changes in shopping habits, flexible working hours, telephone quizzes, and programming of popular television shows all have had an effect on the distribution of telephone calls. On an increasing number of traffic routes the busy hour occurs at a different time on different days of the week ("bouncing busy hour" effect), traffic does not remain in statistical equilibrium even during the busy hour, and there are significant differences between traffic volumes generated on different days of the same working week. This is particularly noticeable on the smaller traffic routes.

In view of the above observations, a review of reference traffic estimation methods was undertaken in Telecom Australia to investigate the problems encountered with the present TCBH method and, if necessary, devise a better one. This paper reports on the results of this investigation.
2. **EVALUATION CRITERIA**

To assess the suitability of a reference traffic definition and to compare it with other definitions the following criteria were used; they are formulated here as a set of desirable properties. Thus, a method used for estimating reference traffic load was considered satisfactory, if it:

(a) was universal - i.e. independent of traffic intensity and its distribution;

(b) gave a fair representation of the underlying traffic load regardless of its daily and hourly variations;

(c) used collected traffic data efficiently;

(d) produced a statistically reliable estimate, meaningful for both design and performance evaluation purposes;

(e) was easy to calculate from automatic load measurements;

(f) was compatible with existing dimensioning methods and grade of service standards;

(g) did not result in a significant change in total common plant provision level.

If no method of estimating reference traffic load was found that met all the above requirements, the one that satisfied most of them was to be preferred.

3. **REVIEW OF PRINCIPAL METHODS**

In this section we briefly look at the more important methods proposed for estimating the reference traffic load, or traffic base, as it is sometimes called, and review them against the criteria laid down in the previous section.

The reference load defined as the average of daily-time-consistent busy hour traffic has already been described in the introduction. Its many versions differ only in the selection of days over which the traffic is averaged. It appears to be the most widely used method for estimating reference loads despite some serious shortcomings. It is implicitly based on the assumptions that busy hour traffic is stationary and that the busy hour on a given traffic route always occurs at the same time. Empirical evidence suggests that there are many traffic routes which do not conform to either one or both of these assumptions. When assessed against the criteria of the previous section, the ATCBH traffic base fully satisfies only the last three (it must satisfy the last two, because the dimensioning methods and the grade of service standards are generally based on it). If the number of days included in the estimation process is large (e.g. \( \geq 20 \)), the TCBH estimate of the mean traffic intensity will be fairly reliable and adequate for design purposes, but not very meaningful for network performance evaluation, which is usually based on whole day's observations. It necessitates collection of considerable amounts of data, but only one hour's data from each day is used in the estimate. It does not give a fair representation of the traffic load whenever busy hours are not time-consistent, or traffic peaks last less than 1 hour, or the daily and weekly traffic profile departs markedly from the "normal" pattern.

The other fairly widely used method estimates reference traffic load by averaging daily peak hour (ADPH) traffics over a number of consecutive (or non-consecutive) working days. As the time-consistency constraint is not included in this definition of the reference load, it can cope well with traffic routes possessing a "bouncing busy-hour". However, here also only one hour's data is used from each day's measurement and variations in traffic flow profile have no effect on the reference load estimate. Likewise, this definition is also based on the "busy-hour" concept and the assumption of statistical equilibrium during this hour. If the same number of days is included in the sample as for the ATCBH reference, this method will, naturally, produce a higher estimate. If the same investment level in common plant is to be maintained, the sample size has to be increased, or the design grade of service standards tightened up.

The third approach to reference traffic estimation employs a distribution of measured traffic samples, taken over a number of days. Traffic samples are average traffic intensities, taken over 30 or 60 minute periods during the busy part of the day, which includes several hours of data. The reference traffic load and the number of circuits required are then estimated from the moments of this distribution (mean and standard deviation).

This approach has been canvassed from time to time in the Traffic Engineering Working Parties of the CCITT Study Groups and has received its share of attention in the literature (Refs. 3-8). The distribution models proposed to represent the traffic sample distribution include Normal, Pearson Type III, and Weibull. Distribution-based methods do not involve the busy hour concept or the assumption of statistical equilibrium. By including all hours of significant traffic flow in the day good use is made of the data and a statistically reliable estimate can be obtained from fewer days of measurement than with methods using only the busy hour traffics.

On the other hand, the dimensioning of circuit groups in accordance with specified grade of service standards depends on the distribution model chosen. Thus, dimensioning tables based on the Normal distribution have been published (Refs. 3, 8) to support the reference traffic proposals made by the authors. The need to introduce new dimensioning models and traffic capacity tables probably explains why this approach has received little support from telephone administrations.
Finally, the reference load estimation method that has received considerable amount of attention in recent years is generally referred to as extreme value engineering. It depends on the recording of only the peak value from each hour of measurement. The mean and standard deviation of the extreme value distribution thus obtained are then used to calculate the reference traffic load. The number of candidate hours in the sample from which peak measurements are taken can be adjusted to yield reference traffic estimates that would lead to the same overall circuit provision level as that obtained from ATCBH estimates. This method is very economical in the amount of data that needs to be collected and is being applied to the administration of small exchanges, where busy hours are rarely time-consistent or the traffic stationary (Refs. 9-10).

4. RTL BASED ON DAILY TRAFFIC DISTRIBUTION

As stated in the introduction, this review was started because of the failure of the ATCBH traffic base to represent fairly the traffic load on routes where daily traffic peaks are not time-consistent, are of shorter duration than 1 hour, and occur many times during the day. Although other busy hour based estimation methods are not constrained by a time consistency requirement, they still do not differentiate between routes with quite different traffic intensity profiles.

Also, by discarding most of the day's traffic data, BH-based reference load estimation methods require a fairly long measurement period to obtain a statistically reliable sample. Thus, BH-based methods do not meet the first three of our evaluation criteria listed in Section 2.

In view of above considerations we decided to move away from the busy hour concept and to base the reference load definition on the daily traffic distribution, or at least on the upper tail of this distribution. As elements of this distribution we chose average traffic intensities over successive 30-minute periods. Shorter averaging periods would introduce correlation problems, while longer periods would smooth out many traffic peaks that last less than one hour, but may contribute significantly to aggregate congestion losses. Our proposal is, thus, similar to those of Karlsson and Rahko (4,5,6).

Distributions of half hour carried traffic averages were obtained from 33 local and trunk routes and the following statistics computed: mean ($\bar{x}$), median (m), standard deviation (s), and skewness (k), which is derived from the other three statistics as follows:

$$k = (\bar{x} - m)/s$$  \hspace{1cm} (1)

Analysis of these data showed that some distributions were fairly symmetrical about the mean, some were positively skew, and some negatively skew. Plot of the daily profiles showed the familiar three humps, corresponding to morning, afternoon and evening busy periods, but there was considerable variation between routes. Three composite daily profiles, representing data recorded on 5 successive working days, are shown in figures 1 to 3. Because they are composite profiles, the variation between half hour averages is less than for a single day's data. The time-consistent busy hour for the week is also shown for each route.

Fig. 1 Traffic Flow Profile Over 5 Business Days on a Local Junction Route
Fig. 2 Traffic Flow Profile Over 5 Business Days On a Local Junction Route

Fig. 3 Traffic Flow Profile Over 5 Business Days On a Local Junction Route
It is necessary now to consider the basis for circuit provision in the various parts of the network. All dimensioning methods known to the author aim to satisfy some specified design grade of service (loss or delay) with respect to the reference traffic load, which is expressed in erlangs, i.e. in units of traffic intensity. This intensity in all BH-based traffic references represents average conditions during the busy hour of the day and, if the circuits are provided in accordance with an appropriate traffic capacity table (or computed from an appropriate dimensioning formula), the route in question is assumed to provide a grade of service equal to, or slightly better than, the specified standard during the busy hour. Yet network performance is generally assessed on the service given throughout the day. It is not difficult to see, for example, that if three routes carrying the traffics represented by figures 1 to 3 were dimensioned for the same blocking probability during their respective busy hours, the total percentages of blocked calls during the period 9 to 24 hours would be different in each case.

Obviously, it would be an advantage to bring the design and performance grades of service closer into line. It seemed that by basing the reference traffic on the whole day's traffic this could be achieved, if we found a simple mathematical model that would accurately represent the traffic distribution during the busy season. Karlsson (4,5) found that for his data the Normal distribution provided a satisfactory fit. Analysis of our data failed to confirm his conclusion: less than half of our data distributions satisfied the chi² goodness of fit criterion with respect to the Normal distribution. We then decided not to tie the reference traffic load definition to any distribution model, but to base it directly on the traffic distribution during the busy season. Karlsson's definition will result in more reliable traffic estimates and more realistically dimensioned networks.

The proposed reference traffic definition, based on all day traffic distribution (ADTD), applies equally well to large, medium, and small traffic streams and appears to meet the criteria laid down in Section 2 for a design traffic base. Some practical application notes need to be made, however, to complete the proposal. Since a design traffic base must represent offered traffic, carried traffics measured on congested routes must be converted to offered traffics, before estimating the parameters of the n busiest half hours traffic distribution (this must be done in estimating design reference traffic by any method and does not represent anything new).

A question may be asked, whether ADTD-based reference traffic may be used for the design of alternative routing networks, where, at least in theory, we dimension for the network busy hour. Alternative routing dimensioning techniques have been developed on the assumptions of statistical equilibrium and a common busy hour. Reality, however, does not quite meet the idealised assumptions; traffic does not often remain stationary for 1 hour on a route, let alone on all routes leaving an exchange; on many routes the time of the busy hour varies from day to day - there is no common, clearly defined time-consistent busy hour in many exchanges; the design traffic estimates contain measurement and forecasting errors, which increase the probability that there will be significant differences between the expected and actual traffic intensities during the nominated exchange or network busy hour.

Most traffic engineers realise these limitations and are not surprised when subsequent traffic measurements disagree with the traffic intensities calculated in the alternative routing design. By dropping the dependence on the TCBH concept and taking all significant traffic data into consideration, the proposed ADTD-based design load definition will result in more reliable traffic estimates and more realistically dimensioned networks.

5. COMPARISON WITH OTHER DEFINITIONS

The comparisons in this Section are based on carried traffic measurements taken over 5 consecutive working days, which have been processed to 30-minute averages. This is standard procedure in Australia and such pre-processed traffic data are readily available. All measurements were taken from routes which were liberally provided with circuits at the time, hence congestion was negligible and carried traffics could assume to be equal to offered traffics.

In these comparisons we have assumed that all routes are offered pure chance traffics and provide full availability access. They are dimensioned from traffic capacity tables based on Erlang's Loss Formula. In addition to the number of trunks that would be provided for either reference traffic, we have also computed the proportion of traffic lost (PTL) during the 50 busiest 30-minute periods (PTL = erlanghours lost/erlanghours offered), as a measure of...
service performance. We first compare the two busy-hour based reference traffics (ATCBH and ADPH) with the reference load based on all day traffic distribution (ADTD), using the data of the routes illustrated in figures 1 to 3. The ADTD Traffic Base has been computed from the moments of 50 busiest half hours distribution, as defined by equation (2); the constants in that equation have been given the following values:

\[
c_1 = c_2 = 1.0 \quad c_3 = 0; \quad n = 50
\]

Next we compared ADTD-based reference traffic with the currently used ATCBH reference on all 33 traffic routes that have been analysed. Again we used the distribution of 50 busiest 30-minute periods to estimate the ADTD reference, computing it from equation (2), with equal weights (=1) given to \( x, s \) and \( k \). That is we defined the reference traffic load as follows:

\[
A_{50} = x + s + k
\]  

The routes were then dimensioned from Erlang B traffic capacity tables for three different grades of service - 0.005, 0.01 and 0.02.

<table>
<thead>
<tr>
<th>Route No.</th>
<th>ATCBH Base</th>
<th>ADPH Base</th>
<th>ADTD Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Cts</td>
<td>Traffic Cts</td>
<td>Traffic Cts</td>
<td>Traffic Cts</td>
</tr>
<tr>
<td>C-0039</td>
<td>9.42</td>
<td>17</td>
<td>0.01305</td>
</tr>
<tr>
<td>M-0185</td>
<td>12.71</td>
<td>21</td>
<td>0.00806</td>
</tr>
<tr>
<td>R-0001</td>
<td>11.75</td>
<td>20</td>
<td>0.00304</td>
</tr>
</tbody>
</table>

Table 1. Comparison of Traffic Bases on Data of Figures 1 to 3; Grade of Service = 0.01

These are relatively low traffic loads and the number of trunks indicated by the standard Erlang B traffic capacity table do not differ much between the three reference traffic definitions. However, the comparison shows the advantage of the distribution-based reference traffic definition with respect to the proportion of total loss during the week. With the ADTD Traffic Base this proportion varies only from 0.00455 to 0.00532, whereas in the case of ATCBH reference this range is 0.01305 to 0.00304, i.e. 13 times wider.

<table>
<thead>
<tr>
<th>Route No.</th>
<th>Reference Traffics</th>
<th>Circuits Required</th>
<th>PTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-0039</td>
<td>9.42</td>
<td>10.90</td>
<td>17</td>
</tr>
<tr>
<td>C-3004</td>
<td>239.34</td>
<td>248.96</td>
<td>262</td>
</tr>
<tr>
<td>C-3050</td>
<td>252.22</td>
<td>259.97</td>
<td>275</td>
</tr>
<tr>
<td>B-0011</td>
<td>74.15</td>
<td>76.19</td>
<td>90</td>
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<tr>
<td>B-3001</td>
<td>126.26</td>
<td>124.84</td>
<td>145</td>
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<tr>
<td>M-0010</td>
<td>25.95</td>
<td>28.01</td>
<td>37</td>
</tr>
<tr>
<td>M-3004</td>
<td>320.89</td>
<td>312.56</td>
<td>345</td>
</tr>
<tr>
<td>M-3050</td>
<td>333.51</td>
<td>324.28</td>
<td>358</td>
</tr>
<tr>
<td>S-0052</td>
<td>26.90</td>
<td>28.58</td>
<td>38</td>
</tr>
</tbody>
</table>

Table 3. Comparison of Traffics, Circuit Requirements, and Lost Traffic Ratios
The total number of trunks that would be required in accordance with the two reference traffic definitions are shown in Table 2.

Looking at the routes individually, only on 9 routes the difference in trunk requirements for the two traffic bases exceeded 1. The relevant statistics for these routes at 0.01 grade of service are shown in greater detail in Table 3.

Table 3 again shows that estimating reference load from all day traffic distribution results in a more even allocation of losses. The range and coefficient of variation of PTL in the case on ATCBH reference are 0.0094 and 0.418 respectively; for ADTD base the corresponding figures are significantly lower - 0.00217 and 0.144, as would be expected.

6. CONCLUSIONS

Analysis of continuous traffic measurements in the Australian telephone network has indicated wide variations in daily traffic intensity profiles between different traffic routes and even on different days in the same route. Reference traffic load definitions based on the concept of time-consistent busy hour, therefore, do not produce uniformly representative and realistic estimates of real traffic loads. A better and more reliable reference load estimate can be obtained from the distribution of all significant traffic flow periods during the days of traffic measurement. The proposed distribution-based reference traffic load definition meets all the criteria set down for a design traffic base and compares favourably with the currently used average time-consistent busy hour traffic reference.

7. ACKNOWLEDGEMENT

The author gratefully acknowledges the permission of the Chief General Manager, Telecom Australia, to present this paper. Thanks are also due to Ms Sue Choy, who carried out most of the numerical analysis of the data.

8. REFERENCES


Summary of Questions/Answers

Date: 09 June 1983
Session: 1.4
Paper: 2

Q.1 (Douglas Barnes)

In your paper you mention EVE methods as an approach to your problem but make no statement about its ability to meet your 7 evaluation criteria. If my understanding of your proposal is correct the EVE method would meet all of your criteria as well at low data cost. It also is not an averaging system and gives measurement interval (such as \( \frac{1}{2} \) or 1 hour) definition most useful with comparison with related measurement to define switching and measurement maintenance condition. My question is did you consider this method to meet your criteria, do you disagree about its meeting criteria or is it rejected for other reasons.

A.1 (J. Rubas)

I made no statement about the EVE method's ability to meet our criteria for a traffic base, because I had no extreme value data at my disposal for comparisons with other traffic bases that I have studied. The number of well documented and plausibly argued papers on EVE published by yourself and your colleagues is clear evidence that a large amount of research has been done in developing this method, which appears to be soundly based. It does, however, require introduction of new traffic measuring and computation procedures, which are more complex than the method I am proposing.
Date: 10 June 1983
Session: 1.4
Paper: 2

Q.1 (Halgreen)

Have you tried to calculate the no. of circuits from one weeks data and then compared the losses from the traffic profile of another week?

A.1 (J. Rubas)

I did and naturally observed some variations from week to week, but variations will occur with whatever traffic base one choses; generally, no two weeks will produce exactly the same traffic.

Q.2 (Halgreen)

In the test of your proposal of a Reference Load, you neglect the skewness in the comparison of losses (table 1) but take skewness into account in the comparison of total no. of circuits (table 2 and 3). Which parameter is then "the proposed distribution based reference load"?

A.2 (J. Rubas)

The general definition of the proposed traffic base is given by equation (2) of the paper. The constraints $c_1, c_2, c_3$ can take any numerical value, including zero, and depend on empirical "calibration" of the new base to ensure that about the same investment in total common plant is maintained as with presently used method. The skewness of the daily traffic distribution is generally less than one and approximate estimates could be neglected. Its inclusion would not have changed the indicated circuit requirements in Table 1 of the paper.

Q.3 (J.G. Kappel)

Apparently all blocking estimates in sect. 5 are based on one week of data, so that "ADTD" is from 50 half-hours, whereas "ATCBH" and "ADBH" are based on only 5 hours each. Since more data is used and the PTL is computed over the same 50 half-hours used for ADTD estimation of ref. load, isn't the observed equality of losses virtually certain to occur?

A.3 (J. Rubas)

Certainly, one would expect the distribution-based reference load to show less variation in the proportion of traffic lost, but this was by no means certain, as it does depend also on the parameters chosen. I felt that it was necessary to present the evidence to convince those who thought differently.