Traffic Measurements

(Exercises included)

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TRAFFIC MEASUREMENT

1 INTRODUCTION

By the concept **Traffic Measurement** is meant the methods used for collecting data of interest for the traffic being handled. This implies the measurement of traffic, number of calls, number of lost calls, waiting times etc. By **Traffic Supervision** is meant the supervision of the operation in order to keep the traffic and their operating conditions under control. A long-term form of traffic supervision is the collection of statistical data at regular intervals. A form of supervision of the same type is the supervision of the service quality of telecommunication plant i.e. observation of the number of technical faults of different kinds.

Traffic measurement and traffic supervision in telecommunications plant may be classified as follows:

1a Short-term (supervision)
1b Long-term (forecasts)
1c Occasional special investigations (charting)

2a Continuous measurements
2b Regularly recurring measurements
2c Sporadic measurements (may be started in response to an indication of unsatisfactory operation)

3a Measurement based on direct measures
3b Measurements based on indirect measures indications

4a Measurement for collection of statistics
4b Measurements which decide further action to be taken

Supervision is primarily short-term (1a) and should be continuous (2a). One can use either direct or indirect measures (3a or 3b). The result of supervision may call for occasional special investigations (1c) or sporadic measurements (2c), which may be started automatically in response to an indication. This is done if the action needed to deal with a situation is not directly obvious from the observed data.

Forecasts are based on long-term measurements (1b), which are made continuously (2a) or at regular intervals (2b). Measurements for collecting of statistical data should preferably be based on direct measures (3a) and should not give rise to immediate action (4a). In drawing up a programme of traffic supervision one should have a clear idea as to what steps towards service improvement can be undertaken immediately and what steps require long-term planning over a period of perhaps six months, one year or five years. This depends on the flexibility of the telecommunication system, i.e. how quickly existing spare equipment and other resources can be brought into use at the point required or how a quickly a fault can be remedied.

Another question which arises is the following: If direct automatic measures are required as a result of supervision of traffic and service, can these statistics be used for other purposes? Can the collected statistics be used as well for the long-term planning of future plant extensions, or is it necessary to collect special statistics for these forecasts? It is always desirable not to spend more time and money on the collection of statistics than necessary. The storage of traffic data without undue labour, on the other hand, may be useful for future requirements. But it is always difficult to foresee in advance what should be saved and what scrapped. To much data may be saved, at too great a cost.

1.1 The traffic situation

Telecommunication traffic has considerable variations. These may be classified as:

1. Variations during the day;
2. Variations of the time for the busiest hour;
3. Day-to-day variations;
4. Seasonal variations;
5. Weekday variations;
6. Tendency to traffic increase.

Hence, when making occasional as well as regularly recurring measurements, one must know how the traffic at these times is related to the traffic when no observations are made. It also follows from this that it is rather difficult to estimate whether a single value or a number of values obtained in a given manner are especially high or low. It is, therefore, necessary to make continuous observations of certain statistics in order to be able to judge the significance of the other observations.

In organizing a traffic supervision programme, it is necessary to work against established service criteria; certain threshold values should be used in the supervision. The level, or levels, should be made that a reminder or an alarm only is given when really needed. If the limits are set too low, one gets too much data and it is difficult to sift out what is a serious matter and what is not. If the limits are set too high, one gets no warning when a serious situation occurs.

For determination of suitable threshold levels, one must use available experience of the traffic variations and try to estimate how often the congestion may in future exceed certain values. (See figure 1).

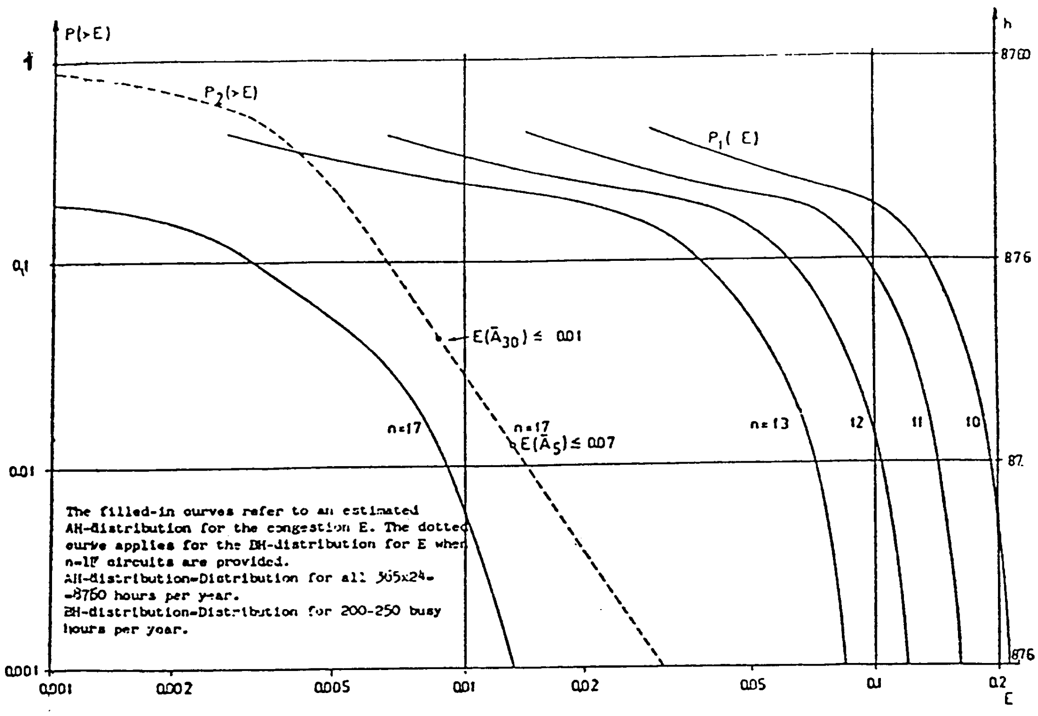


Fig. 1 Resulting distribution of congestion in a route at N=10, 11, 12, 12 and 17 circuits, based on a prediction of the future traffic variations.

Explanation: If we consider the case with n=17 circuits for the busy hours only (dotted curve), we can expect the congestion to exceed 1% (E=0.01) in about 25-30% of the busy hours, that is, about 50 of the 200-250 busy hours during the year. The congestion will exceed 2% in about 1 case of 250, that is once a year in the busy hour.

In the same way, if we look at the curve for all hours during a year (=8760h) for n=17 we find that E=0.01 will exceed with a probability of about P(>E)=0.006, that, in 0.006 • 8760=53 occasions (of which about 50 occur during the busy hour! We also see that a value of about E=0.013 will exceed about one time in 1000, that is, about 9 times during a year.

Even if the example given in figure 1 for n=17 circuits is not expected to give disturbingly high congestion during the coming year, it may be reason to set an alarm if E exceeds 2-3%, since high congestion will occur if some of the circuits become out of service. The alarm is then more likely to indicate operational troubles than high traffic which could very well have been the initial intent of the alarm.

1.2 Historical development

Measurements have been carried out since the beginning of telephony. Some of the first observations of traffic leading to analytical models of traffic were performed by the director of the Copenhagen Telephone Company who published a paper on the matter already in 1908. He employed **A.K. Erlang** (1878-1929), the founder of modern teletraffic theory.

Erlang's work was carried on by **Conny Palm** (1907-1951) in Sweden. He developed a general measuring philosophy, and in his thesis (1943) one gets an idea of his reflections when collecting data for the verification of theoretical models. His measurements were subject to strong restrictions, because of the limited possibilities of collecting, storing and evaluating the data.

During the last decades, new demands on traffic data have been made. Manual exchanges have been replaced by automatic equipment, allowing subscriber trunk dialing (STD) and other facilities. The result of this is that a lot of verbal information from the operators is lost and has to be replaced by new observations.

The first automatic exchanges were only sparsely provided with measuring facilities. The same happened when the SPC systems were introduced.

Furthermore, due to short-term considerations, many administrations have been reluctant to invest in measuring equipment.

Of late, the telephone network has become world-wide with the introduction of international subscriber dialing (ISD). the larger the overall network to be controlled, the more important the role of measurements. An urgent demand for traffic data has, therefore, arisen.

On the other hand, the possibilities of obtaining data are improved. The measuring technique has been utterly simplified by the advent of computers (mini- and micro-computers). Measurements, which earlier required extensive manual work for retrieval and processing, can now be carried out by means of computers.

1.3 The system to be measured

To analyze a teletraffic system, it is necessary to make up a model which describes all or part of it. Such a model may consist of three elements, viz.:

1 The structure (hardware);
2 The strategy (software);
3 The traffic process (user requirements).

The **Structure** is technically well-defined, and we are in principle able to obtain any degree of detailed information on parts of the system.

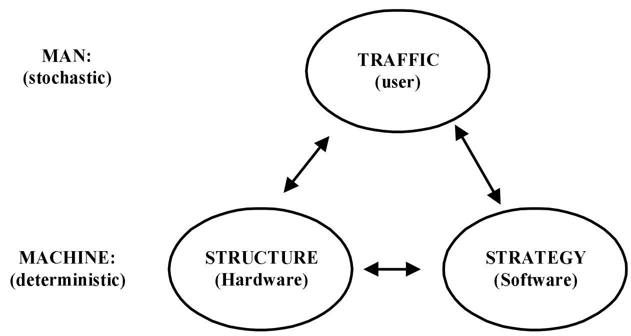


Figure 2: The telecommunications system is a complex man-machine system. The purpose of traffic engineering is to design optimal systems. This can only be fulfilled by making observations of subscriber behaviour.

The **Strategy** consists of rules and principles, which the traffic engineer applies to obtain the best from the system in a given traffic situation. In electro-mechanical systems, the strategy is implemented in the wired logic, in SPC systems in the software = programmed logic.

A realistic description of the traffic process can only be arrived at by observations on real operating systems.

Thus the traffic engineers try to adapt the system to the traffic process by applying different strategies, such as routing, priorities etc.

Difficulties may arise because the three elements interact. Thus, the observed traffic is NOT independent of the structure or the strategy (Fig. 2).

1.4 The traffic process

The number of subscribers dialing simultaneously, the number of calls on a trunk group, etc. vary incessantly with time. The traffic process takes place in **continuous time** and in **discrete space**. Changes are due either to the arrival of calls or to the termination of existing calls (Fig. 3).

Thus, it is natural to divide the description of the statistical properties of the traffic flow into two processes:

1 The holding time process;
2 The call arrival process.

1.4.1 Holding time distribution

Every time interval, e.g. holding time, congestion time etc., is a non-negative stochastic variable **X,** which we call a life-time. **X** is characterized by a distribution function:

$$F(t) = P(X \le t) \qquad t \ge 0 \tag{1.1}$$

For this type of distribution, we have the useful identity:

$$M_n = \int_0^\infty t^n f(t)dt = \int_0^\infty nt^{n-1}\{1 - F(t)\}dt \qquad \text{n=1,2,...} \tag{1.2}$$

$\mathbf{M_n}$ is the n^th^ non-central moment and **f(t)** is the density function. For the first moment we get the mean value μ:

$$\mu = \mathrm{M}_1 = \int_0^\infty \mathrm{tf(t)dt} = \int_0^\infty \{1 - \mathrm{F(t)}\}\mathrm{dt} \tag{1.3}$$

Palm introduced a **form factor** ε can be introduced to characterize the dispersion of a life-time distribution:

$$\varepsilon = \frac{M_2}{M_1^2} = 1 + \frac{\sigma^2}{\mu^2} \ge 1 \tag{1.4}$$

where σ^2 is the variance of the distribution. For a constant time interval, we get $\varepsilon = 1$. If we choose the mean value as a time unit, we get $\varepsilon = M_2$

In principle, we may use any distribution function with non-negative arguments for describing life-times. However, for the practical and analytical applications, the **exponential distribution** has some outstanding features, which make it the most important distribution among all life-time distributions. It also yields a good description for many real observations of time intervals. Below are shown the distribution and density functions.

$$\begin{aligned} F(t) &= 1 - e^{-\lambda t} \\ &\qquad \lambda > 0, t \ge 0 \\ f(t) &= \lambda e^{-\lambda t} \end{aligned} \tag{1.5}$$

Thus the distribution is characterized by one parameter, viz., λ.The mean value is 1/λ and the form factor equals **2**. The essential property of the exponential distribution is the missing memory. The remaining life-time is independent of the present life-time.

Departing from the exponential distribution, we can define two comprehensive classes of distribution, forming a most convenient way of representing analytically the distributions obtained by measurements. Moreover, they appear as a natural consequence of the re-shaping that the traffic undergoes in its passage through a telecommunications system, as they correspond to exponential intervals in series - **steep distribution**, ε<2 and in parallel - **flat distribution**, ε>2.

Any life-time can be described by a combination of these two classes of distribution. This combination is called a **generalized Erlang distribution** or a **Cox distribution**.

1.4.2 Call arrival process

The arrival of calls during a period of time at a certain point within a telecommunications system is within the theory of stochastic processes denoted as a **Stochastic Point Process**. In a point process two events - calls - only differ by the point of time they occur. Information on the individual calls is ignored.

Let us consider only regular point processes, i.e. where multiple events are excluded. In the field of telecommunications, this is done by choosing a sufficiently small time unit.

Starting observations at time $\mathbf{T_0=0}$ and denoting the time of arrival of the $\mathbf{i^{th}}$ call by **T** we get:

$$\mathbf{0 = T_0 < T_1 < T_2 < ... < T_n < ...} \qquad (1.6)$$

The number of calls in the half-open interval **(0,t|** is denoted by $\mathbf{N_t}$. This is a discrete stochastic variable. The distance between two events:

$$\mathbf{X_i = T_i - T_{i-1}} \qquad \mathbf{i = 1,2,...} \qquad (1.7)$$

is called the **inter-arrival time**. This is a continuous stochastic variable defined by the inter-arrival distribution.

Corresponding to $\mathbf{N_t}$ and $\mathbf{X_i}$, a point process can be characterized in two ways:

1. **Number representation** $\mathbf{N_t}$: the time interval **t** is fixed and we observe the stochastic variable $\mathbf{N_t}$.

2. **Interval representation** $\mathbf{T_i}$: the number of events is fixed and we observe the time **T** required for the occurrence of events.

A simple but fundamental relationship between these two representations is:

$$P\{N_t < n\} = P\{T_n > t\} \qquad n = 1,2,\ldots \qquad (1.8)$$

The interval representation corresponds to the classical time series analysis. If for example **n = 1**, we get statistics on the individual call, i.e. **call averages**. The statistics obtained from the number representation are in general **time averages**. In teletraffic measurements, it is very important to distinguish between these two types of averages.

When the inter-arrival times are exponentially distributed we arrive at the **Poisson process**, which is the most important among all point processes. For the **normal** distribution used in mathematical statistics superposition is implemented by **addition**. For the Poisson process, used for description of point processes, superposition is implemented by **multiplication**. The Poisson process gives a good description of many physical point processes.

1.4.3 Traffic process

By the expression **Traffic**, we usually mean **intensity of traffic**, which is defined as follows:

For a group of circuits or devices, the average intensity of traffic during a period **T** equals the total occupancy divided by T.

The unit of traffic as defined above is called **Erlang**, abbreviated **Erl**.

In classical teletraffic theory and in classical measuring methods, the traffic process is studied through the state space - **vertical measurement**, where it is not possible to follow individual calls.

The above-mentioned decomposition of the traffic process is not in agreement with the operating principle of computerized equipment, which monitors the individual circuit, and thus operates on the time space - **horizontal measurements**.

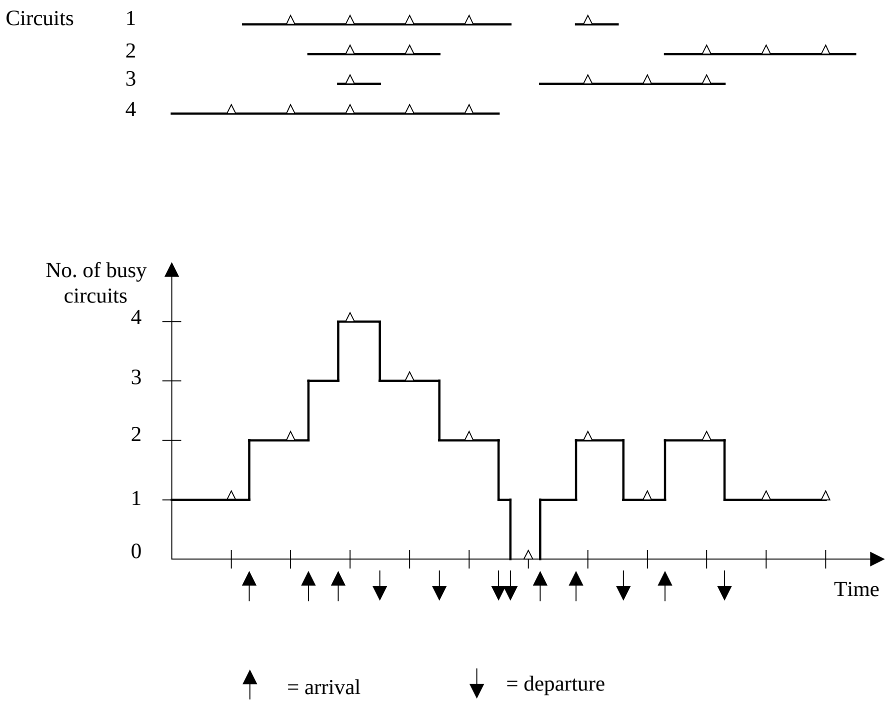


Figure 3 : Continuous traffic process

Every traffic process takes place in continuous time and in discrete space. By a continuous measurement, the course of the traffic process is recorded accurately. In classical measurements, we monitor the total number of busy circuits - vertical observation, and it is not possible to identify the individual calls. In computerized measurement - horizontal observation, we monitor the individual circuits.

2 MEASURING TECHNIQUE

In this section we shall concentrate on the principles used by existing measuring equipment for the collection of data. We shall not consider manual observations by operators and engineers, although these observations are still of great value. From a statistical point of view, these observations are dealt with in the same way as those performed by automatic measuring equipment.

2.1 Basic tasks for measuring equipment

For all observations it holds that the individual device can only be **free** or **occupied**.

There are two fundamental operations in measuring techniques:

1. **Counting the number of events**, e.g. successful calls, lost calls, occupations, time releases, charging pulses

2. **Recording time intervals or fixing points of time**, e.g. holding times, inter-arrival times, waiting times, congestion times

Any measuring equipment must be able to perform one or both of these operations and somehow store the results. The data is often evaluated on-line to reduce the amount of output. There is an essential distinction between active and passive measuring points.

Active measuring points call the attention of the measuring equipment when an event takes place. They may initiate an impulse, when the state changes, or they may be operated during a time interval. This corresponds to cases where we are able to measure time intervals. Even if it is a continuous measuring method, the result may be an integer. Example: call meters.

Passive measuring points have information on the state of the measuring points, but the measuring equipment must ask whether new events have occurred. This is done, for example, by scanning methods, and it corresponds to cases when the record is a number.

In general, active measuring points are more expensive than passive ones, but passive measuring points require more expensive common control equipment, e.g. a computer. At regular intervals the computer investigates whether the states of the measuring points have been changed. So the time is, in fact, not recorded continuously, but as an integral number of scanning intervals. This principle is also applied for charging of calls by the **Karlsson** method.

The CCITT's recommendations (CCITT, 1977) for measurement and recording of traffic, concerning mainly international relations are useful as a general point of reference. The CCITT recommends greater use of automatic methods for recording and analyzing traffic data, because more information will be required due to the expansion of the networks.

The equipment should be able to provide output information in a form which is adaptable to automatic data processing. The equipment should preferably be able to run continuously. Furthermore, it should be easy to arrange remote traffic control.

2.2 Classical measuring methods

Definition: By this we will understand equipment where the readings of the measuring points and the on-line processing are performed by **wired logic**. Most existing equipment belongs to this type. The operations performed may be rather advanced. Often the equipment exploits the logic inherent in the exchanges and the collected data may be evaluated off-line by a computer.

2.2.1 Call meters

The classical device for counting the number of events is **the electromechanical meter**, which receives a pulse for every event. It is useful for counting the number of charging pulses, lost calls, time releases, etc., and in fact, also for measuring time intervals. The data may be read by using a camera to take pictures of a group of meters at given points of time.

In most exchanges, call meters are widely used. There may be call meters for each register and marker and for the various routes from the group selectors (e.g. reading numbers of calls and the number of reported calls).

By combining several meters we may accomplish different tasks. A simple device for ratio supervision is obtained by using two meters, one counting the total number of events and another counting the number of some pertinent events. When any of the two counters comes to a predetermined number, both are reset. If the counter for the critical events comes first, an alarm is given as well.

2.2.2 Time measurements

This may be carried out manually by stop watches. Short holding times may be displayed by an oscilloscope. A method which is a little more automatic is a pen-recorder. Being applicable to many special purposes, however, these methods cannot record large amounts of data. They require considerable maintenance and operating attention, and the subsequent evaluation of the results is very tedious.

A frequently used method for measuring time intervals is as follows: a counter is connected to a device. Pulses from a clock are only counted if the device is occupied. Comparison between the number of pulses on the counter and the total number of clock pulses gives the occupancy of the observed device. This occupancy time meter is frequently called **ICUR** (Individual Circuit Usage Recording). If e.g. 3600 pulses are sent out during one hour, the circuit usage is obtained as the sum of all seconds recorded on the counter, divided by 3600.

Mean holding times are obtained by dividing the carried traffic by the number of calls, (the latter obtained by a call meter). The individual time intervals (i.e. the distribution) is more complicated to record. They must be obtained on an output medium (e.g. punched tape) or from a histogram, using one counter for each class of a histogram. This requires that a selector is stepped forward by pulses during the holding time.

2.2.3 Traffic load measurements

This is in fact a total of all holding times for a trunk group within a time interval. If the grade of service is good, the traffic carried may be used as an estimate of the traffic offered. There are measuring principles: continuous and discrete.

Traffic is defined as the mean number of simultaneous occupations. In a continuous measurement the traffic carried is equal to the sum of the time for all occupations divided by the measuring time (T).

$$A_{carr} = \frac{1}{T} \cdot \sum_{\mu} t_{\mu}$$

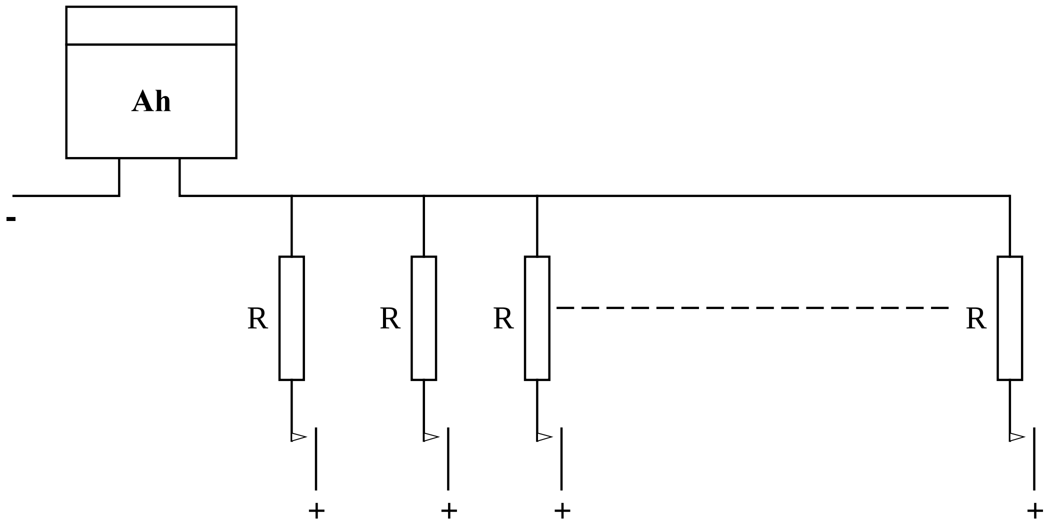


Fig. 4 The current in the Ah-meter is proportional to the number of operated contacts

The principle of a **continuous measurement** is shown in Fig. 4. Every device has a metering resistor through which current flows when the device is occupied but not when it is free. The current to the ampere-hour meter is then dependent on the parallel resistance of the metering resistors connected. The current through the ampere-hour meter is thus proportional to the number of occupied devices:

I(t) = U/R P(t)

where P(t) is the number of occupied devices at time t.

In the ampere-hour meter the current is integrated over the total duration of the measurement so that traffic carried is obtained from the equation below, where K is a calibration constant which must be determined for each individual ampere-hour meter.

$$A_{carr} = K \cdot \int_{t=0}^{T} I(t)dt$$

The other method of measuring traffic is to count the number of occupied devices at particular times. This is called **scanning**. The traffic carried is then estimated as;

$$A_{carr} = \frac{1}{N} \cdot \sum_{i} P_i$$

where P_i is the number of occupied devices at the i'th scanning. N is the total number of scannings.

Scanning implies counting the number of engaged devices at given times. The traffic estimate A_{carr} is then determined as the average number of simultaneously occupied devices. As the traffic is not observed continuously, scanning implies an element of uncertainty and the random error in a measurement can be estimated from formulas dealt with in section 2.4.5. The precision increases with diminishing scanning interval.

The scanning method can also be used for measurement of congestion time and mean waiting time. The scanning interval must then be accordingly adjusted.

In most manufactured traffic meters for scanning, the ampere-hourmeter is replaced by a resistance bridge which is connected at regular intervals. The bridge compares the parallel resistance for the number of occupied devices with a comparison resistance, and the number of occupations so determined is then transmitted by pulses to call meters or a punchcard machine. Te meter is switched automatically from one group of devices to another. A traffic meter may serve, for example, 60 groups of maximum 20 devices or in other cases, 20 or 40 groups of 30 devices each. In measurements of normal conversation traffic, one usually makes around 100 per group, and up to 1 000 scannings for registers and other devices with short holding time. Some administrations make only about one scanning per group, each 120 or 180 seconds. This type of meter was developed before the present electronic era but is still in use.

Scanning is more computer oriented than the continuous measuring method. Computerized measuring methods, however, make scannings on the individual devices and not on the group as a whole.

2.2.4 Traffic routing and traffic quality

It is necessary to have accurate information on the traffic dispersion within an automatic telephone network to be able to decide on network management actions, especially when alternate routing is applied.

Modern equipment based on information of registers is able both to record the dialed digits and the fate of the call, i.e. the quality of traffic (e.g. control registers). Thus the call dispersion (call matrix) is obtained by recording dialed digits. If the calls are weighted by their duration we obtain the traffic dispersion (traffic matrix). These measurements are performed on live traffic.

To check the service performance, test calls are used. In **test-calling**, artificial calls are generated and the fate of the calls recorded. This is a method which only slightly increases the load but the results are sometimes difficult to evaluate from a statistical point of view, because the statistics obtained are dependent on the time of day they are made. From a practical point of view, the information obtained is still very useful for identifying trouble points in the network.

2.3 Computerized measurement

Definition: By computerized measurements it is understood measurements, where the data collections and/or the on-line processing of data is controlled by software. Many conventional measurements apply electronics and the off-line evaluation may be performed by computers.

Computerized measurements can be implemented in two ways: by software monitors or by hardware monitors.

2.3.1 Software monitors

These are implemented in Stored Program Control (SPC) systems and in general purpose computers, by letting them make the observations themselves. The measuring equipment is simply a computer program. If this program is given a low priority, the traffic process is not influenced, but during busy periods there may be no time left for measurement.

It has been found in many cases that the extra load from traffic measurement has, on occasions, degraded the traffic handling capacity of the central processor of a SPC-system.

In SPC-systems, the strategy may be to list, for example, every 1 000nd call on magnetic tape. This loads the computer in a regular way, and the results are call statistics, which is useful for estimating the grade of service.

2.3.2 Hardware monitors

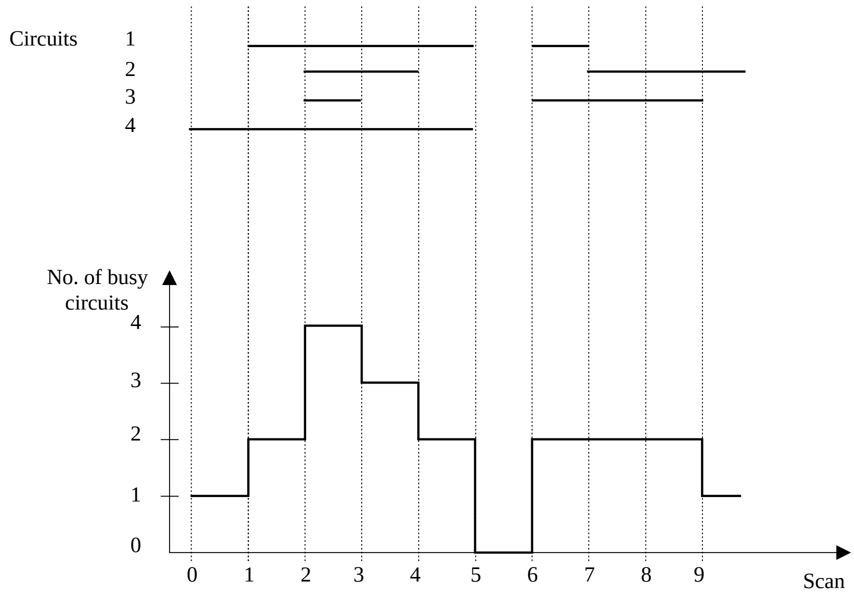
This is an autonomous equipment, e.g. a minicomputer or a micro-processor, which has free access to necessary information in a SPC-system, a computer, or a conventional exchange.

We will mainly deal with hardware monitors. The first hardware monitor for applications in teletraffic was developed in 1969, at IMSOR, Denmark Technical University (Fig. 6). Similar equipment has now been designed at many other places. In general, this equipment is based on a commercial minicomputer. However, a micro-processor is sufficient for many purposes.

2.3.3 The scanning principle (Fig. 5

Computerized equipment has the advantage of **mass memories.** Actually, the traditional scanning principle is applied, but the individual measuring points are monitored, and only relevant changes are recorded.

It operates according to the **"last-look principle"**, by which it performs the two basic operations; counting the number of events and fixing points of time.



		0	1	2	3	4	5	6	7	8	9	
Circuits	1	0	→1	1	1	1→	0→	1→	0	0	0	5
	2	0	0	→1	1→	0	0	0	→1	1	1	5
	3	0	0	→1→	0	0	0→	1	1	1→	0	4
	4	1	1	1	1	1→	0	0	0	0	0	5
Totals	Σ	1	2	4	3	2	0	2	2	2	1	19

Fig. 5 Discrete Traffic Process: The scanning principle with regular scan intervals applied to the traffic process of Fig. 3. In conventional recording of traffic, no information is obtained on the individual circuits. Only the total switch count for each scan or for the total measuring period is recorded. Computerized equipment monitors the individual circuits and records all relevant changes by a) circuit number, b) time = scan number, c) type of change, $0 \rightarrow 1$ or $1 \rightarrow 0$.

A measuring point is either free or occupied. Its state can be stored in a single bit. At regular intervals, **scan intervals** (e.g. every 10th ms), the state of a measuring point is read into the computer and compared with the previous reading.

If no changes are observed (0 -> 0 or 1 -> 1), nothing is done. If the state differs from the previous reading (0 -> 1 = start of occupation), (1 -> 0 = termination of occupation) this is recorded for on-line processing or stored in a mass storage unit.

Counting the number of events corresponds to counting all changes ($0 \rightarrow 1$) or ($1 \rightarrow 0$).

Measuring **time intervals** corresponds to calculation of the lengths of sequences of “1” (or “0”). So the time is measured as a discrete variable.

When choosing a scan interval, we consider several factors:

1. It must be so large that the computer can complete the execution of the necessary programs before the next scanning time;

2. To ensure registration of every event, it must be less than the smallest occupation time and also less than the smallest interval between two occupations of the same circuit;

3. The accuracy of the data and the quantity of output depends o the scanning interval.

In some cases, it is practical to choose several scan intervals. In a measurement on a crossbar trunk exchange in Denmark, 20 ms was applied for registers and markers and 200 ms for trunk lines. In general every event should be detected at least twice.

Typical scan intervals are 10-100 ms. IMSOR’s data logging equipment can manage 1 024 measuring points within a 5 ms scan interval. Now 10 ms is generally used for most measuring points.

2.3.4 Priority levels

To obtain optimal utilization of the computer, priorities are allotted to its various functions. A minimum of two levels is necessary. They may be implemented by software or by hardware.

The **highest priority** level is allotted to programs which must be executed within each scan interval. These programs read the measuring points, record changes of state and collect simple statistics.

Lower priority levels are assigned to programs, which supervise the measurements, list information, communicate with the operator, and ensure a current control and correct course of programs. It is very important to take precautions on-line to disclose and remove sources of error.

In principle, one can introduce an arbitrary number of scan intervals and priority classes. However, the time required for administration also increases, and the programs become more exposed to errors.

2.3.5 Examples of computerized measuring systems

The measuring equipment shown in Fig. 6 was first used in 1969 for the **Holbæk Measurements** (Iversen, 1973). The measured exchange was a crossbar trunk exchange. (ARM 201/2 L.M. Ericsson).

The equipment has later on been applied for detailed measurements on other types of exchange, among others:

- AKD 791 and ARD (PABX) (L.M. Ericsson)
- ESK-10.000 (Siemens)
- Pentacona (ITT)

Furthermore, it has been used by L.M. Ericsson, Stockholm for several measurements.

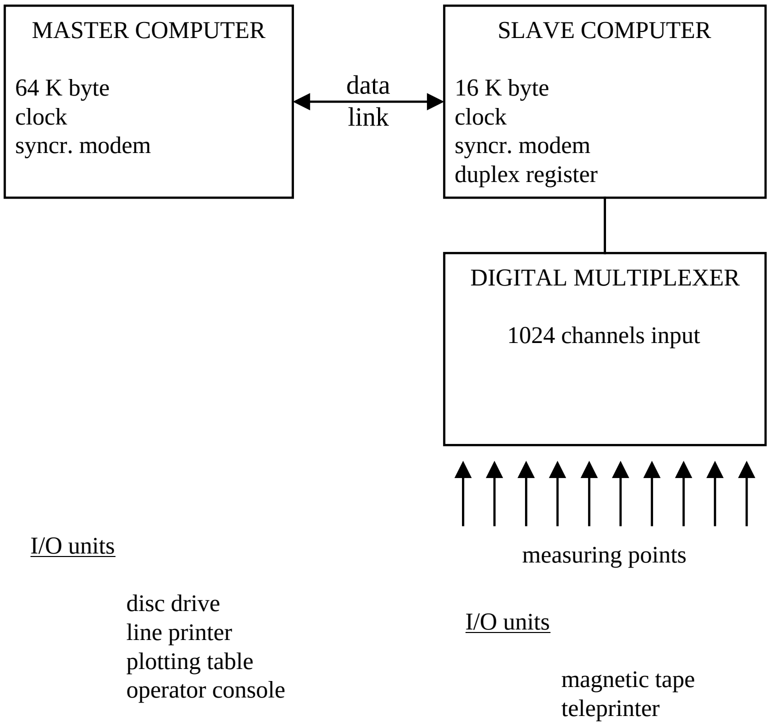


Fig. 6 Configuration of IMSOR's data logging equipment. The master computer is a general-purpose computer at the Institute for research and teaching.

Today many measuring systems exist, based on the same philosophy, which is becoming more and more widespread. L.M. Ericsson and the Swedish Telecommunications Administration have jointly purchased similar equipment based on the same multiplexer.

The Copenhagen Telephone Company has used measuring equipment based on the same principle. For several years, it monitored in detail about 1 600 subscribers on the **Ordrup** local exchange. The Jutland Telephone Company in Denmark has used similar equipment operating at the **Grindsted** exchange, for both maintenance and traffic purposes. In Norway, similar equipment **(CARAT)** has been monitoring 500 subscribers for several years. In France there has been extensive activity within this field and ESTOC OCTOPUS II AND ASMODEE are examples of such measuring equipment.

These measuring systems have been used for research and development purposes. Several companies have introduced measuring systems based on similar principles for the management of complete telephone systems. We mention a few examples: Autrax (Telesciences & ITT), Alston & Atemis (Conrac-Corp.), TIS (GTE Int.) and AOM (L.M> Ericsson).

Most companies have used equipment of this type. The Bell System has introduced TNDS, (Total Network Data System) which has been involved in large-scale implementation of centralized data management. A description of the design of a measurement and analysis centre is given by (Sapsfor, Jamison & Holloway and Spiefelhalter & Brown). A general description of computer-based equipment is given by Connell. A description of equipment developed in France is given by Bernard & le Gall.

2.3.6 Advantages of computerized equipment

In comparison with conventional equipment, generally designed for a particular purpose, computerized equipment has several advantages.

It fulfills all the CCITT'S recommendations (1977) as it is both **flexible** and **automatic**. It is able to **run continuously** and can be operated from a **remote control** centre.

Conventional equipment usually records mean values. By computerized equipment, we are able to record the **dynamic** properties of traffic. All conventional measurements can be integrated into one single measuring equipment. However, in the long run, it is not reasonable to copy all the conventional measurements, which have been fixed under constraints from the electro-mechanical technology. These measurements may only be necessary during a transitional period to provide necessary comparison data.

By computerized equipment and by well-defined measuring points, it is possible to perform any type of data collection. The recorded information, which in conventional measurements is subject to many inconsistencies, can be validated on-line. The data may be evaluated on-line (**"quick-look"** reports) and the editing of the data can be directed towards the **equipment for maintenance**, or towards **calls for traffic engineering**. Or the data can be stored for later off-line evaluation (charging, planning, research, etc.).

The information is presented in compatible formats where needed: a report in plain words for the staff at the exchange or at a centralized control centre, computer compatible tapes for off-line evaluation etc. The formulas of the traffic theory may be programmed so that decisions on extensions, traffic routing, etc. are suggested by the monitor.

In fact, the possibilities only depend on the availability of measuring points and the costs for connecting these points to the measuring equipment. The changes in switching technology, the increase in traffic and the decreasing costs of computers speak in favour of computerized equipment.

In digital systems, no special measuring equipment is needed. All data concerning each call and each device are stored in the memory of the exchange processor, and it is only a matter of dedicated software (measuring programs) to extract the desired raw or processed data.

The above descriptions of equipment may be considered as a retrospective look at what has been done for the conventional systems.

3 FIELDS OF DATA APPLICATION

We shall restrict our attention to telephone systems, even if there are similar problems in computer systems and data networks.

Today many telecommunications administrations expend significant measurement resources in order to obtain reliable data. Examples of measuring programmes are given in the literature.

A measuring programme should be designed with considerable care to ensure that no unnecessary data are recorded. The purpose of every collected record should be well-defined, and the purpose of different measuring methods must be formulated. It is very important to eliminate useless and uninteresting data as fast as possible.

General questions about measuring values are:

- availability: easy to collect?
- actuality: required on-line?
- quality: required continuously and accurately?
- quantity: statistical confidence?

3.1 Call charging

The economic basis of all administrations is the payment made by the subscribers and by other administrations. A continuos check on the correctness of the charging is important. These are tasks that are best handled by computerized measurements.

3.2. Operational aspects

The **purpose** of traffic engineering is to maximize the efficiency of existing equipment. There is a close connection between measuring, dimensioning and service criteria. Traffic data is the basis of traffic engineering. The primary use of data is for day-to-day equipment management. This necessitates speedy receipt of traffic records.

The daily traffic profile may be observed over the whole day. By computerized equipment, the average time-consistent busy hour may be changed when observed more closely. Data may only be recorded when the traffic is higher than a pre-set level, and it should be possible to distinguish between congestion caused by technical errors and high traffic.

Special attention should be paid to unusual events (disasters, cables being cut, etc.). It is also important to take notice of artificially busied circuits.

The **switching performance** is controlled by load congestion, balance data, load measurements, waiting times, time-outs, etc.

The **network performance** is mainly controlled by load measurements, which give an up-to-date picture of the actual load on existing traffic routes.

The ever-more sophisticated network requires a high efficiency level because of its high investment. However, the high efficiency makes the network more sensitive to traffic variations. Once congestion or **overloading** has occurred, it is very difficult to estimate true traffic levels or to interpret the results of measurements.

Congestion is some critical parts of the network may cause more repeated call attempts, which increase the load on the common control equipment. It is, therefore, important to detect and identify network troubles and take action before the troubles become too serious. These problems are dealt with in a dynamic way by **Network Management** actions.

The traffic distribution in the network (traffic matrix) should be recorded regularly, especially where alternate routing is applied.

3.3 Maintenance

The purpose of short-term supervision is to postpone extensions by checking that the equipment is used as efficiently as possible. Data are collected for preventive and corrective maintenance. Investigations show that about 30% of all errors can be intercepted by preventive and corrective maintenance.

Although it looks as if a system is operating as efficiently as possible, detailed measurements may reveal that some circuits are inoperative. The monitoring of individual circuits is important since it can prevent serious disturbance of the traffic. On-line monitoring of the performance allows “quick-look” reports and exception reports.

3.4 Planning and forecast

Collection of data for long-term planning and forecasting defines and presents demands and helps the forecaster to envisage the future development. Forecasts based on measured records must, however, take into account many other factors that may affect traffic growth.

3.5 Research and traffic theory

Observations from live traffic are essential for the feed-back to system designers when evaluating new types of switching equipment, as well as for the description and explanation of the behaviour of the man-machine complex, consisting of the telephone system and the subscribers.

Traffic theory is an inductive discipline. It is necessary to use real data to obtain ideas and make up new models. Real data are often used in computer **simulations** to evaluate new systems which are so complex that analytical models cannot be dealt with.

4 THE RELIABILITY OF MEASUREMENT

In this section we will consider the general statistical basis for estimating the reliability of measurement.

4.1 Precision of scanning

When using the scanning method with constant scan intervals of length h, the continuous traffic process of Fig. 3 is transformed into a discrete traffic process shown in Fig. 5. We notice that there is no one-to-one relation between a continuous real time interval and the observed discrete time interval (Table 1). However, the two distributions will always have the same mean value.

OBSERVED DISCRETE TIME	REAL CONTINUOUS TIME
0	0 - h
h	0 - 2h
2h	h - 3h
3h	2h - 4h
4h	3h - 5h
...	....

Table 1 : The relationship between discrete time intervals observed by regular scan intervals of length h and range of the real continuous time interval. (Cf. Fig. 7)

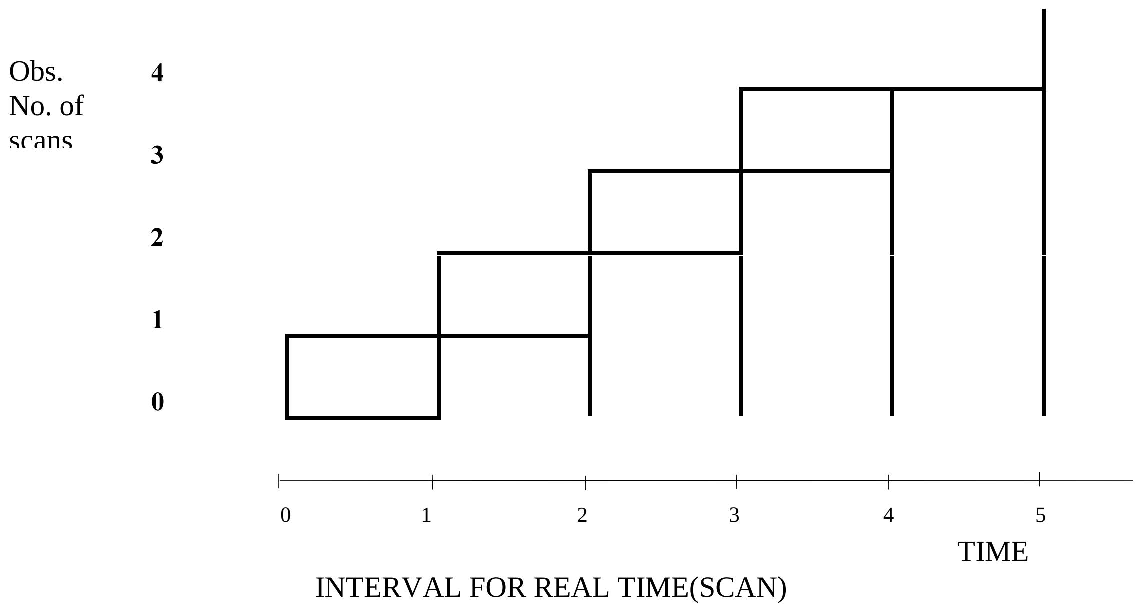


Figure 7 : By the scanning principle with regular scan intervals, a continuous real time interval is transformed into a discrete time interval. This transformation is ambiguous.

With the scanning we have the possibility to estimate the duration of time intervals. Our estimate is then expressed in how many consecutive times we find the state of the observed device unchanged. This means that we can duly express the duration in multiples of the scanning interval as shown in Table 1.

If we observe times that are exponentially distributed, we can transform the intervals into the discrete **Westerberg distribution** which tells us how many successive scans will be obtained dependent on the mean of the exponential distribution $1/\lambda$ and the scanning interval h:

$$p(0) = 1 - \frac{1}{\lambda \cdot h} \cdot \left(1 - e^{-\lambda h}\right)$$
$$p(k) = \frac{1}{\lambda \cdot h} \cdot \left(1 - e^{-\lambda h}\right)^2 \cdot e^{-(k-1)\lambda h}, \quad k = 1,2,\ldots.. \tag{4.1}$$

The value of (4.1) is $\frac{1}{\lambda \cdot h}$. The form factor is :

$$\varepsilon = \lambda \cdot h \cdot \frac{e^{\lambda \cdot h} + 1}{e^{\lambda \cdot h} - 1} > 2 \tag{4.2}$$

Thus, the scanning process increases the form factor of the exponential distribution.

There are two sources of error in the observation of a time interval:
a) error due to the sampling;
b) b) error due to the measuring method.

Only the latter can be reduced by increasing the scanning frequency.

An example of the use of the Westerberg distribution on scanning of call interarrival times is shown in Table 2. The statistical text applied seems to indicate that the call interarrival times may be exponentially distributed.

Scan	Observed	Westerberg	Geometric
0	1115	1150	2162
1	1776	1799	1479
2	1268	1230	1011
3	886	841	692
4	579	575	473
5	387	393	323
6	254	269	222
7	180	184	151
8	122	126	103
9	94	86	71
10	56	59	48
11	45	40	33
12	24	28	23
13	10	19	16
14	15	13	10
15	8	9	7
16	9	6	5
17-18	8	7	6
19-00	4	6	5

Table 2 : Inter-arrival times observed at Holbaek-MC (Monday 1969.08.04, 9-10 am. 6 840 calls). A chi-square test based upon the Westerberg distribution results in a probability of 40% (accepted). A chi-square test based on a discrete exponential distribution (geometric distribution) results in a probability of 100% (rejected). The scan interval is 200ms).

If the arrival process is a Poisson process with intensity y, then the mean value and the variance of the observed mean is:

$$\mu_i = A \quad \text{(4.3}$$

$$\sigma_i^2 = y \cdot M_2 / T = A \cdot \varepsilon \cdot s / T \tag{4.4}$$

where A is the offered traffic (no congestion), T is the measuring period, M_2 the 2nd moment and ε is the form factor of the holding time (see section 2.1.4) which has the mean value s. The form factor, ε, can be evaluated for any continuous measurement and for any scanning method in a limited or unlimited measuring period.

For constant scan intervals and exponentially distributed holding times we obtain:

$$\sigma_i^2 = \frac{A}{T} s\lambda h \cdot \frac{e^{\lambda} \ \ +1}{e^{\lambda} \ \ -1} \tag{4.5}$$

This is the classical result obtained by Palm (1946) and Hayward (1952).

The statistical reliability of a measurement is then obtained in the usual way. The range within which the true mean traffic intensity lies is given by:

$$\mu_i \pm \sigma_i \times cons \tan t$$

where the constant is a fractile of the Normal distribution. For 95% confidence, this constant is 1.96.

Example: T = 5 hours measuring period
h = 1 minute scan interval
s = 1/λ = 3 minutes mean holding time
A = 5 erlang

we find from (4.5): λh = 1/3

$$\sigma_i^2 = \frac{5}{5} \cdot \frac{3}{60} \cdot \frac{1}{3} \cdot \frac{e^{1/3} + 1}{e^{1/3} - 1}$$

$$\sigma_1^2 = 0.1009$$

and thus a 95% confidence interval for A: (4.38-5.62).

If the scan interval is shorter than the mean holding time, the precision is generally sufficient. The form factor of the holding time, which is often around 2, is then of more importance for the accuracy.

The relative error σ_1 / μ_i depends only on the total traffic volume A T.

4.2 Counting of number of events

Counting of the number of events is based on the receipt of a pulse for every event. The number of pulses is stored in a memory which, in its simplest form, consists of a call meter. In this way one can e.g. record the following statistics:

Number of calls
" " occupations
" " lost calls
" " times congestion occurs
" " time releases
" " recorded faults

To determine the accuracy of observations of this kind, one can use statistical methods for rare events, i.e. one can estimate the certainty of a small number of observed events by the Poisson distribution. Say that a measurement shows $\mathbf{x_0}$ lost calls. If the number varies according to the Poisson distribution, one can write the probability of **x** lost calls as follows:

$$P(x) = \frac{\lambda^x}{x!} e^{-\lambda} \tag{4.6}$$

The mean value and variance for the number of lost calls observed will then be

$$\begin{aligned} Ex &= \lambda \\ D^2 x &= \lambda \end{aligned} \tag{4.7}$$

The mean error in number of observed lost calls is thus;

$$dx = \sqrt{x}$$

or

$$\frac{dx}{x} = \frac{1}{\sqrt{x}} \tag{4.8}$$

This illustrates very well that one must be extremely cautious in drawing conclusions from a small number of observations, as the mean error **dx** is relatively large.

4.3 Evaluation of results

The traffic measuring and supervising equipment themselves are unfortunately not always free from error and may sometimes present incorrect results. Apart from uncertainties inherent in the actual method of observation, one must count on technical faults of one kind or another. It is therefore important to check all measuring equipment before, during and after use.

It is also very common that certain switches, circuits and trunks are blocked and out of service. Sometimes too, installation and repair work go on in parts of the exchange during the measurement. This complicates the interpretation of the results of measurements. One must therefore know what is happening in the exchange when measurements are being made.

The service performance of a telephone exchange can, to some extent, be evaluated from the results of measurements. A simple and effective method is to calculate the mean holding times for different devices. One usually knows fairly well from experience what they should be, and deviations from the normal can, as a rule, be explained by some technical reason.

A comparison between measured traffic and congestion can sometimes provide information that certain devices must be out of service.

An observation of the number of faults recorded during a traffic measurement can provide information as to whether the exchange was functioning satisfactorily during the measurement. All service alarms and technical fault alarms should, therefore, be recorded as background information.

4.4 Final comments

When judging the precision of measurements, two questions arise:

- What is the precision of the measurement performed?
- How representative are the values observed?

The first question has been extensively dealt with in this section and the accuracy estimates should generally be quite satisfying from a practical point of view - as long as the assumptions for the statistical distributions are realistic enough.

The answer to the second question depends on the purpose of the observations.

If the measurements aim at defining present service performance - a certain day and a certain time - the values are of course representative for this point of time, provided the measuring method is correct and the measuring equipment works without errors. This goes for all types of day-to-day observations, where no long-term aspects are included.

On the other hand, if the purpose is to provide forecasting data, it is important that the values provided are representative and can be used for compilation of historical data.

This goes especially for recording of **busy hour traffic** values, since these values are not averages but extreme values. These extremes are situated somewhere on the upper tail of the distribution for all one-hour values during a year, or any other defined longer period. It is here essential that the observations are comparable with earlier observations so the traffic growth can be envisaged by the forecaster. However, since the traffic varies considerably, we can never be sure if observations at other times would have given more representative values. This is always true if the traffic is not observed continuously.

CONSEQUENTLY: the precision of measurements can only be estimated for the times observations are made. We know nothing of occasions when no observations are made! Therefore, there is no point in spending too much effort in trying to define the accuracy of measurements if we do not know how representative our values are.

5 REFERENCES

Anderberg, M., and G. Wikell (1976): A Minicomputer System for Measurements on Real Telecommunication Traffic. TELE (Engl. ed.) nO. 1, PP. 52-60.

Andersen, B, N.H. Hansen and V.B. Iversen (1971): Use of Mini-computer for Telephone Traffic Measurements. Teleteknik (Engl. ed.), Vol. 15, No. 2, pp. 33-46

Brockmeyer, E. (1957): A Survey of Traffic-Measuring Methods in the Copenhagen Telephone Exchanges. First International Teletraffic Congress. Copenhagen, 1955, Teleteknik (Engl. ed.), Vol. 1, No. 1, pp. 99-105.

Buchner, M.M. and W.S. Hayward (1976): The total Network Data System. Eighth International Teletraffic Congress. 10-17 November, Melbourne, Australia, paper 261, 7 pp.

CCITT (1977): Orange Book, Vol. II.2: Telephone Operation. Quality of Service and Tariffs. Rec. E.500 (Measurement of Traffic Flow) and Rec. E.501 (Automatic Traffic-Recording Devices), pp. 195-200. These recommendations will be replaced by Study Group II, Temporary Document No. 26-E. March 1980, 25 pp.

Coates, F.A. (1978): A traffic Data and Forecasting System for Papua New Guinea. Telecommunication Journal, Vol. 45, No. 12, pp. 649-657.

Connel, J. (1979): Traffic Data Acquisition Systems-Computer Based. Ninth International Teletraffic Congress. Torremolinos, 1979, Paper 210, 6 pp.

Conrac Corporation, Alston Division (1973): ATEMIS: Automatic Traffic Engineering and Management Information System. Brochures.

Elldin, A. (1970): On the Extent of Routine Measurements in Telephone Plant. An Operational Research Approach. Sixth International Teletraffic Congress, Munchen, 1970, Paper 531, 6 pp. Published in Ericcsson Technics, Vol. 26, No. 4, pp. 216-236.

Ericsson, L.M. (1977): Network Operation and Maintenance System AOM 101. 16 pp.

Erke, T. and K. Rahko (1976): Traffic Measurements and the Grade of Service. Eighth International Teletraffic Congress, 10-17 November, Melbourne, Australia, Paper 244, 7 pp.

Gaustad, O., A. Flo and R.L. Dadswell (1973): Extensive traffic investigations in a local telephone exchange. (CARAT). Seventh International Teletraffic Congress. Stockholm, June, Paper 138/1-6.

Gosztony, G., and G. Honi (1976): Some Practical Problems of the Traffic Engineering of Overloaded Telephone Networks. Eighth International Teletraffic Congress, 10-17 November, Melbourne, Australia, paper 141, 8 pp. Published in Budavox Telecommunication Review 1977, No. 2, pp. 1-12.

Graves, R.D. and D.A. Pearson (1976): Individual Circuit Measurements. Eighth International Teletraffic Congress, 10-17 November, Melbourne, Australia, paper 445, 6 pp. Notice the Discussion Record.

GTE International (1975): TIS: Teletraffic Information System. System Descriptions, 125 pp.

Hayward, W.S. Jr. (1952): The Reliability of Telephone Traffic Load Measurements by Switch Counts. The Bell System Technical Journal, Vol. 31, No. 2, pp. 357-377.

Holmes, H.S. (1975): Telephone Traffic Recording and Forecasting. Post Office Electrical Engineers' Journal, Vol. 67, pp. 200-206.

Iversen, V.B. (1973): Analysis of Real Teletraffic Processes based on Computerized Measurements. Ericsson Technics, Vol. 29, No. 1, pp. 1-64.

Iversen, V.B. (1980): Measurement, Recording and Validation of Traffic Data. ITU, Teletraffic Engineering Seminar, Istanbul, 5-16 May.

Johannsen, Fr. (1908): “BUSY” - the Frequency of Reporting “BUSY” and the Cost caused thereby. The Copenhagen Telephone Company, 1908, 4 pp.

Kosberg, J>E> (1978): Some Trends in Measurements and Analysis of Telephone Data. Erlang-Centenary, 5-6 September 1978. Copenhagen, 7 pp.

Marlow, G. O’H. (1976): CENTOC - Towards Centralized Traffic Measurement. Telecommunication Journal of Australia, Vol. 26, No. 1, pp.72-82.

O’Shaughnessy, J.J. (1976): Traffic Data - The Need, Nature and Use Eighth International Teletraffic Congress, 10-17 November, Melbourne Australia, Paper 241, 8 pp.

Pallini, R. and M. Buchmayer (1972): Electronic Traffic Measuring Equipment MET 2. Ericsson Review No. 3, pp. 86-91.

Palm, Conny (1957): Fluctuations of Measured Telephone Traffic. TELE (English ed.), No. 2, pp.1-9. First published in Swedish in Tekn. Medd. K. Telegr. Sytr., 1946, No. 3, pp. 127-135.

Parviala, a. (1976): Accuracy Requirements concerning Routine Traffic Measurements, with regard to Service Level Objectives in Telephone Network, and to certain Error and Cost Factors. Eighth International Teletraffic congress, Melbourne, Australia, Paper 245, 7 pp.

Sapsford, B.G. (1977): Measurement and Analysis Centres - System Concept and Equipment Description. POEEJ, Vol. 70, pp. 243-247.

Spiegelhalter, B.R. and R.S. Brown (1979): Measurement and Analysis Centres - Software Design. POEEJ, Vol. 71, January, pp. 233-238.

Telesciences, Inc. (ITT) (1974): AUTRAX. An Integrated Management Information System for the Modern Telephone Operating Company, 16 pp.

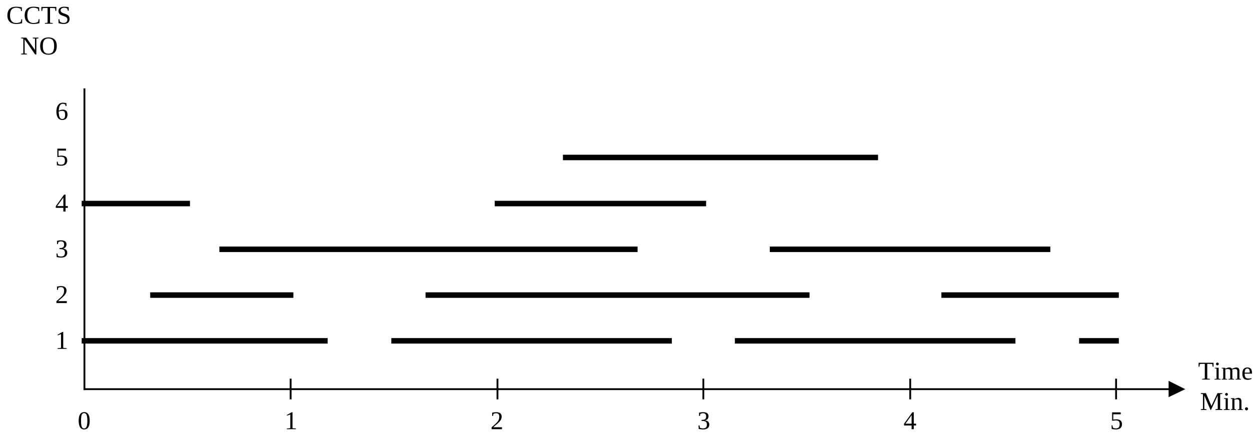
Turner, D.T. (1975): Traffic Measuring Methods. In Proceedings from Seminar on Traffic Engineering and Network Planning. new Delhi, Published by ITU, pp. 153-162.

Note: This chapter is a slightly revised version of the papers by Iversen (1980), and by Elldin, Lind (1967) appearing in above list of papers on traffic measurements.

6 EXERCISES - TRAFFIC MEASUREMENTS

1. A part of a traffic process is shown in the diagram paper. It concerns the occupations during five minutes of a full availability group of six circuits. The horizontal lines mark occupation of the circuits. The time scale is 10 seconds on the time axis.

   - Mark on the line marked “events” with ↑ every time a new occupation starts and with ↓ every time an occupation terminates.
   - How many events were there?
   - Fill in the diagram for the number of occupied devices for the five minute period.
   - Calculate the traffic carried in the period! (Try different ways!).
   - Assume that the group is scanned every 30 seconds, starting at t=5 seconds. What would the traffic be according to the scanning result?
   - What is the average occupation time of those occupations that are fully completed within the five minute interval?



Events

NO. OF OCCUPIED CIRCUITS

2. A special measurement during one hour gave an estimate of the traffic distribution of a group of five devices. The result was as follows:

Number of circuits occupied	0	1	2	3	4	5
Part of the time	0.086	0.214	0.268	0.222	0.140	0.070

- What was the traffic carried?
- What was the time congestion if the group only had five circuits?
- What was the traffic offered if we can assume that B=E?
- How many calls would be rejected during the hour, if we assume the average holding time to be $\bar{h} = 100$ seconds?

3. The traffic in a group of circuits was measured by scanning every 30 seconds over a period of two hours. The counter was read off every 30 minutes, without resetting it. The counter was zeroed at the start of the measurement.

Determine the busiest hour and the Traffic Carried during this hour! What is the standard error of the observed traffic offered? (The average holding time was two minutes).

Time	**Reading**	**Value**
9.30	1	172
10.00	2	434
10.30	3	622
11.00	4	848

4. A measurement on a full availability group is taken by three minute scans for the period 8 a.m.-12 a.m. on ten working days. For this group of circuits the following 15 minute totals (added for all 10 days are found:

340, 400, 430, 440, 500, 480, 470, 450, 450, 435,
400, 380, 365, 350, 310, 340.

We assume it is an Erlang loss system and that the holding times are exponentially distributed with the mean = two minutes.

a. Find the Time Consistent Busy Hour.

b. Find the expected value (mean) of the carried traffic during the busy hour.

c. Find the variance of the measured traffic (intensity) when this value is obtained by:

  i) scanning;

  ii) continuous observations.

d. Find the 95% confidence interval of the traffic intensity.

5. The number of calls arriving on a group of devices in a telephone system was recorded on a counter. The counter was read off every three minutes. The following values were obtained during the busy hour:

16, 13, 21, 17, 23, 22, 13, 18, 23, 21, 19, 16, 18, 19,
28, 23, 22, 20, 29,. 17.

a. Calculate the mean value (expected value) of the number of arriving calls per two minutes.

b. Calculate the variance of the number of arriving calls per two minutes.

c. Estimate the 95% confidence interval of the call intensity.

6. The number of calls carried by a group of circuits are counted at intervals of 10 minutes during one hour and the average holding time is 3 minutes. The number of calls in progress simultaneously were;

   12, 13, 10, 15, 10, 12.

   a. Find the traffic carried!

   b. Find the average number of calls during the hour!

   c. Find the number of calls during a three minute period!

   d. What accuracy has the measurement?

7. In a full availability group of 10 circuits, the load on the last circuit was observed to be 0.05 Erlang during one hour. Sequential hunting was employed.

   What is your estimate of the traffic offered to the group?

8. A long-distance route between two big cities A and B is also used for transit to six other smaller cities. If we want to find the dispersion of the calls with 90% assurance and 90% confidence interval, how many of the calls from A to B must be analyzed? The dispersion is roughly as follows:

Town	**% of calls**
B	60
C	10
D	10
E	5
F	6
G	5
H	5

9. A meter was connected so as to receive a pulse every six seconds when a group is fully occupied. During a certain hour the meter counter increased from 2430 to 2439. How large was the time congestion?

10. A group of 40 circuits is connected to an Ah-meter. The resistances used are 100 k - ohm and the voltage is 50V. How many circuits are occupied if the current to the Ah - meter is 10 m A? What error is introduced if the voltage goes up to 52 V?

11. During one hour, three types of measurements were made on a group of circuits.

   a. Every 36 seconds (start at t=0) the number of occupations is scanned and added to counter A.

   b. Every 2 seconds (start at t=0) the group is scanned. If all devices are occupied counter B is moved one step.

   c. The number of calls is registered on counter C. The readings were:

Counter A:	1500
Counter B:	54
Counter C:	500

   - Estimate the traffic carried, the average holding time and the time congestion!

12. In the country Ut-0-Pia the telecommunication administration decided to apply the CCITT Recommendation E500 for measurements on international automatic relations. They applied it on a national long-distance route (STD.) The busy hour traffic was recorded on every normal working day during the year. Find how many circuits would be required if the CCITT grade of service standards are applied.

$E(\overline{A}_{30}) \leq 0.01 \qquad E(\overline{A}_5) \leq 0.07$

The records for the year were the following after doubtful and erroneous records had been sorted out:

January:	33	37	43	48	46	33	38	30	40	45	
February:	43	49	43	45	38	39	53	49	50		
March:	51	42	56	46	59	45	55	52	45	40	
April:	48	49	60	64	47	60	63	57	53	53	51
May:	60	51	66	56	66	65	57	63			
June:	55	58	54	48	55	59	44	45	40	55	
July:	39	26	38	30	25	31	43				
August:	21	28	35	28	27	35	32	26			
September:	42	36	41	45	44	48	46	36	52	51	
October:	48	54	59	50	45	53	64	61	53		
November:	57	60	64	52	56	56	56	66	60	59	
December:	68	58	73	62	61	66	63	61	69	70	

Find the 30 and 5 highest values during the year and estimate how many circuits would be required.

13. Consider the traffic data given in the table below, which provides 3 x 12 monthly traffic values. We assume that the individual values in the table are the results of monthly measurements executed after a defined routing.

- Discuss what monthly measuring routine should be applied to obtain representative figures for forecasting.
- What data would suit the forecaster best if he is going to forecast the traffic 5 years ahead?

<u>TOTAL ORIGINATING TRAFFIC</u>

MONTH	1979	1980	1981
January	38.6	39.4	45.6
February	37.9	43.7	46.2
March	42.1	48.7	47.2
April	40.6	43.8	46.2
May	40.1	40.2	45.6
June	38.1	42.6	48.5
July	37.7	41.1	44.4
August	39.9	44.2	47.4
September	40.4	41.0	49.1
October	40.7	43.8	48.7
November	40.8	41.8	45.0
December	42.2	49.5	49.5

14. In the neighbouring country, Teleria measurements were made on eight routes, as shown in the table below. Check the records and point out if any of the data are erroneous.

<u>Observations on some Telerian trunk groups</u>
18 August 1980; 9.30-10.30

Trunk group	No. of circuits	Observed traffic Erlangs	Observed congestion %	No. of occupa-tions	Complaints	Other observations
1	18	10.51	1.8	300	None	
2	24	12.03	12	827	yes	Install work ongoing
3	36	24.52	6.8	503	None	
4	10	11.52	10.5	27	None	
5	20	18.6	31.5	1865		
6	16	5.0	0	148	None	
7	75	68.0	4	2101	None	Completion rate low
8	75	60.0	2.1	1487	Yes	

15. On a Tuesday, during the busy hour, six “errors” occurred in an exchange. This was regarded as being too much, so on Wednesday, certain adjustments were made. The following Thursday, during the busy hour, two “errors” occurred. Assume that the traffic offered to the exchange in both busy hours is the same and that the occurrence of error can be described by a Poisson-process.

a. Is this reduction in the number of “errors” evidence of improved reliability of the system?

b. The same question, if the number of errors were 22 before and 9 after the adjustments.