ABSTRACT

This presentation is a study of the economic trade-offs that should be considered in the development of a traffic data collection program. The study is tailored to the requirements of GTE operating telephone companies and will comment on the three primary functions of data collection in GTE:

1. Traffic Engineering Studies
2. Facilities Administration Studies
3. Division of Revenues Studies (Separations Studies)

The basic objectives of the three functions will be presented together with alternatives for achieving the objectives. Of primary interest will be the results of having too little data to achieve the objectives in an economical manner, as well as the result of collecting too much data to be economically justifiable. There would appear to be a point where the cost of over-engineering and/or administering an office could be offset by the costs of obtaining more exact data.

With respect to obtaining less than maximum data, three areas will be discussed:

1. Sampling within equipment groups
2. Sampling within the busy season (i.e., collection of less than complete busy season data)
3. Compositing of data (i.e., using studies offices assuming characteristics of non-studied offices)

Each area will be discussed with relation to each of the three traffic functions.

1. INTRODUCTION

The economic collection of usable traffic data is fundamental to any telephone company. In GTE, the data collection program is directed toward three distinct types of studies.

Traffic Engineering Studies are conducted for purposes of equipment dimensioning to a specific level of blocking and/or delay. Major items of central office equipment, such as linefinders and first selectors in Step-by-Step offices, are dimensioned on the basis of total office averages. These average values of traffic intensity are then applied to traffic tables which are based upon mathematical analysis and empirical evaluation, to arrive at equipment quantities. Since the process involves average values of a large number of customers, as well as dependence upon mathematical assumptions, it would seem that sampling techniques could be used to some advantage in the collection of Traffic Engineering data. All three areas mentioned in the abstract would appear to have merit for this type of study.

Division of Revenues Studies are conducted for purposes of dividing toll revenues among all participating telephone operating companies in the USA. There is no need to go into detail about how they are conducted except to say that they are based upon broad averages of holding times on a total company basis. For many of the same reasons presented above, this type of study lends itself quite nicely to the use of the three areas of sampling mentioned in the abstract.

Facilities Administration Studies, however, are quite different from either Traffic Engineering or Separations Studies. They are not based upon predictable and expected customer demand, but rather they are used to detect the unpredictable. They are used to measure overall office grades of service, but they are also used to insure that individual sub-groupings within the office are not outside acceptable limits. Because of the inherent nature of Facilities Administration Studies, continuing studies are necessary, thus affecting any program to sample within the busy season. They are required in much more detail than the other two types of studies, thus affecting any program involving compositing of data.

The one area left is that of sampling within equipment groups, and it appears to be the area in which the greatest savings can be realized. The remaining portion of this paper deals with the specific case of obtaining linefinder measurements in Step-by-Step offices. The techniques are sufficiently general to be applicable to other measurements.

In this paper a case study is presented in which the value of a particular set of traffic measurements is compared to the value of a smaller subset of measurements. The analysis is a classic example of the trade-off between the value of increased information and its associated increased cost. The particular case considered concerns the engineering of linefinder equipment groups in a Step-by-Step office. From an engineering point of view, the question is how many linefinders to have in each group. From a statistical point of view, the issue is how many linefinders in each group to wire for usage studies. Although the analysis of linefinder-group engineering may at this point seem
somewhat specialized, it will be possible through this simple example to demonstrate an approach to the problem of determining the value of traffic information and to illustrate that in at least some case something far short of "full measurement" is optimal, current reductions in measurement costs notwithstanding.

Section 2 defines the problem of linefinder-group engineering and illustrates the calculation of the value of traffic data as a function of the number of linfinders studied. In Section 3 the costs of measurement are considered for various measurement plans. Then in the final Section the results of Sections 2 and 3 are combined to compute the minimum cost traffic measurement plan.

2. THE VALUE OF MEASUREMENT

2.1 The Problem: Linefinder-Group Engineering- For the purposes of this paper, the problem of linefinder-group engineering is that of determining the minimum number of linefinders in an equipment group (group of linfinders that service 200 lines) that will on the average lead to no more than 1.5% of the calls having to wait for more than three seconds for dial tone during a specified busy period. Since the relationship between the number of linfinders required in a group and the expected cost for that group is well known, the engineering is rather straightforward.

2.2 Estimation of Expected Average CCS for Linefinder Groups

Estimates of expected CCS are based on usage measurements and in the case of linefinder groups on actual observation of CCS for particular linefinders during the busy period. Typically, linfinders in a group are divided into two partitions, each partition serving 1/2 of the subscribers assigned to that equipment group. Only when all linefinders in a particular partition are busy, do subscriber demands for service "spill over" into the other partition. In order to estimate group CCS, it will be necessary to make certain assumptions concerning the manner in which linfinders are assigned to demands for service. Here it will be assumed that linfinder assignment is made with a rotary switch so that each linfinder within a partition will have the same distribution of observed CCS during the busy period. Generally the estimate that is needed for engineering purposes is the expected CCS at some future time other than when the observations are made for the present analysis, the forecasting problem will be ignored and it will be assumed that observations of CCS are available for the busy period in which it is desired to engineer the equipment groups. Under these conditions, the usual unbiased estimate of expected CCS is given by the weighted average of observed linfinder usage. To be precise, let

\[ \bar{M}_j = \text{estimated expected CCS for group } j. \]

\( N = \text{number of linfinders in each partition} \)

\( n = \text{number of linfinders observed in each partition} \)

\( s_{i,j} = \text{observed CCS for linfinder } i \text{ in group } j \)

\( \bar{M} = \text{expected average CCS per equipment group} \)

\[ \bar{N} = \text{number of groups in the office} \]

\( S_{1,j} = \text{the set of indices of linfinders observed in the first partition of group } j \)

\( S_{2,j} = \text{the set of indices of linfinders observed in the second partition of group } j \)

The estimate of expected CCS for group } j \text{ is given by

\[ \bar{M}_j = \frac{1}{n} \sum_{i=1}^{n} s_{i,j} \]

(2.1)

and the estimate of expected average CCS per group for the office is

\[ \bar{M} = \frac{1}{N} \sum_{j=1}^{N} \bar{M}_j \]

(2.2)

2.3 Engineering Policy- On the basis of the estimate of expected average CCS given in (2.2), each linefinder group is engineered. The better the estimate, the more closely the group can be engineered. The value of observing a set of linefinders is therefore expressed in terms of the accuracy of the estimate \( \bar{M} \).

The policy used to engineer an office given an estimate \( \bar{M} \) will, of course, depend on local agreements and the strength of one's desire to guarantee a specified grade of service. Two policies will be considered here—one representing a rather conservative engineering philosophy and the other considerably less restrictive. It is felt that most operational designs would reflect something between these two extremes. Both policies will depend only on \( \bar{M} \) and its standard deviation, \( S \).

For the less conservative policy, denoted one-sigma it is assumed that each linefinder group in an office is engineered for a CCS load of \( \bar{M} \) plus one standard deviation initially. In subsequent years when additional studies are made, it is assumed that the only reason linfinders are added is growth and not uncertainty in CCS load. With one-sigma the expected overdesign is 5 per group and this is assumed to be sufficient for all time.

The second policy considered, two-sigma requires an initial design of \( \bar{M} \) plus two standard deviations. In this case the % assurance is obtained that the expected overdesign will not be exceeded. When subsequent studies are made, the policy is assumed to be maintained so that the expected overdesign will be at least 25 per group at all times.

For both policies the linefinder groups are designed for a load \( \bar{M} \) with an expected overdesign (proportional to \( S \)) to account for sampling error. An overdesign can be directly related to the first cost of linefinder equipment installed. In the case of linfinders, each 28 CCS corresponds to approximately one additional linfinder.

In terms of these two policies, the value of increased measurement is then reflected through a reduction in \( S \) and, correspondingly, a reduction in equipment requirements.

\[ \sigma_{ik} = \text{the covariance of } s_{i} \text{ and } s_{k} \]

\( \text{Variance } R_j = \frac{1}{(k/n)} \sum_{i=1}^{k} (s_{i}-\bar{M})^2 \)

\[ = \frac{1}{(k/n)} \sum_{i=1}^{k} (s_{i}-\bar{M})^2 \]

\( \bar{x}_B = \text{average CCS per linefinder} \)

\[ \bar{x}_{SB} = \text{average } \bar{x}_B \text{ for group } j \]

\( \bar{R}_j = \text{average } \bar{R}_j \text{ for group } j \]

\[ \bar{M}_j = \text{average } \bar{M}_j \text{ for group } j \]

\[ \bar{M} = \text{average } \bar{M} \text{ for all groups} \]

\[ \bar{R} = \text{average } \bar{R} \text{ for all groups} \]

\[ = \frac{1}{n} \sum_{i=1}^{n} \sigma_{ik} \]

(2.1)

(2.2)

(2.3)

(2.4)
Since each $a_i$ within a partition is distributed identically, define
\[
\begin{align*}
\sigma_A^2 &= \sigma_{11} \\
\sigma_B^2 &= \sigma_{11} \\
\end{align*}
\]
where $k + \epsilon < 2 L$.

Then,
\[
\text{Variance } \hat{\sigma}_i^2 = \left(\frac{k^2}{n}\right) \left[ \sum_{A} \sigma_{i}^2 \right] + \left(\frac{2}{n}\right) \sum_{k \neq k} \sigma_{i} \sigma_{k}
\]
where $i \neq k$.

If correlation is ignored, (2.3) becomes
\[
\text{Variance } \hat{\sigma}_i^2 = \left(\frac{k^2}{n}\right) \sigma^2
\]
and
\[
\text{Standard Deviation } \hat{\sigma}_i = \left(\frac{k}{n}\right) \sigma
\]
where $\sigma^2 = \sigma_A^2 + \sigma_B^2$.

It is typically assumed that each of the equipment groups in an office has independent demand for service during the busy period. In this case, $S$ is simply the square root of the sum squares of (2.4) for each equipment group.

In particular, if each group has identical variance, $\sigma^2$, the expected CCS overdesign for each group is given by
\[
S = \left(\frac{k}{n}\right) \sigma
\]
and since there are $N$ groups, the total expected CCS overdesign is
\[
\text{Total Overdesign } = N \times \left(\frac{k}{n}\right) \sigma
\]
\[
(2.5)
\]

The difference in expected CCS design between full measurement $(n=1)$ and a sample of $m$ linefinders from each group is therefore
\[
\text{Difference } = \left(\frac{k}{n}\right) \sigma - \left(\frac{k}{m}\right) \sigma
\]
or
\[
\text{Difference } = \left(\frac{k}{n}\right) \sigma \left(\frac{1}{\sqrt{n}} - \frac{1}{\sqrt{m}}\right)
\]
\[
(2.6)
\]

Expression (2.7) will be used to compute the cost of expected overdesign necessitated by observing a sample $(n=1, 2, 3, \ldots, k)$ of linefinders relative to full measurement $(n=k)$.

2.5 The Cost of Expected Overdesign for Two-Sigma Policy With this type of policy not only is there an expected overdesign initially but there is an expected additional overdesign for each subsequent study. Assuming that traffic studies are made annually, the amount of expected overdesign will increase each year.

Let $\hat{\gamma}$ represent the estimated expected average CCS in year $y$. Each $\hat{\gamma}$ is distributed approximately Normally with standard deviation $\hat{\sigma}$ and some mean $\hat{\mu}$ (assuming stationarity from year to year). Furthermore it is reasonable to expect that $\hat{\mu}_1, \hat{\mu}_2, \ldots$ are independent.

In the first year the expected overdesign per group is $2\sigma$. In the second year additional capacity is allowed for in the amount of
\[
\hat{\gamma} = \left(\frac{M + 2\sigma}{M}\right) - \left(\frac{M + 2\sigma}{M}\right)
\]
and in general the CCS increment per group in year $y$ is
\[
\hat{\gamma} = \left(\frac{M + \sigma}{M}\right) - \left(\frac{M + \sigma}{M}\right)
\]
where $y > 0$ and zero otherwise. The expected CCS overdesign for year $y > 1$ is therefore
\[
\sum_{y=1}^{\infty} \left[ \left(\frac{M + \sigma}{M}\right) - \left(\frac{M + \sigma}{M}\right) \right] P[\hat{\gamma} = \hat{\gamma}]
\]
\[
(2.8)
\]

where $P$ is the Normal density with mean $\hat{\mu}$ and standard deviation $\hat{\sigma}$. By a change of variable (2.8) can be shown to be independent of $\hat{\mu}$ and equal to the product of $y$ and the value of the integral when $\hat{\gamma}$ is distributed with zero mean and standard deviation one. The value of (2.8) has been computed numerically for $S=1$ and is shown in Table 1 as $B(y)$ where $B(1)$ is defined to be 2.

The expected total CCS overdesign added in year $y$ can now be expressed as
\[
B(y) = N \times B(1)
\]
\[
(2.9)
\]

The standard deviation, $S_y$, is given by (2.5).

Substituting, (2.9) becomes
\[
B(y) = \left(\frac{\sigma}{\sqrt{n}}\right) \left(\frac{1}{\sqrt{y}}\right)
\]
\[
(2.10)
\]

Relative to full measurement $(n=k)$ with a two-sigma policy, the expected total CCS overdesign added in year $y$ is therefore
\[
B(y) = \left(\frac{\sigma}{\sqrt{n}}\right) \left(\frac{1}{\sqrt{y}}\right)
\]
\[
(2.11)
\]

Table 1 Value of $B(y)$
\[
\begin{array}{|c|c|}
\hline
\text{Year} & \text{Value of } B(y) \\
\hline
1 & 2 \\
2 & 0.161 \\
3 & 0.033 \\
4 & 0.021 \\
5 & 0.014 \\
6 & 0.006 \\
7 & 0.006 \\
8 & 0.002 \\
9 & 0.001 \\
10 & 0.001 \\
\hline
\end{array}
\]

2.6 A Numerical Example—To evaluate (2.7) and (2.11) an estimate of $\sigma^2 = \frac{\sigma^2}{k}$ is needed. Typically many observations of a particular group for the busy period are not available or reliable due to variations from study to study. What is available are observations for each group in a central office taken during a particular study. In this case it is possible to get an estimate of $\sigma$ by examining the variance of $\hat{\sigma}$, where $\hat{\sigma}$ is the estimated CCS with $n=k$ and $N$, is the corresponding quantity with $n=k$. It can be shown that

\[
\text{Variance } \hat{\sigma}_i^2 = \left(\frac{k}{n}\right) \sigma^2
\]
\[
(2.12)
\]

The development of (2.12) requires the same assumptions made in the development of (2.7) and (2.11). It should be noted, however, that (2.12) does not require expected CCS to be the same from group to group. To use (2.12) first the variance of the expected overdesign for each linefinder group is estimated in the usual manner using observed CCS on the linefinders studies, and then $\sigma$ is computed. Based on data obtained from an actual central office with $k$ linefinder groups, $l = 10$, and $n = 1$, $\hat{\sigma}$ was estimated to be 2.33. Figure 1 shows actual estimates for the variance $\hat{\sigma}_i^2$ obtained as a function of $n$. The smooth curve plotted is (2.12) with $r = 2.33$.

With an estimate of $\sigma$ all that remains is to compute first cost of investment in each year for a one-sigma and two-sigma policy is to estimate the marginal cost of adding an additional linefinder to an existing group. Table 2 gives such an estimate. With this result each CCS of overdesign may be interpreted as resulting in $\$432/28$ additional investment.

As an example of the use of (2.7) and (2.11), consider the computation of the first cost of expected overdesign (relative to a measurement plan of $n=k$) in a 1 unit (N=50) office with three linefinders (n=3) measured in partitions of size eight ($L = 8$).

Figure 1—Expectation of $\sigma$
Associated with the first cost of investment are additional costs having to do with maintenance and moves. Furthermore there is the effect of taxes and depreciation which alters actual cash flow. Tables 3 and 4 present the effect of taxes and depreciation and other entries are based on estimated percentages of first cost. Cash flows are shown for a 15-year planning horizon which will be used in the subsequent analysis.

To convert the cash flows of Tables 3 and 4 to their present worth an 8% rate of return has been chosen. This calculation yields a present worth of the cost of expected overdesign for \( n = 1 \) (relative to full measurement) of $507 and $1371 for the one-sigma and two-sigma policies, respectively.

Since the entries of Tables 3 and 4 are proportional to first cost and the present worth calculation is a linear operation, the present worth of cost is proportional to first cost with a proportionality constant of 407/502 for one-sigma and 1371/502 for two-sigma. Therefore with the cost figures of this example the present worth of cost of expected overdesign is

\[
\text{Cost of \( n \) sigma} = \left( \frac{507}{502} \right) \left( \frac{1371}{502} \right) \times \left( \frac{1}{(1+0.08)^n} \right)
\]

or

\[
\text{Cost of \( n \) sigma} = \left( \frac{1371}{502} \right) \left( \frac{1}{(1+0.08)^n} \right)
\]

for a one-sigma policy and

\[
\text{Cost of \( n \) sigma} = \left( \frac{507}{502} \right) \left( \frac{1}{(1+0.08)^n} \right)
\]

or

\[
\text{Cost of \( n \) sigma} = \left( \frac{507}{502} \right) \left( \frac{1}{(1+0.08)^n} \right)
\]

for a two-sigma policy.

It should be noted that (2.13) and (2.14) represent the after-tax cost, employ 8% discounting, assume costs of an incremental linefinder as stated, and are relative to the cost of full measurement (\( n = 1 \)). Figure 2 displays this cost for the example as a function of the measurement plan \( n \).

### 3. THE COST OF MEASUREMENT

#### 3.1 Description of Measurement Techniques

In order to compute the cost of measurement, it is necessary to have a basic understanding of how the measuring is to be accomplished. Here, a typical measuring technique is assumed.

To measure usage on a linefinder it is necessary to bring a "C-Lead" from the linefinder to a terminal from which a "Cross-Connect" is made--thus one "C-Lead" and "Cross-Connect" for each linefinder to be measured. The "Cross-Connect" is made to a scanner which has the ability to measure total CCS for groups of inputs in increments of 10 and up to 50 per group. The maximum number of inputs is 500 and therefore from 10 to 50 groups can be measured. The CCS measured for each group is recorded on electronic registers.

### TABLE 2

<table>
<thead>
<tr>
<th>ITEM</th>
<th>MATERIAL COST</th>
<th>LABOR HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted Labor Hours</td>
<td>$277.34</td>
<td>7.56</td>
</tr>
<tr>
<td>Labor Cost</td>
<td>$39.70</td>
<td></td>
</tr>
<tr>
<td>Total Cost (non-loaded)</td>
<td>$317.04</td>
<td></td>
</tr>
<tr>
<td>Total Cost (loaded)</td>
<td>$432.00</td>
<td></td>
</tr>
</tbody>
</table>

For a one-sigma first cost is computed with \( \sqrt{3} \) multiplying by \( \frac{1}{268} \)-the cost per CCS:

\[
\text{Cost of \( n \) sigma} = \left( \frac{1}{268} \right) \left( \frac{1}{\sqrt{3}} \right) \times \left( \frac{1}{(1+0.08)^n} \right)
\]

For a two-sigma policy the first cost of investment is twice as much initially and then the incremental cost diminishes each year in accordance with \( B(l) \). Thus, a two-sigma policy leads to a cost in year \( y \) of

\[
\text{Cost of \( n \) sigma} = \left( \frac{1}{268} \right) \left( \frac{1}{\sqrt{3}} \right) \times \left( \frac{1}{(1+0.08)^n} \right)
\]

### TABLE 3

<table>
<thead>
<tr>
<th>ITEM</th>
<th>MATERIAL COST</th>
<th>LABOR HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanner</td>
<td>$1,709.73</td>
<td>130.0</td>
</tr>
<tr>
<td>Registers (per 1000)</td>
<td>$8,486.00</td>
<td>147.0</td>
</tr>
<tr>
<td>Centralized C-Leads</td>
<td>$80.45</td>
<td>4.6</td>
</tr>
<tr>
<td>Jumapers (100)</td>
<td>$8.3</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 4

<table>
<thead>
<tr>
<th>ITEM</th>
<th>MATERIAL COST</th>
<th>LABOR HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanner</td>
<td>$3,512.00</td>
<td></td>
</tr>
<tr>
<td>Registers (per 1000)</td>
<td>$12,918.00</td>
<td></td>
</tr>
<tr>
<td>Centralized C-Leads</td>
<td>$150.00</td>
<td></td>
</tr>
<tr>
<td>Cross-Connections</td>
<td>$75.00</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 5

<table>
<thead>
<tr>
<th>ITEM</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanner</td>
<td>$3,512.00</td>
</tr>
<tr>
<td>Registers (per 1000)</td>
<td>$12,918.00</td>
</tr>
<tr>
<td>Centralized C-Leads</td>
<td>$150.00</td>
</tr>
<tr>
<td>Cross-Connections</td>
<td>$75.00</td>
</tr>
</tbody>
</table>

### 3.2 First Cost of Measuring Equipment

Tables 3 and 4 show a computation of first cost for the scanner, registers, "C-Leads", and "Cross-Connections".
Putting these expressions together, the first cost of investment for measurement without group identity is given by

\[ 2nN \left( \frac{150}{100} \right) + \frac{1}{N} \left( \frac{2n-1}{2n} \times \frac{1}{10} \right) \]

For the case with group identity, the first cost measurement is

\[ \left( \frac{(2n-1)/10}{1} \right) \times \left( \frac{3512}{50} \right) \times \frac{1}{1000} \]

With group identity, the corresponding expressions become

\[ \left( \frac{(2n-1)/10}{1} \right) \times \left( \frac{3512}{50} \right) \times \frac{1}{1000} \]

In addition there is a $4 per register annual cost.

To convert first cost of investment into present worth of after-tax cost, a cash-flow analysis is needed similar to that presented in the calculation of incremental linefinder cost. Table 7 gives an after-tax analysis of a first cost investment of $1000 in measurement equipment, assuming 30% tax rate and straight line depreciation. Other entries are based on a percentage of first cost. The present worth of the cash flow at 8% is $999. Therefore, $999 multiplied by first cost will yield the present worth of the cost of measurement for the fifteen-year planning horizon.

Expressions for after-tax present worth of cost are obtained from (3.1) and (3.2) by multiplying by .999 and adding in the after-tax present worth of the annual data processing expense (4.45 x annual charge):

Without group identity, present worth of cost is given by

\[ 2nN \left( \frac{150/100 + (75/100)}{1} \right) \]

With group identity, the corresponding expression becomes

\[ 2nN \left[ \left( \frac{(2n-1)/10}{1} \right) \times \left( \frac{3512}{50} \right) \times \frac{1}{1000} \right] \]

To indicate the minimum total cost obtainable with group identity, the first cost of measurement is expressed as a function of the number of linefinders studied per group.

To convert first cost of investment into present worth of after-tax cost, a cash-flow analysis is needed similar to that presented in the calculation of incremental linefinder cost. Table 7 gives an after-tax analysis of a first cost investment of $1000 in measurement equipment, assuming 30% tax rate and straight line depreciation. Other entries are based on a percentage of first cost. The present worth of the cash flow at 8% is $999. Therefore, $999 multiplied by first cost will yield the present worth of the cost of measurement for the fifteen-year planning horizon.

Expressions for after-tax present worth of cost are obtained from (3.1) and (3.2) by multiplying by .999 and adding in the after-tax present worth of the annual data processing expense (4.45 x annual charge):

Without group identity, present worth of cost is given by

\[ 2nN \left( \frac{(2n-1)/10}{1} \right) \times \left( \frac{3512}{50} \right) \times \frac{1}{1000} \]

With group identity, the corresponding expression becomes

\[ 2nN \left[ \left( \frac{(2n-1)/10}{1} \right) \times \left( \frac{3512}{50} \right) \times \frac{1}{1000} \right] \]

4. A COMPARISON OF COSTS

4.1. The Minimum Cost Measurement Plan- The minimum cost measurement plan is that plan which minimises the total cost, i.e., the sum of the cost of expected overdesign and the cost of measurement. In Section 2 the cost of expected overdesign was computed for two engineering policies, one-sigma and two-sigma. In the last Section the cost of measurement was computed for two methods, with and without group identity.

There are therefore four cases to be examined. For the example being considered—a one unit office with 16 linefinders per group—the costs for each of the four cases have been computed and are displayed as Figures 3, 4, 5, and 6. In each case it will be seen that the minimum cost measurement plan results in a substantial savings over the plan of full measurement. Expressed as a percentage, the minimum cost plan saves from 32 to 69% of the cost of full measurement depending on which case is being considered. In addition it should be noted that the minimum cost plan never results in more than 10 out of 16 linefinders in a group being studied and in most cases less than 6.

4.2. Other Comparisons—Figures 3, 4, 5, 6 in addition to indicating the minimum cost measurement plan also make it possible to answer such questions as what is the cost of maintaining group identity? Or what is the cost of a two-sigma policy relative to that of a one-sigma policy?

For the example, it is apparent from Figure 4 that the minimum total cost obtainable with group identity is $5620. and from Figure 3 the corresponding cost without group identification is $6950. Hence, with a one-sigma policy the cost of group identification is $2820 minus $3651 or $770. Similarly from Figure 5 the minimum total cost with a two-sigma policy is $4140 as compared to that of $8450 with a one-sigma policy (Figure 3). Thus the conservative two-sigma policy costs $4140 minus $2850 or $1290 when group identity is not maintained.

4.3 Conclusion—This paper has illustrated in a specific example how the value of traffic measurements may be expressed quantitatively and then compared to their associated cost. In this way, a rational decision is made concerning the amount of traffic data that should be collected. In the example chosen something far short of full measurement is indicated.
Table 3—After tax cost of expected overdesign for a one-sigma policy

<table>
<thead>
<tr>
<th>ITEM</th>
<th>YEAR</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Investment</td>
<td></td>
<td>452.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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Attachment 2

Table 4—After tax cost of expected overdesign for a two-sigma policy

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