Chapter VII

NETWORK DIMENSIONING AND CONFIGURATION

Contents

Chapter VII

NETWORK DIMENSIONING AND CONFIGURATION

Purpose of this chapter

Given the complexity of the development over time of even a modestly large network, its optimisation by manual methods would be almost impossible or, at best, extremely time-consuming.

In this chapter, the concept of network dimensioning using computer-assisted methods is introduced, in particular the use of the general optimisation and dimensioning programme known as PLANITU (which is the property of the ITU). The most difficult case of network optimisation, the metropolitan network, is discussed in some detail.

Traffic measurements, together with their possible limitations, are also considered in this chapter and include examples of measurements on a digital system.

Finally the organisation of network planning in general is discussed together with a review of the application of data bases in this field.

Outputs to be obtained

- Establishment of computerised network optimisation system within the planning group;
- Establishment of computerised information system for use by the entire organisation, including planning functions.

Inputs required

- Attendance at a PLANITU course;
- Study of hardware and software requirements for computerised facilities above;
- Acquisition of the above, and training of personnel in its use.

Chapter VII

NETWORK DIMENSIONING AND CONFIGURATION

7.1 Introduction

Telecommunication networks should be **Simple**, **Flexible** and **Cost Effective**. However, there are several possible courses of network development from which to choose, and for each one, there is a range of different technologies and products to consider.

Nevertheless, even if we had a fixed network scenario and a given product selection with which to work, the task of optimising and dimensioning the network would still be both difficult and time consuming if the work had to be done manually.

One single network scenario comprises furthermore complete and rather detailed network calculations for a number of points of time: which of course is the idea of scenarios - to give a picture of how the network might develop from the present state to a target network perhaps 15 years ahead.

A number of such different scenarios should be designed and calculated, and not only that - the sensitivity of the solutions should also be investigated, in order to see how robust they are to unexpected traffic increase, to technical faults etc.

For each single case, the geographical, physical and logical structure of the network should be calculated and demonstrated in some detail, showing the function, type, size, location and boundaries for all switches and nodes; transmission systems, cable runs, ducts and manholes, transmission media logical routes and routing; quantities of all equipment and related costs; partial and total traffic flows for all traffic cases and for all routes, congestion levels for all traffic cases and all routes; and, as a check, important input data.

It would actually be practically impossible to carry out proper network investigations without good software tools and without a team of properly trained network planning staff.

The terms **Network Planning** and **Network Dimensioning** are not clearly defined. As a matter of fact, it is rather difficult to find a clear border between **Network Dimensioning** and other activities in the field of **Network Planning**. This is so, because network dimensioning is really a very complex activity, requiring competence in all network planning disciplines. The chief of a corresponding work group should definitely be a highly skilled network planning expert.

Many network dimensioning computer programmes exist today. Some of them are designed for the specific network types of particular countries; others solve only a limited part of the network planning problem. Only a few of the programmes solve all optimisation and dimensioning problems for all network levels in a generalised and still sufficiently precise and correct way. One such general, integrated network optimisation and dimensioning programme is known as **PLANITU** and is the property of the **ITU**.

Due to the general approach on which **PLANITU** is based, a description of the programme applications, input and output data etc., will also be a fairly good description of network dimensioning in general.

The by far most complex application in the public telecommunication field is metropolitan network planning; rural and especially national network planning is a more simple task; **rural**, because the networks are simpler, subscribers are usually concentrated in points (villages and towns), and there is no need for subscriber categorisation (villages and towns might be categorised instead); **national**, because subscribers are not involved in the planning (the traffic is still generated by subscribers, but that is a forecasting matter), so the important questions are the choice of transmission systems, routing of traffic and network hierarchy (which switches should be on which levels etc.).

Sections 7.2.6 to 7.2.9 illustrate the optimisation and dimensioning process and input and output data for metropolitan network planning. If the planning group can master this kind of planning, it can certainly also carry out rural and national planning as well.

7.2 PLANITU

PLANITU is a computer tool for network optimisation and dimensioning. It can be applied to most kinds of telecommunication networks; there are no limitations due to size or complexity, except those depending on the host computer. The network model is sufficiently sophisticated to allow for all standard network types, and most local variations. Due to its modular structure, new facilities can be added with reasonable ease.

PLANITU is designed to find minimum cost solutions for any or all of the following tasks:

- Optimal locations for new exchanges and Remote Subscriber Units, and their optimal service area. Application: urban and rural networks.
- Optimal routing strategy and circuit quantities between exchanges, including optimisation of exchange hierarchy. Application: urban, rural, national and international networks.
- Optimal choice of transmission media, taking into account existing equipment and multiplexing possibilities. Application: urban, rural, national and international networks.
- For new switching equipment, optimal selection of type of equipment to be installed; for existing switching equipment, optimisation of replacement strategy. Application: urban, rural, national and international networks.

PLANITU can be run in 2 modes:

- “manual mode”: the user tells the programme what to investigate and most decisions are made by the user; it has the advantage of making use of the professional judgement and knowledge of local conditions of the planning engineer.
- “automatic mode”: the user initially defines the task and only major decisions are made by the user.

In both modes, extensive use is made of displaying all network aspects graphically; this is a major aid in the planning and evaluating process.

7.2.1 General model

The problem to be solved is how to extend a given network, over a certain period of time, for specified demands regarding subscriber and traffic development, using certain types of exchange and transmission equipment, observing specifications concerning quality of service, in the most economic way.

Real telecommunication networks are rather complex, and it would be very difficult to use mathematical methods for finding exact solutions to the various planning tasks involved. Also, it is essential to find methods to deal with any kind of network, rather than with a particular one. To make this possible, one has to make a *model network*, an abstraction of the real network, expressing the relations between the various entities in mathematical terms.

In designing a model, the question arises how close to reality such a model should be. Simpler models will usually lead to simpler, and therefore faster solutions, but also to a certain loss of accuracy in the results. A reasonable compromise has thus to be found between accuracy of results and speed of calculation. it should also be remembered that for different types of networks, the impact of the complexity of the model on the accuracy of the results can vary considerably.

For all sorts of *equipment*, this task is relatively simple. The cost structure of any particular part of an exchange or transmission system and their technical properties are available from administration or manufacturer. The structure and properties of the various types of equipment are, moreover, independent of the network under investigation, although the actual values for costs involved may vary considerably from one network to another.

The same is valid for the various quality of service considerations.

More problematic are the models concerning the *subscriber distribution* and the *traffic interests* in the network.

a) Subscriber network

For larger networks it is obviously impractical to define the location of every subscriber individually. Although the locations of the existing subscribers are known, the forecasts being made for the entire population of a city or for subsets of that population would be meaningless for defining the location of individual subscribers.

The subscriber distribution can therefore be defined in one of the following ways:

i) *Nodes*

Here subscriber density is defined in *discrete points*, usually corresponding to DPs or cabinets. this approach is often used in sparsely populated areas, such as *rural areas*, or the outskirts of metropolitan areas. Each node is defined by its coordinates, and the subscriber forecasts for the points of time to be considered.

ii) *Rectangular grid*

For more densely populated areas, a rectangular grid is placed over a map of the area under consideration, and the forecasts then define the number of subscribers in each grid element; within a grid element, the subscribers are then assumed to be *evenly distributed.*

The size of the grid element should be chosen according to local conditions, typically ranging from 100 - 500 metres per side.

iii) *Arbitrary areas*

Instead of a grid, forecasts can be defined for arbitrary polygons, i.e. areas enclosed by a sequence of straight lines. These areas correspond usually to blocks of houses, cabinet areas, industrial complexes, etc. Again, the subscribers are assumed to be evenly distributed within each such area.

Which of the above methods to choose depends on the type of network and the data available; it is also possible to use a *combination* of these for any given network.

As regards the exchange area boundaries, the way of defining the subscriber distribution has the following effects:

Nodes: each node is assigned to one exchange and to one traffic area;

Grid: any grid element is assigned to one exchange and to one traffic area;

Areas: any area is assigned to one exchange and to one traffic area.

For “grid” and “areas”, it is also possible to split an entity between a number of exchanges; this cannot be done for “nodes”.

b) Traffic demand

As in the case of the subscriber distribution, it makes no sense, from a statistical point of view, to make assumptions regarding traffic volume and dispersion for *individual* subscribers. On the other hand, the model should recognise differences in traffic behaviour for the various categories, such as residential, business, PBXs, etc. The traffic forecasts are usually easier to make for such categories than for the whole population, as categories will react differently to such environmental changes as provision of new services or alterations in the tariff policy.

Local networks

For the cases of rural, urban and metropolitan areas, it has been found convenient to subdivide the total network area into a number of so-called *traffic areas.* The traffic properties for all subscribers in such an area are assumed to be uniform; in defining such areas, attention has to be paid to the present and future “mix” of categories and the possibilities of making traffic measurements to obtain the necessary “raw data” for the traffic forecasting process.

The traffic between such traffic areas can then be described in matrix form. As the exchange area boundaries will usually not coincide with the traffic area boundaries, traffic between exchanges will then be found by simple calculations involving the subscribers per exchange per traffic area.

Long-distance networks

For national or international networks, the detailed approach used for local networks is hardly necessary. The traffic matrix defined for these cases will contain the traffic interests between the exchanges involved.

Non-coincident busy hours (NCBH)

The traffic matrices mentioned above usually define traffic values valid for the *busy hour* of the network or for the traffic cases involved. As considerable savings can be achieved in the junction network dimensioning if the busy hours for the various traffic cases are not coincident, the fact should be utilised when appropriate. In this case, traffic profiles have to be defined, showing the variations during the day. The traffic between exchanges or traffic areas for a given time period is then calculated by multiplying the corresponding element of the traffic matrix with the appropriate profile value for that time period. It is thus up to the user to define the contents of both traffic matrix and profiles; if the matrix contains total daily traffic volume (in erlang hours), the profile must contain proportions for each time period, and the sum of these proportions should then be equal to 1; if the traffic matrix contains busy hour traffic values, the profiles should contain *factors* relating the traffic during a given time period to the peak traffic.

7.2.2 Data required

The data required for planning of telecommunication networks are obviously dependent on the type of network to be planned, for example:

- rural networks;
- metropolitan multi-exchange networks;
- long distance networks;

and on the questions to which answers should be found, such as:

- where and when to introduce new exchanges;
- which exchanges to replace;
- how to re-arrange the present exchange area boundaries;
- whether or not to use remote subscriber units and where to place them;
- what type of exchange and/or transmission equipment to choose, e.g. electromechanical or electronic exchanges, physical pairs or PCM, submarine cables or satellite, manufacturer X or Y, etc.

What the computer programme(s) described in this document will do is to find, with or without active participation by the planner, the most economic solution for a given set of data. These data must therefore contain all relevant information to make the necessary decisions. It remains of course the responsibility of the planner to provide data that are reasonably correct, to run the programme(s) for various data sets as indicated and draw the necessary conclusions from the results. It should also be remembered that the programme cannot check whether the data specified are correct or not, except for obvious errors, such as negative traffic quantities and other absurd parameters; the planner should therefore check the results of the computer rather carefully to avoid making policy decisions based on incorrect, or incorrectly specified, data.

The data to be specified concern the following main items:

- the present network configuration;
- forecasts of subscriber and traffic distribution;
- costs and technical specification of exchange and transmission equipment;
- grade of service and transmission requirements;
- other specific considerations for the network to be investigated.

Present Network Configuration

- Exchange locations;
- Exchange boundaries;
- Cable runs;
- Exchange equipment;
- Transmission equipment;
- Floor space in buildings;
- Routing arrangement.

Forecasts

- Subscribers: location, category;
- Traffic: per category, distribution, profile.

Exchange equipment

- Capacity (subscriber lines, junction lines, call attempts, etc.);
- Costs (per subscriber, per junction line, per basic exchange unit, etc.);
- Traffic handling specification (full availability, gradings, link systems);
- Floor space requirements.

Transmission equipment

- Capacity;
- Costs;
- Connectivity;
- Attenuation;
- Resistance.

Grade of service

- Final routes;
- Point-to-point;
- Various traffic cases (local, LD, special services, etc.).

Transmission plan and signalling requirements

- For each exchange type;
- For various traffic cases;
- CCITT recommendations;
- Telephone sets.

Other considerations

- Costs: investment costs/annual charges/present value;
- Buildings: sizes (standards), costs, available sites;
- Distance calculation method;

- Geographic considerations: maps, obstacles, nodes, possible cable runs;
- Fixed exchange boundaries;
- Fixed exchange locations;
- Specific locations to be investigated;
- Specific locations to be excluded;
- Special routing arrangements due to local conditions.

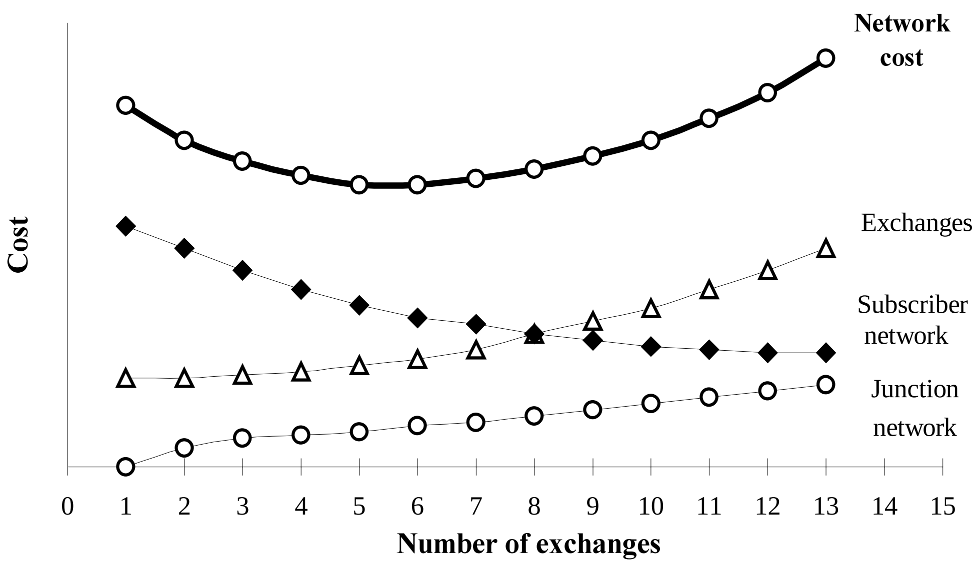
7.2.3 Iterative planning process

Owing to the complexity and size of the typical network, it is not possible to treat all aspects of the network simultaneously. The problem to be solved has to be divided into a number of suitable **sub-problems**, these to be treated **iteratively** in a certain order. Such sub-problems are:

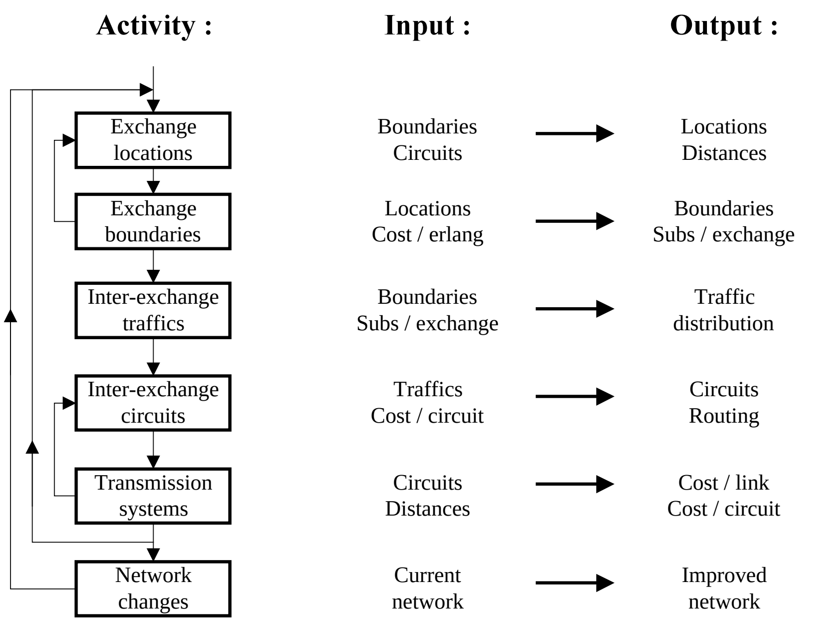
- exchange location optimisation;
- exchange boundaries optimisation;
- traffic calculations;
- inter-exchange circuit optimisation and dimensioning;
- choice of transmission systems.

For the solution of any of these sub-problems, we assume that the rest of the network has been correctly optimised and/or dimensioned. Initially, of course, this will not be the case, and the necessary data will then have to be estimated. Subsequently, the results of the calculations performed in previous steps within an iteration or in previous iterations can be used.

The graph below gives an idea of the cost components in a local network, and shows the overall cost of such a network as a function of the number of exchanges.



The following flow chart shows the main steps in the iterative procedure. Details of the methods used for each such steps are given in the various sections of this chapter. Not shown here are the various input and output blocks, and the points at which interaction between planner and programme is possible, a certain flexibility in this respect is valuable and is easy to achieve, inserting the relevant instructions into the programme. It is obvious that for some network planning tasks, some of the blocks below are irrelevant.



The “boxes” above show the main calculation and optimisation blocks in the programme, and the “arrows” show the sequence of activities to be followed. As there is a very strong interaction between exchange **locations** and **boundaries**, sub-iterations should be carried out until a stable solution has been reached. The same applies to **circuits** and **transmission systems**.

The “Total network cost” as a function of the number of exchanges (see graph on previous page) reflects the best solution for a given number of exchanges. Therefore, before introducing any **new exchanges**, the configuration under consideration should be optimised until a stable solution is reached for the given number of exchanges.

7.2.4 Documentation

The purpose of the documentation provided with PLANITU is to present complete information on all aspects of the network planning programmes currently in use in various UNDP/ITU projects. The various chapters are intended to clarify the objectives, methodology and usage of the network planning programmes to the personnel involved or interested in the planning process, at various levels of decision-making.

For this reason, the documentation has been split into 10 chapters, each dealing with a specific aspect of the programmes as follows:

Chapter 0, *GENERAL ASPECTS*, describes the background and use of the programmes in general terms.

Chapter 1, *NETWORK MODEL*, describes the various assumptions and simplifications used to make the network model reasonably true to reality, while keeping it simple enough to make the investigation of large networks a practical possibility.

Chapter 2, *METHODS FOR DIMENSIONING AND OPTIMISATION*, describes the mathematical and statistical methods and procedures involved to solve the problems posed by the user of the programmes.

Chapter 3, *PROGRAMMING CONSIDERATIONS*, deals with the translation of these methods into efficient computer programmes.

Chapter 4, *COMPILING, LINKING, EXECUTING*, shows how to get from source code to execution of the programme and how to adapt the size of the programme to the network(s) to be investigated.

Chapter 5, *SUBROUTINE USAGE*, gives a formal description of the purpose and the parameters of every subroutine.

Chapter 6, *STOP & ERROR LISTS*, deals with the various foreseen error conditions;

Chapter 7, *SPECIFICATION OF DATA*, discusses the way to prepare the input data for the various applications of the programme and contains samples of some typical networks.

Chapter 8, *RESULT INTERPRETATION*, shows how to read the output produced by the programme and contains results for the sample networks.

Chapter 9, *SOURCE CODE*, contains the complete FORTRAN code of the programmes.

7.2.5 ITU's role and responsibility

The ITU, at present, carries out the following activities related to PLANITU:

- organisation of basic training courses;
- organisation of advanced training courses;
- transfer of PLANITU to Member Administrations on request;
- investigation of local, rural and national networks on request by Administrations.

As regards the PLANITU transfers, the ITU will:

- install the software on the local computer;
- carry out tests to ensure that PLANITU works properly in the local hardware/ software environment;
- assist in a pilot investigation for a network chosen by the Administration;
- update PLANITU continuously to allow for new facilities, new telecommunication technology, improved computer capabilities, etc.;
- update the PLANITU versions installed at Administrations accordingly.

It is ITU policy to transfer PLANITU to Member Administrations under three conditions:

1. that the requesting Administration and the ITU sign an agreement concerning copyright, the rights of the Administration to use PLANITU, and the obligations of the ITU regarding maintenance of the software;
2. that staff members of the Administration participate in one of the courses arranged by the ITU, with a view to being trained in the correct use of PLANITU;
3. that the Administration has the computer hardware necessary to run PLANITU.

7.2.6 Optimisation of switching unit locations in metropolitan areas

<u>Programme Objectives</u>

For given:

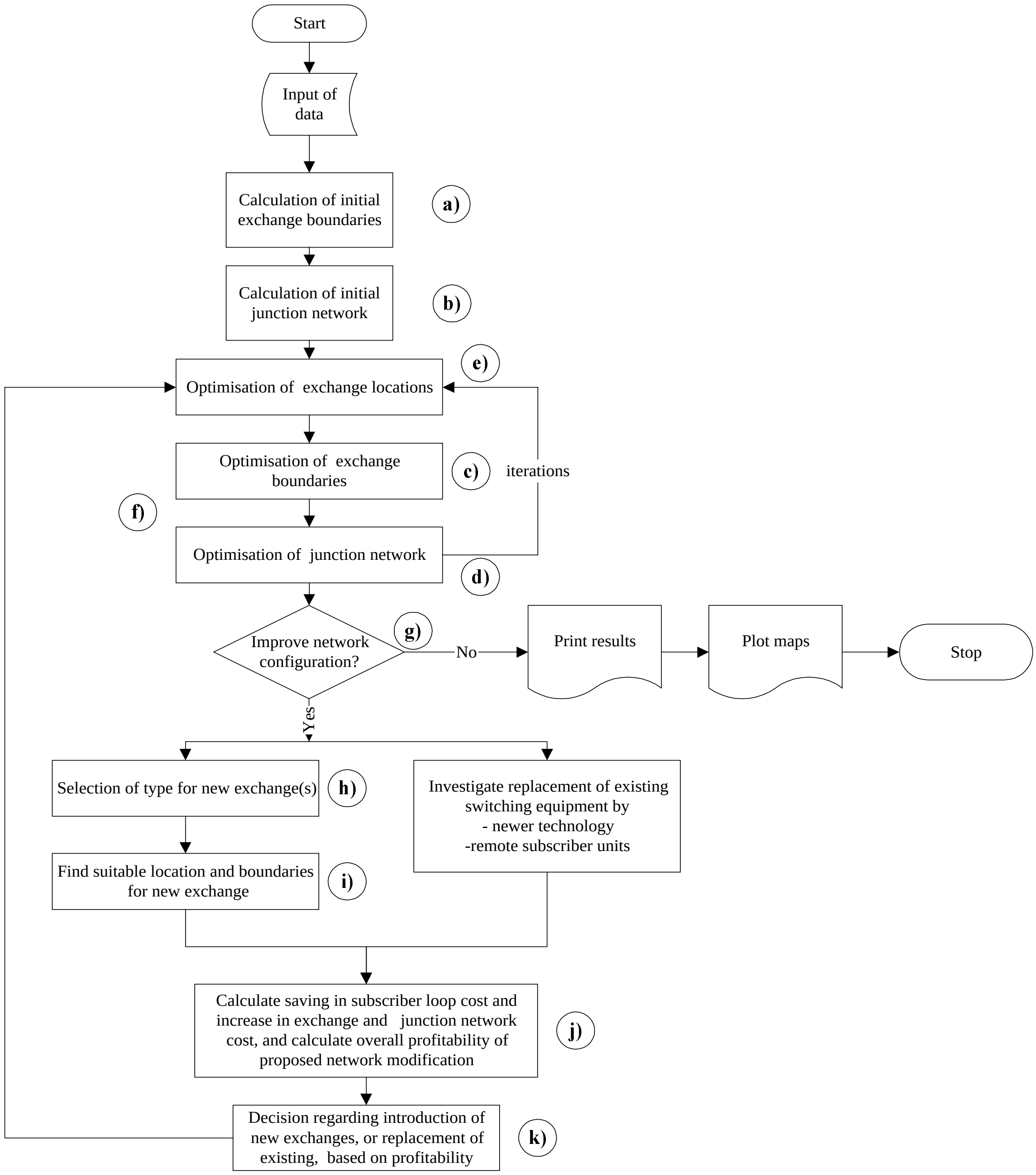
- geographical area;
- subscriber inventory;
- exchange and remote subscriber switch specification;
- routing constraints;
- grade-of-service plan;
- transmission plan;
- signalling requirements;
- traffic demand;
- switch costs;
- transmission costs and technical properties.

the following have to be determined for a certain future point in time:

- optimal number of exchanges and remote subscriber switches;
- optimal location of exchanges and remote subscriber switches;
- optimal boundaries between exchanges, between remote subscriber switches and between exchanges and remote subscriber switches.

Model description

The optimisation process adopted in the programme could be illustrated by the following sequence giving the consecutive steps in the iterative process. For convenience, remote subscriber switches are also designated “exchanges”.



a) Calculation of initial borders

Accepting temporarily the number and location of exchanges as given by the input data, exchange area boundaries are calculated without taking any notice of the effect of the junction network, of which nothing is, as yet, known. The appropriate method is to consider only the subscriber network, i.e. to make a geographical division into exchange areas with shortest distance as criteria.

b) Calculation of initial junction network

This is in itself an iterative procedure carried out by:

- calculation of distances between exchanges;
- choice of transmission media based on these distances and on the transmission plan;
- calculation of traffic interests between the exchanges is based on the initial exchange area boundaries;
- optimisation of high usage routes by use of “the improvements factor method” given by Y. Rapp;
- overflow traffic, mean and variance is calculated and summed up, and the final routes are dimensioned by use of Wilkinson’s ERT-method.
- making a re-choice of transmission media, but now considering economic factors.

c) Optimisation of borders

Temporarily assuming fixed exchanges locations, the cost function is minimised by connecting each subscriber to the exchange giving the least cost increase. The cost function comprises the subscriber line cost and the part of the cost of the inter- exchange routes which is due to the traffic of the considered subscriber.

d) Optimisation of junction network

A new calculation of traffic interests between the exchanges results in a changed routing and a changed number of channels in the routes. Also the transmission media are more properly chosen.

e) Optimisation of locations

Temporarily assuming fixed areas, the cost function is minimised by finding the optimal coordinates for each exchange. The cost function comprises:

- the distance dependent cost of cable connecting subscribers to the exchange;
- the distance dependent cost of transmission media between the exchange and other exchanges.

f) Optimisation of borders and optimisation of the junction network

A repetition of steps c) and d), in order to obtain more optimal results. Optionally, steps e) and f) may then be repeated once more.

g) Introduction of new exchanges

In principle, the number of exchanges should be increased only if this will decrease the total cost of the network. Introducing a new exchange at any given location in the area and optimising the boundaries of this exchange will decrease the cost of the subscriber network due to shorter and less expensive cables, at the same time increasing the cost of trunk network due to the fact that the efficiency of the inter-exchange routes decreases with decreasing traffic.

As the economic loss in the trunk network is not greatly affected by the exact position of an exchange, the obvious thing to do is to look for locations where the gain in the subscriber network is high.

As the highest gain is obtained for subscribers with long and expensive cables, and these are found along the exchange boundaries, we may assume that suitable locations may be found where two or more exchange boundaries intersect. These intersection points, however, are not the optimal points due to the influence of the trunk network and the irregularities in the actual subscriber inventory and have to be corrected accordingly.

This line of discussion suggests a calculation procedure starting from a point when the exchange area boundaries for already introduced exchanges are optimised.

When no profitable locations can be found, the process is interrupted and the number of exchanges has been optimised.

h) Calculation of possible new locations

This is simply to find all intersection points of the boundaries.

i) Approximate calculation of borders for and location of new exchanges

For each intersection point, the optimal location and the optimal boundaries of a presumed new exchange are calculated alternatively until the locations are stable.

j) Approximate calculation of effect on junction network of new exchange

The gain in the subscriber network and the cost increase in the junction network is calculated separately for each presumed new exchange.

k) Choice of new locations

- The possible new exchanges are arranged in a sequence with decreasing total gain values and temporarily those locations which are close to the ore profitable sites higher in the sequence are eliminated, in order to avoid a double calculation of gains in the subscriber network.
- Exchanges are now introduced at all points in the sequence where the gain values exceed a given threshold value corresponding to the cost of site, building, power, etc.
- The procedure can now continue to find the best locations, exchange areas and junction network for this increased number of exchanges.

7.2.7 Optimisation of metropolitan inter-exchange networks

Programme objectives

For given:

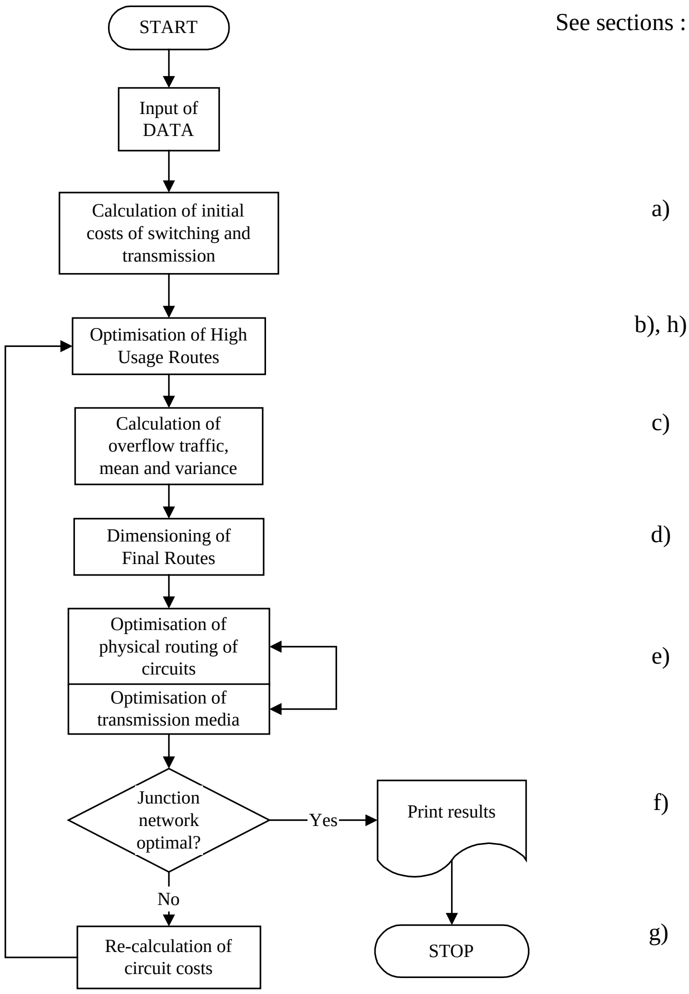
- physical network layout;
- locations of exchanges;
- exchange specification;
- routing constraints;
- grade-of-service plan;
- transmission plan;
- signalling requirements;
- traffic demand;
- switch costs;
- transmission costs and technical properties.

the following have to be determined for a certain time in the future:

- optimal routing principles;
- optimal number of channels on all routes in the network;
- optimal type of transmission media for each route;
- optimal availability for each outgoing route from systems not employing full availability.

Model description

The optimisation process adopted in the programme can be illustrated by the following sequence giving the consecutive steps in the iterative process.



a) Calculation of initial marginal costs

The optimisation process is based on the concept of “marginal cost”, i.e. the cost of one additional circuit in the route. This cost consists of two parts:

- transmission cost, i.e. cost of one cable pair or one channel of a multiplex system, which is dependent on the number of circuits in the route, the transmission plan, the signalling requirements and the distance between the exchanges;
- switching cost, i.e. the cost of exchange equipment for one additional line in both originating and terminating exchange.

Since the choice of transmission media - physical pairs or PCM - is dependent on the number of lines in a route, an initial assumption regarding the type of transmission medium to use has to be made. An approximation is achieved by assuming a PCM system fully utilised and using this cost per channel when comparing with the corresponding cable pair cost.

b) Initial optimisation of high-usage routes

When optimising the high-usage routes in the network, consideration is given to the costs of additional circuits on direct and overflow routes and the utilisation of circuits on direct and overflow routes as well as the utilisation of the overflow routes. This utilisation, i.e. the partial derivatives of the number of lines on the tandem routes, with respect to the mean of the traffic on these routes, is of course not known in the first iteration.

c) Calculation of overflow traffic, mean and variance

After optimisation of the high usage routes, it is possible to calculate the mean and variance of the overflow traffic from each such route.

d) Dimensioning of final routes

The dimensioning of final routes is carried out in accordance with Wilkinson's ERT method.

e) Optimisation of transmission media and physical routing of circuits

The junction network, both high-usage and final routes, has now been designed, based on the initial assumptions regarding the cost of transmission media. An iterative process is now started:

- select the most economic path for each circuit group based on cost per circuit per link;
- add circuits to links accordingly;
- select the most economic combination of transmission media for each link, taking into account existing equipment;
- calculate the cost per circuit for each link and repeat process until no significant changes occur.

f) End of iteration process

If the number of iterations exceeds, or if the cost reduction between two consecutive iterations is less than, previously defined values, the iteration process ends.

g) Calculation of new marginal costs

The choice of new transmission media on some routes implies that new marginal costs have to be calculated.

h) Optimisation of high-usage routes

The high-usage routes now have to be re-optimised since the basis, i.e. the utilisation of the tandem routes, the transmission media, and thus the marginal costs and the availabilities could have been changed since the previous calculation.

In the first iteration, we had no knowledge of the marginal utilisation the tandem routes since this is based on a certain number of lines. Thus we made an approximate calculation. In the second and subsequent iterations, we have access to both marginal costs and marginal utilisation (based on the previous iteration), and thus it is possible to make a more correct calculation of the optimal number of lines in the high-usage routes.

The iterations process then proceeds from step c).

7.2.8 Input data required for optimisation of metropolitan networks

a) Geographical data

A map showing the geographical properties of the area is necessary.

On this map, the positions and areas for existing exchanges should be indicated. Suitable locations for new exchanges should also be marked (e.g. available sites). Also existing cable runs in the inter-exchange network, their capacities and distances should be indicated. Furthermore, information about the primary network regarding existing cable runs, their capacities, distances and geographical locations and the boundaries of the existing cabinet areas should be given.

A rectangular grid is laid on the map in a suitable way. The grid is used for definition of input data and results, e.g. subscriber inventory, traffic interest areas and exchange locations. The length of the sides of the rectangles in the grid should be between 100 and 500 metres. A practical value is 200 metres. To each rectangle in the grid is related an X- and Y- coordinate.

Rivers, airports, etc., are obviously not suitable locations for exchanges and these should also be marked on the map.

The distance between two points in the network is calculated as the shortest geographical distance (i.e. as the crow flies). To get a more realistic estimation, this distance should be multiplied with an empirically found constant, valid for the network under study. This constant should thus be defined for both subscriber and junction network and is normally found to be between 1.2 and 1.4.

b) Physical network layout and locations of exchanges

The physical layout of the transmission network should be described with the aid of nodes and links, i.e. the cable runs between the nodes. In some of the nodes, exchanges are located. The nodes and cable runs should be depicted on a geographical map. The nodes are identified on the map with, for example, a number.

The nodes map should be supplemented with tables, showing:

- the relation between node number and the name(s) of the exchange(s) situated in the node;
- the distances between all adjacent nodes;
- existing ducts and transmission systems: capacities and utilisation;
- existing physical pairs: attenuation and electrical resistance figures;
- planned extensions of ducts and transmission systems.

c) Subscriber inventory

The forecast number of subscribers should be given related to cabinet or remote subscriber switch areas or to the above-mentioned grid map, to a combination of those, or according to arbitrary polygons. The forecast should be given for each category of subscribers.

d) Traffic demand

The area is divided into a number of so called traffic interest areas. All subscribers in a traffic interest area are, in the optimisation procedure, considered as having uniform traffic properties (originated and terminated traffic per subscriber and traffic interest). The traffic interest areas should ideally be formed with regard to commercial and residential areas, geographical and social structure, etc.. However, traffic measurements are made at the existing exchanges and thus the existing exchanges areas are often used as traffic interest areas. Preferably, traffic per subscriber category should be forecast.

e) Routing constraints

The definition of the routing principles could be carried out in one of the two following ways:

- the routing is defined from all exchanges to all exchanges in the whole network;
- the exchanges are grouped together in such a way that the same routing principles apply to all exchanges in a group.

The routing could be given in a matrix where the following codes could be used for different routing areas:

Code	**Explanation**
D	Direct low loss route;
$\mathbf{E_x}$	Optimal choice between all traffic direct via a low loss route (D) vs all traffic via a specified tandem exchange (x);
$\mathbf{F_n}$	Direct low loss route with a fixed (specified) number of lines (n);
$\mathbf{H_x}$	High-usage route with an optimised number of lines. The overflow traffic is carried via a specified tandem exchange (x);
$\mathbf{T_x}$	All traffic is routed via a specified tandem exchange (x);
$\mathbf{V_{nx}}$	High-usage route with a fixed (specified) number of lines (n). The overflow traffic is routed via a specified tandem exchange (x).

It may be preferable to specify a lower limit for the number of lines in a high usage route as it is often not practical to install routes with only a few lines.

f) Exchange and remote subscriber switch specification

For all exchanges in the network, i.e. local, tandem and transit, the appropriate data according to the following list should be given:

- name of the exchange;
- superior tandem/transit;
- type of switching system;
- number of connected subscriber lines;
- installed subscriber line capacity;
- maximum subscriber line capacity for this type of switching system.

For each exchange building, available space for extension of existing exchanges and for installed new exchanges should be specified. The information could be given as number of subscriber lines and/or number of square metres.

A type of definition for the exchanges, according to the other input data, should also be given regarding:

- grade of service;
- transmission and signalling requirements;
- routing principles;
- marginal switch costs.

The size modules of remote subscriber switches should be given.

The model concerning exchanges has three main aspects, i.e.:

- *exchange configuration*, depending on subscribers, circuits and traffics;
- *floor space requirements* for a given configuration;
- *line terminal equipment*, depending on the transmission medium used and the type of exchange on either end of the line.

It is possible to define various exchange types to be investigated in the course of optimising and/or dimensioning the network. What has to be defined are capacities and costs of equipment, and the possibilities of interacting with other equipment, switching or transmission.

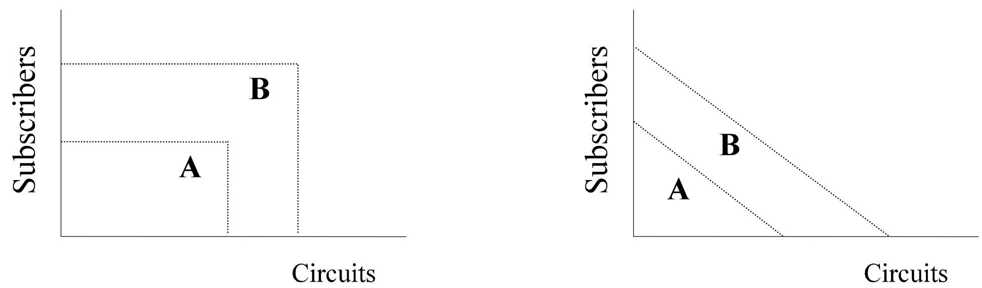
Exchange configuration

An exchange has a certain *maximum capacity*, expressed in:

- number of *subscribers* that can be connected;
- number of *circuits* terminating;
- amount of *traffic* that can be handled;
- number of *call attempts* per hour;
- or a combination of these.

At present, the programme takes into account the first two of these only; as the number of terminating circuits is directly related to the traffic, the third point is indirectly taken into consideration. The call attempts pose a more difficult problem as there is a strong dependence on *actual network performance*, so that this aspect is not considered for the time being.

For a given exchange type, two ways of defining these capacities are recognised by the programme, i.e. independent and dependent subscriber and circuit capacities as shown in the following diagram:



A and B refer to different sizes of a given exchange type.

The cost for a given exchange configuration is defined in the following terms:
- cost of equipment for *one subscriber*;
- cost for equipment common for a *group of subscribers*;
- the size of that group;
- cost of equipment common for *complete exchange unit*.

g) Switch costs

In order to optimise the number of circuits in a high-usage route, the marginal cost for one additional circuit must be estimated. This cost consists of switching costs in the originating and terminating exchanges and a transmission cost that is dependent on the chosen transmission medium and the distance between the exchanges.

Only the components that are significant for the dimensioning of the exchange, with regard to the number of incoming and outgoing circuits, should be included in the marginal switch cost.

The components of this marginal switch cost are:

- exchange terminal equipment;
- appropriate part of group switch;
- proportional part of equipment common to a number of incoming or outgoing circuits.

The marginal switch cost is specified in a matrix where the exchanges are grouped together so that exchanges within a certain group have equal cost.

Some of the costs related to exchanges cannot be expressed as marginal costs since they are not traffic dependent. These are “fixed” costs for:

- site;
- building;
- air conditioning;
- power supply;
- exchange equipment (e.g. processor).

These costs can be expressed as, and given as, a step function depending on the number of subscriber lines. This information should be given both for extensions of existing buildings and for new buildings.

The costs that are equal for all the subscribers (e.g. cost for telephone sets) do not affect the optimisation and should therefore not be considered.

h) <u>Transmission costs and technical properties</u>

In order to make an optimal choice between the transmission media that fulfil the transmission requirements, their costs and technical properties must be specified.

<u>Physical pairs</u>

In the network, cables of different types (i.e. different conductor diameter, loaded, not loaded) and different sizes (50, 100, 200, etc., pairs) are used. For the inter-exchange network and the subscriber (primary) network, the following data for each cable type should be specified:

- cable type;
- resistance (Ω/pair km);
- attenuation (dB/pair km);
- cost for cable (including installation costs) for the most used sizes (100, 300, etc., pairs);
- the occurrence (in percent of the total amount of cable of the specified type) of the most used cable sizes;
- the mean utilisation of pairs in the cable.

Furthermore, the following information should be supplied:

- costs for duct system (i.e. cost for digging, ducts and manholes);
- the mean utilisation of the duct systems.

The PCM transmission system consists of two parts:

- the multiplex system;
- the line system.

<u>Multiplex system</u>

The following data shall be specified for the first order multiplex system:

Technical properties:

- signalling system (depending on type of analogue exchange);
- channel capacity.

Costs for:

- signal converters (depending on type of analogue exchange);
- A/D converters;
- multiplex equipment;
- portion of racks.

For higher order multiplex systems, the following information should be given:

- channel capacity;
- cost for multiplex equipment;
- cost for portion of racks.

Installation costs should be included.

Line system

Different transmission media can be used, for example:

- physical pairs;
- coaxial cable;
- radio link;
- optical fibre.

The data to be specified for each line system are:

Technical properties

- channel capacity;
- distance between repeaters.

Costs for:

- line terminal;
- repeater;
- system cable per system km (physical pairs, optical fibre or coaxial cable);
- portion of repeater box;
- portion of racks;
- portion of radio link tower.

Installation costs should be included.

i) Transmission plan & signalling requirements

For correct choice of transmission media in the subscriber and junction networks, definitions of upper limits for line resistance and attenuation are needed.

These requirements are of course dependent on CCITT recommendations, type of telephone instruments, types of exchanges and the transmission plan applied in the network.

The defined values should be valid for the transmission media only, not including telephone instruments or exchanges.

The maximum permitted line resistance and attenuation (switching equipment not included) should be defined for each combination of types of exchanges for the junction network and for each type of exchange for the subscriber network.

j) Grade of service plan

A definition of service criteria is needed for the dimensioning of final routes in the network. These service criteria could be given in either of the following two ways:

- as a maximum permissible congestion of final routes. This should be given for high usage routes as well, since these routes could be transformed into low loss routes in the optimisation process. These congestion conditions may often be given between groups of exchanges (local, tandem, transit, etc.) where exchanges within the group are equal from a congestion point of view.
- as a maximum permissible congestion for different traffic cases. The total congestion for each traffic case must not exceed this specified value. These grade of service values are specified for groups of exchanges. The maximum congestion on the tandem routes in the network could then be calculated so that the point-to-point congestion for each traffic case does not exceed the specified value.

The specified congestion values should include the congestion in the outgoing group selector stage of the originating exchange.

7.2.9 Output data from optimisation of metropolitan networks

Listing of input data

- Specification of group switch types, i.e. type designations, sizes of inlet and outlet multiples, and in case of restricted availability, permitted availabilities for outgoing routes.
- Grade of service plan, i.e. maximum permitted congestion values, specified per combination of exchange types, either for last choice routes or for traffic cases.
- Routing principles for all levels of the network.
- Specification of considered PCM equipment, i.e. system capacities, repeater distances and cost figures for repeaters, cables and terminals.
- Exchange locations related to node numbers.
- Definitions of cable runs and link distances related to node numbers.
- Switch costs specified per combination of exchanges types for each traffic direction.
- The total number of subscribers, the grid size and the distance multipliers for the subscriber network and for the junction network.
- Exchange capacities.
- Construction cost for existing and new exchanges.
- Transmission plan and maximum permitted resistance for the subscriber network and for the junction network.
- Specification of permitted cable types for physical pairs, i.e. type designations, resistance and attenuation values and costs per pair/kilometre for the subscriber network and for the junction network.

Results

- For all exchanges and remote subscriber switches in the network the result is given as a listing of the locations expressed in coordinates relative to the grid map, number of connected subscribers and cost of subscriber pairs. The exchange area boundaries are related to the grid map; each grid is then given a number corresponding to the exchange area. This information may be printed out, but is in most cases via file storage directed to a plotter (visual display or paper plotter) where the boundary and exchange location map is drawn.
- Number of physical pairs and PCM systems between all nodes, the distances, the marginal costs and the total costs are given.

- A specification of the costs of switches, subscriber cables, junction cables and PCM systems is given.
- The distance distribution in the subscriber network and the mean distances from exchanges to subscribers.
- The traffic interest matrix between exchanges and the total originating and terminating traffic are listed.
- For all routes in the network, the result is primarily given as a listing of the offered traffic in erlang, the number of circuits in the route, the congestion on the direct route and the total congestion for the offered traffic. As an option every terminating route with traffic and number of termination could be listed as well.
- For all cable runs in the network information about the route, i.e. the number of lines on each route, the distance between the nodes and the transmission media chosen for each route in the cable run is listed.
- For the PCM systems used, exact information about their physical layout, i.e. on which cable runs they are installed, the number of terminals, the number of repeaters and repeater boxes on all cable runs, etc. is obtained.
- In total, a complete specification of all transmission media used in the network is given.
- Finally, a cost application, comprising the costs of PCM equipment, cables and switching equipment, is given.

7.3 Traffic Measurements

7.3.1 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.

7.3.2 The system to be measured

To analyse a tele traffic 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.

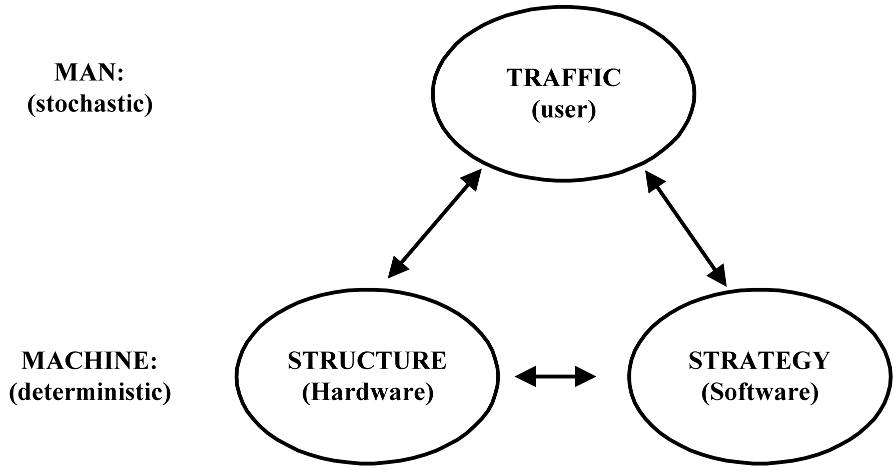


Figure 7.1: The telecommunications system is a complex man-machine system. The purpose of traffic engineering is to design optimal systems. This can only be fulfilled by making observations of subscriber behaviour.

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 of the strategy.

7.3.3 Measuring possibilities vs. data needed

When we are to design a measurement plan, it is very important to define what the real need of data is, and to compare that with what can be really measured in the telecommunication system. This should be done systematically, and the first thing then would be to structure the problem carefully.

As an example, we may consider two main fields of application, viz. **planning**, which is a long term matter, and direct **dimensioning**, which is a matter of continuously updating and re-arranging the equipment in the network, i.e. a short term task.

1 **P** = Planning = a long-term task
2 **D** = Direct Dimensioning = a short-term activity

Also, we may consider the main traffic parameters on which these activities are based:

1 **A** = Traffic Intensity
2 **Y** = Call Intensity
3 **H** = Holding Time
4 **B** = Blocking Level

Now, we may also distinguish between:

1 **d** = Demand
2 **o** = Offered
3 **c** = Carried
4 **r** = Rejected

For **Planning**, we most of all would need the future **Traffic Demand** $\mathbf{A_d}$, i.e. the traffic interests between traffic areas. What we can get is however not at all that. The only traffic intensity that can be measured is the present **Carried Traffic** $\mathbf{A_c}$, mostly route traffics, but some times traffics per address or exchange area. Demanded, offered or rejected traffic can never be measured since they do not at all exist physically in the network: they all belong to the theoretical model that is used to describe the reality so as to permit the use of mathematical methods in our engineering work.

We have the same situation in the field of **Direct Dimensioning**, where we would need the present **Offered Traffic** in different points of the network, to be able to re-dimension circuit groups and remove bottle-necks.

A most useful exercise is to go through all this thoroughly, defining the exact needs vs. the measurement possibilities for the different fields of applications, and considering the different points and parts of the network, such as **speech-carrying devices** vs. **common control** and **signalling,** and **switches** vs. **trunk groups** etc.

7.3.4 The traffic process

The number of subscribers dialling 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.

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

a) 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 characterised by a distribution function:

$$F(t) = P(X \le t) \qquad t \ge 0$$

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

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

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

$$\mu = M_1 = \int_0^\infty tf(t)dt = \int_0^\infty \{1 - F(t)\}dt$$

A **Form Factor** ε can be introduced to characterise the dispersion of a life-time distribution:

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

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.

$$F(t) = 1 - e^{-\lambda t}$$
$$\lambda > 0, t \ge 0$$
$$f(t) = \lambda e^{-\lambda t}$$

Thus the distribution is characterised by one parameter, viz., λ.The mean value is $1/\lambda$ 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 **generalised Erlang distribution** or a **Cox distribution**.

b) 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:

$$\mathbf{0 = T_0 < T_1 < T_2 < ... < T_n < ...}$$

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:

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

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 characterised 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:

$$P\{N_t < n\} = P\{T_n > t\} \qquad n = 1,2,...$$

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.

c) 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 computerised equipment, which monitors the individual circuit, and thus operates on the time space - **<u>horizontal measurements</u>**.

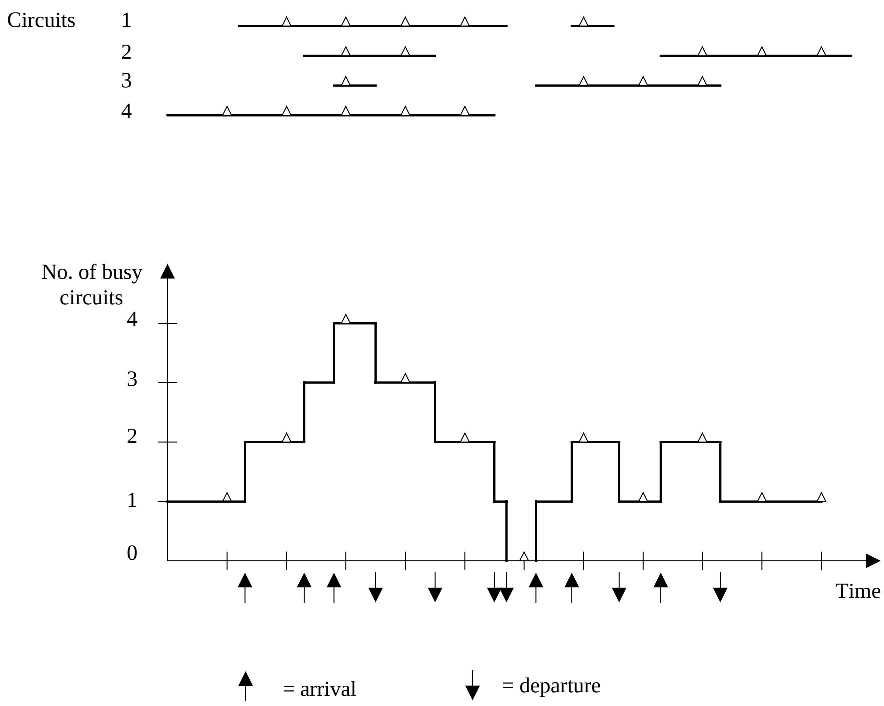


Figure 7.2 : Continuous traffic process

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 - <u>vertical observation</u>, and it is not possible to identify the individual calls. In computerised measurement - <u>horizontal observation</u>, we monitor the individual circuits.

7.3.5 Measuring technique

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.

To perform more or less detailed measurements on each individual call means that the call must be supervised from beginning to end and the points of time for all relevant events be registered. This principle is called **Call Supervision**. In a non-SPC register controlled exchange, there are suitable measuring points for call supervision, but a special kind of measuring equipment has to be connected to these points, furthermore by the use of interface equipment that is specific for the technology of the particular exchange. In a digital exchange, all events concerning each call are registered in the data memory. By running special software that can be added to the exchange software, the corresponding data can be continuously fetched from the data memory and processed so that the desired types of measurements are obtained, either in form of direct printouts, or stored in an external memory to be further processed later.

The other principle is to observe circuits and to register the events on a group of circuits or maybe on each individual circuit. This principle is called **Trunk Supervision**. In non-SPC register controlled exchanges there are usually measuring equipment for the supervision of groups of circuits. Measuring takes place by scanning, the scanning interval being relatively long, e.g. 36 seconds, in order that counters may give traffic values directly in Erlang, provided that the total measuring time is one hour. Other equipment counts the number of arriving, carried and rejected calls.

The situation can be radically improved by connecting a modern scanning equipment to each individual circuit. This type of scanner is very fast, the scanning interval being a few milliseconds. This means that the scanner can detect the beginning and end of **each call**. Therefore, not only number of calls and traffic intensity is measured, but also the length of each individual occupation, and everything that actually happens on the circuit. This equipment thus produces both very good data for further processing and valuable data for operation and maintenance purposes.

In a digital exchange, no equipment is needed, only special software for the fetching of data from the data memory and for the simple processing of this data.

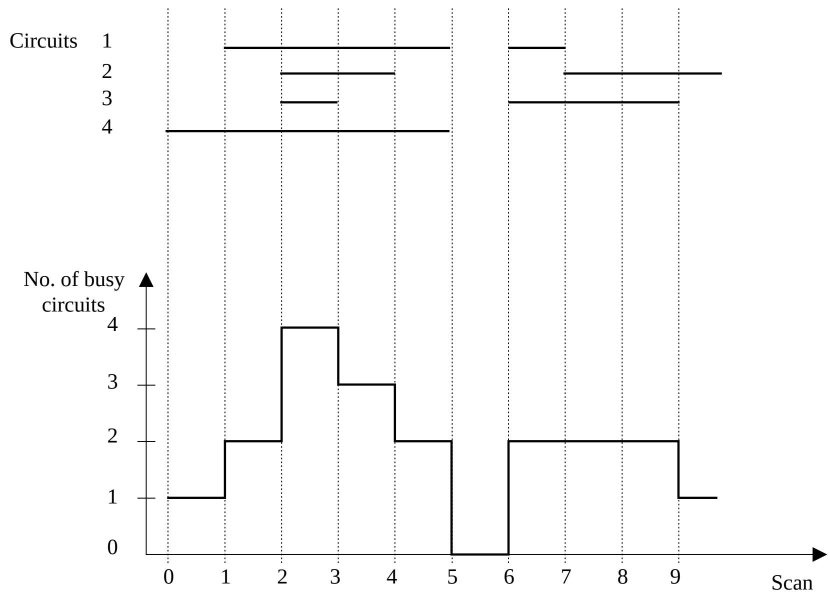
7.3.6 Reliability of measurement

Traffic measurement results are almost always presented as single values, without indication of the quality or precision of the values. Maybe the result is presented like this: **"Traffic from A to B is 37.5 Erlang".**
First of all, is this a direct measurement, i.e. **carried traffic**, or is it the estimated **"offered" traffic**, or maybe a forecast of the **traffic demand**, etc. ? Secondly, were the measuring point, the point of time, the measurement principle and the measuring period relevant? Maybe a confidence interval should be included so that the result would read **"Carried traffic on the route X from A to B was 37.5 ± 7.2 Erlang".**

There is much to say about these intricate and very important matters, but in this subsection only general statistical viewpoints are considered.

a) Precision of scanning

When using the scanning method with constant scan intervals of length **h**, the continuous traffic process of Figure 7.2 is transformed into a discrete traffic process as shown in Figure 7.3. We notice that there is no one-to-one relation between a continuous real time interval and the observed discrete time interval. However, the two distributions will always have the same mean value.



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

Figure 7.3 : Discrete traffic process

The scanning principle with regular scan intervals applied to the traffic process of Fig. 84. 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. Computerised equipment monitors the individual circuits and records all relevant changes by a) circuit number, b) time = scan number, c) type of change, 0 -> 1 or 1 -> 0.

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 7.1 and Fig. 7.4.

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

Table 7.1 : The relationship between discrete time intervals observed by regular scan intervals of length h and range of the real continuous time interval.

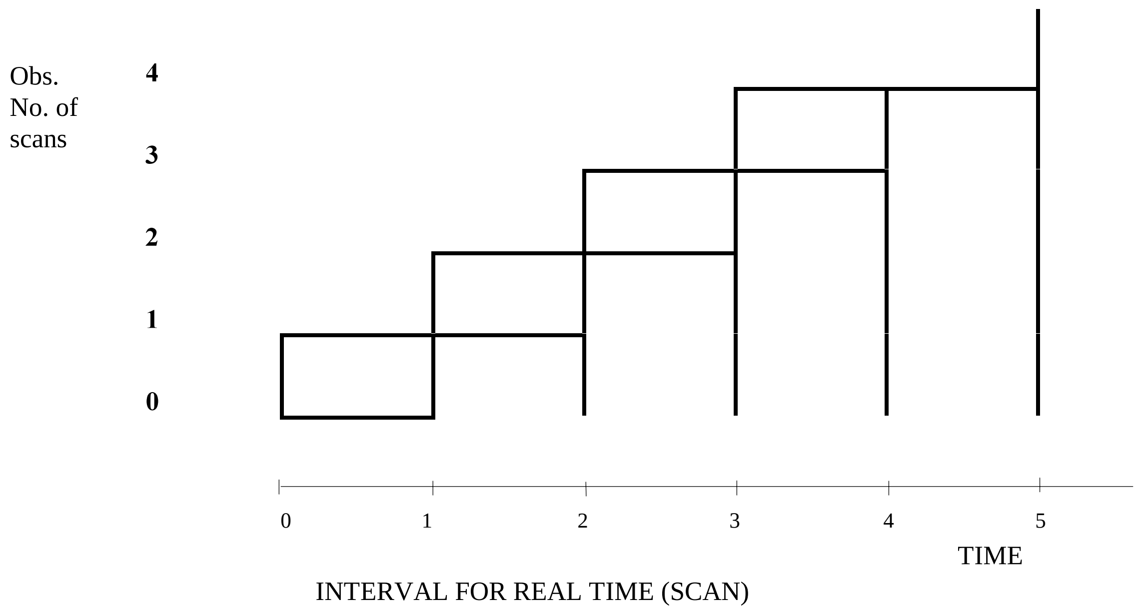


Figure 7.4 : By the scanning principle with regular scan intervals, a continuous real time interval is transformed into a discrete time interval. This transformation is ambiguous.

The scanning process increases the form factor ε of the real time distribution. If this is exponential with mean holding time = **s = 1/λ,** scanning with a scanning interval = **h** will give a form factor ε:

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

There are two sources of error in the observation of a time interval:

1 Error due to sampling
2 Error due to the measuring method

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

If the arrival process is a Poisson process with intensity **y**, then the mean value μ and the variance σ^2 of the observed mean is:

$$\mu_i = A$$

$$\sigma_i = yM \ \ / T = A\varepsilon s / T$$

where **A** is the offered traffic (no congestion), **T** is the measuring period, $\mathbf{M_2}$ the **2nd** moment and ε is the form factor of the holding time, which has the mean value **s=1/λ.** 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:

$$\sigma_i^2 = \frac{A}{T} s\lambda h \frac{\varepsilon^{\lambda h} + 1}{\varepsilon^{\lambda h} - 1}$$

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 a constant**

where the constant is a fractile of the **Normal** distribution. For **95 %** confidence, this constant = **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 first λ**h = 1 / 3**

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

$$\sigma_i^2 = 0.1009$$

and thus a **95 %** confidence interval gives **A = 5 ± 0.62 Erlang (4.38 to 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 $\sigma_i \mu_i$ depends only on the total traffic volume **AT**.

For **<u>continuous observation</u>**, the variance σ can be calculated as:

$$\sigma = A\varepsilon s / T$$

In our example, **A = 5,** ε **= 2, s = 2/60, T = 5** ; which would give a variance σ^2 **= 0.1000**, i.e. only slightly less than for scanning. This means, that the scanning frequency in this case is quite satisfactory.

b) Counting the number of events

Counting the number of events is based on the receipt of a pulse for each 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 number of:

- Calls;
- Occupations;
- Lost calls;
- Times blocking 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:

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

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

$$Ex = \lambda$$

$$D^2 x = \lambda$$

The mean error in number of observed lost calls is thus

$$dx = \sqrt{x}$$ which can be re-arranged as:

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

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.

7.3.7 Examples of measurements in a digital system

Traffic and service measurements are essential in order to provide the data base from which the important activities of traffic administration, traffic engineering and service evaluation are carried out.

A digital exchange has normally a rather comprehensive set of measurement functions. Such functions collect data basically in three different ways: With software counters, call records, and observations of selected calls.

Besides output suitable for later data processing, reports can also be generated for immediate presentation e.g. in work stations. In that way, quick actions can be taken to cope with unsatisfactory conditions.

a) Traffic measurements

i) Basic set of measurements

Provided that the exchange has transit functions, eight **Traffic Types** may be defined:

1. Total originating traffic.
2. Originating outgoing traffic.
3. Internal traffic.
4. Terminating incoming traffic.
5. Total terminating traffic.
6. Transit traffic.
7. Total outgoing traffic.
8. Total incoming traffic.

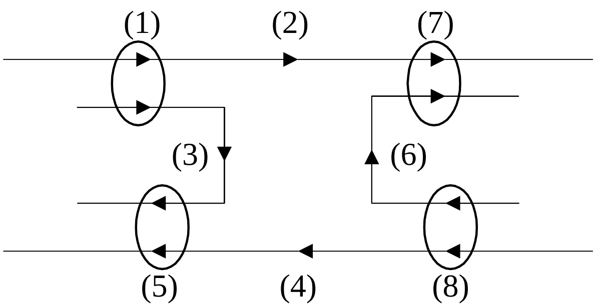


Figure 7.5 : Traffic Types

To obtain data needed both for day-by-day control and follow-up of system performance as well as for postprocessing for planning purposes, the following **Measurement Types** may be defined:

1 Traffic intensity.
2 Number of correctly dialled calls.
3 Calls lost due to exchange and common control blocking and due to own exchange technical faults.
4 Through-connected calls.
5 Answered calls, %.
6 Internal congestion, %.
7 External congestion, %.
8 Total number of one-way circuits.
9 Mean number of one-way circuits out of service.
10 Total number of both-way circuits.
11 Mean number of both-way circuits out of service.

A combination of **Traffic Types** and **Measurement Types** gives a large number of possible particular measurements.

ii) System input measurements

There is a need to measure system input and processor load. The following measurements may be defined:

1 Originating call intensity to the system.
2 Originating call intensity accepted by the system.
3 Terminating call intensity to the system.
4 Terminating call intensity accepted by the system.
5 Mean processor load, %.

iii) Measurements on particular subscriber or line groups

Particular groups of lines or subscriber lines may be defined and studied. As for the whole exchange, **Traffic Types** and **Measurement Types** may be defined and the combinations will constitute different measurements. The results can be used for line administration.

Traffic Types:

1 Total originating traffic in the group.
2 Total terminating traffic in the group.
3 Internal traffic in the group.
4 Originating outgoing traffic in the group.
5 Terminating incoming traffic in the group.

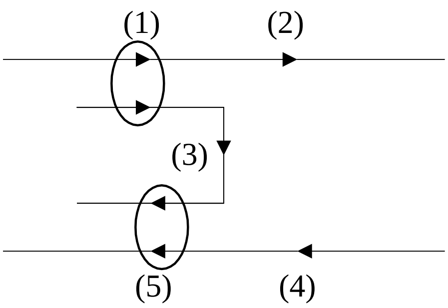


Figure 7.6 : Traffic types in a subscriber group

Measurement Types:

1 Number of correctly dialled calls.
2 Traffic intensity.
3 Number of answered calls.
4 Number of calls to busy B-subscriber.
5 Number of calls to ringing but not answered.

iv) ISDN measurements

For the planning and dimensioning of ISDN facilities, measurements on the digital subscriber ISDN access may be defined, e.g. as follows.

On the B-channels:

1 Originating telephony traffic.
2 Originating data traffic.
3 Terminating telephony traffic.
4 Terminating data traffic.

On the D-channel:

5. Number of originating telephony calls.
6. Number of originating data calls in B-channel.
7. Number of terminating telephony calls.
8. Number of terminating data calls in B-channel.
9. Number of rejected originating calls due to busy B-channels.

v) Measurements on routes

Measurements can be defined both for loss- and delay-system routes. The output can be used both for follow-up and verification of circuit group dimensioning and for planning purposes.

Loss systems:

1 Number of calls.
2 Traffic intensity.
3 Variance of traffic.
4 Mean holding time.
5 Call congestion.
6 Time congestion.
7 Number of circuits per group.
8 Number of circuits out of service.

Delay systems:

1 Number of calls.
2 Traffic intensity.
3 Number of calls going to the queue.
4 Number of seizures after queuing.
5 Mean queue length.
6 Mean queue time for queuing calls.
7 Mean holding time.
8 Number of circuits per group.
9 Mean number of circuits out of service.

vi) Measurements on CCITT No. 7 signalling links

Data according to the CCITT recommendation Q.791 should be recorded, e.g.:

1 Number of transmitted and received octets of different types.
2 Number of retransmitted octets.
3 Congestion indications.
4 Transmitted and received carried traffic, MSU kbit/s.
5 Number of received MSUs.

vii) Measurements on operator handled traffic

The recorded data can be used for supervision, dimensioning, follow-up of trends and planning. Measurements should be defined for **Delay Service Calls**, **On Demand Service Calls**, **Queue Calls** and **Total Calls**.

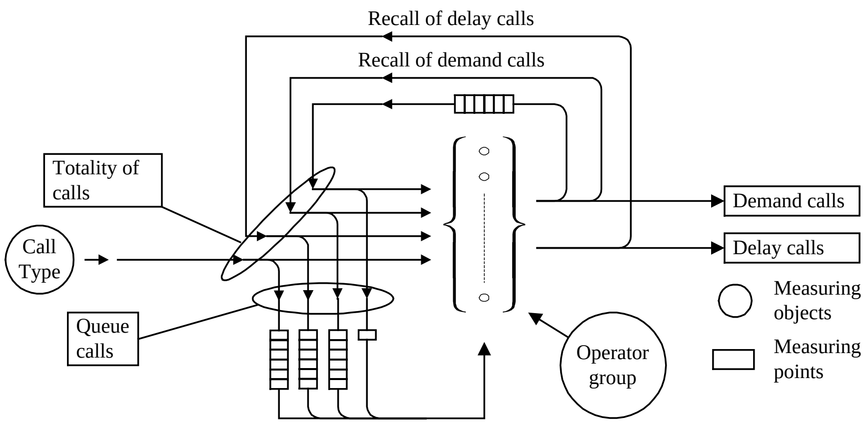


Figure 7.7 : Measuring objects and measuring points.

Demand calls:

1 Number of calls answered by the called party
2 Mean service time for the ordering phase, cancelled calls included
3 Mean service time for the connection phase, recalls included

Delay calls:

1 Number of ordered calls, excluding cancelled calls
2 Number of calls answered by the called party
3 Mean service time for the ordering phase
4 Mean service time for the connection phase

Queue calls:

1 Mean queue length
2 Mean waiting time for queuing calls

Total calls:

1 Total number of incoming calls
2 Number of incoming calls interrupted before operator answer
3 Number of cancelled calls
4 Number of incoming calls answered by operator
5 Number of charged calls

viii) Traffic dispersion measurement

The originating traffic from any exchange is composed of partial traffics which have different final destinations. Some of these partial traffics are routed directly to their destinations, while other traffics are routed in a much more complex way through the network. These partial traffics can thus not be recorded via ordinary route traffic measurements. Special measurement software has to be implemented in the digital exchanges to make such measurements possible. The results can be used as a basis for traffic interest matrix forecasts. The result from the measurements in a particular exchange corresponds to one row in the matrix for present traffic interests between exchange areas. An input to the measurement is a specification of codes of destinations and/or circuit groups. Another, more sophisticated version is called **Origin Dependent Traffic Dispersion Measurement**, which is used in tandem exchanges. The result of such a measurement comprises traffics **between** specified combinations of originating and terminating exchanges in the network. It can however not give the total traffics between the exchanges, only the part that passes the tandem exchange where the measurement takes place.

Examples of measurements:

1 Traffic intensity
2 Total number of calls
3 Number of seizures
4 Number of rejected calls
5 Number of answered calls
6 Mean holding time
7 Mean conversation time

Figure 7.8 shows a small example where only one destination is specified, but where the traffic has three choices: first choice via a direct route, second choice via a terminating tandem and third choice via an originating tandem. The corresponding routes are here called **circuit groups**. Note that the traffics recorded are **only** traffics finally terminating in exchange **B** = the destination.

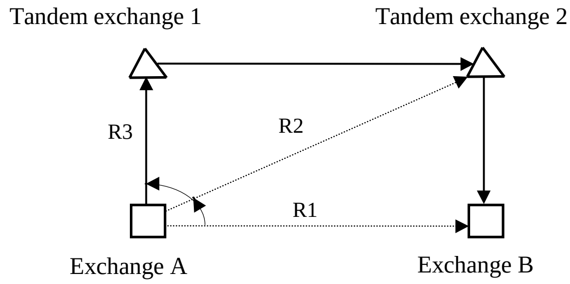


Figure 7.8 : Alternative routing case

The table below shows how the result of the measurement could be printed.

Desti-nation	Circuit Group	Traffic	Calls	Seizures	Rejected Calls	Answers	Mean holding time	Mean convers. time
B	R1	XXX.X	XXX	XXX	XXX	XXX	XXX.X	XXX.X
	R2	XXX.X	XXX	XXX	XXX	XXX	XXX.X	XXX.X
	R3	XXX.X	XXX	XXX	XXX	XXX	XXX.X	XXX.X

Traffic dispersion measurement result

ix) Measurements on a per call basis

The other measurements mentioned above are all of type **Trunk Supervision**. The measurement exemplified here is of type **Call Supervision**. This means that individual calls are picked out and studied in detail. Events and points of time are registered, so that not only the destination of each call is known, but also number information, answer time etc. Particular **types** of calls should be specified, e.g. originating calls, incoming calls etc. Also circuit groups and destinations could be specified.

Examples of measurements and data:

1 Calling subscriber's number
2 Called subscriber's number
3 Number of digits in country code
4 Register holding time
5 Through-connection time
6 Answer time
7 Disconnection time
8 Type of disconnection

b) Service measurements

Overall network performance can be studied via **service quality statistics**. Significant events concerning the exchange and network performance as well as of the subscriber behaviour are registered. Both quick reports and data for further post-processing should be presented. Types of calls, destinations and circuit groups should be possible to specify, e.g. "exchange originated calls to destination **B** on circuit groups R1 and R2".

Examples of registrations:

1. Number of calls
    a) correctly dialled
    b) through-connected
    c) answered
    d) not answered
    e) to busy B-subscriber
    f) to non-existent subscriber number
    g) disconnected before dialling
    h) timed out before dialling
    etc.
2. Number of calls that failed due to signalling errors
3. Number of calls blocked due to network management measures
4. Post-dialling delay
5. Time to answer
6. Exceptionally short conversation times

etc.

Many types of registrations are possible.

7.4 Organisation of telecommunication network planning

In a business oriented development plan, we have to consider the implications of a competitive environment in which the traditional telecommunication Administration may become merely a network provider for the many new services, instead of also being a service provider, if he is not capable of streamlining his organisation to cope with these new services. These services will be stimulated almost exclusively by the business user who is not particularly interested in who provides them, but in their availability, cost and efficiency.

The end user will demand extremely good telecommunication services in the future, in particular:

- services which can promote his own business;
- high quality services;
- fast and easy access to services;
- low cost for services.

If the network provider can manage to provide new high quality services at low cost without delay when demanded, he may be selected as SERVICE PROVIDER. If the service provider can offer and sell attractive services early, i.e. before competition reduces the price, his GROSS INCOME may increase. If the service provider can implement required services at low cost, his NET INCOME may well increase.

The preconditions on the telecommunication service market will change radically in the near future, and thus there is a drastic message to all participants, in particular the network operators: “achieve excellence or fail”.

There are several necessary prerequisites to achieve excellence, but among them is an effective ORGANISATION with the right attitude, and with skilled, experienced and well motivated employees, in other words an organisation based on competence.

Traditionally, a telecommunication network used to be separated into two distinct parts; switching and transmission. This division was also reflected in the organisation of the Administration.

A future network needs to respond to changing conditions in a new and dynamic fashion. The network must be capable of adapting to variations in traffic flow and demand in real time. It must set up switched or permanent and semi-permanent connections on command from operating company staff, or even on command from subscribers, and assign bandwidth on demand in real time.

Essential performance criteria of the future network are:

- efficient service provisioning;
- efficient resource utilisation;
- efficient operations support.

Efficiency stands out as the common denominator in all these areas of interest from the network provider’s point of view.

In order to meet the demand for both market-driven service provisioning and cost effective transport, the structure of the network needs to become increasingly flexible, i.e., the structure should be able to permit a more independent development of the access and transport capabilities on the one hand, and of the service control capabilities on the other.

Thus the development of an integrated network with specialised nodes, e.g., for access, transfer, feature, signalling and management will take place. The traditional concept of “exchange” may relate to “access” and “transfer” nodes.

Furthermore, different networks will develop simultaneously side-by-side, for example, the “ordinary” telephone network, a number of dedicated data networks, mobile networks, and narrowband and broadband ISDN. Ultimately, all these networks must be able to communicate.

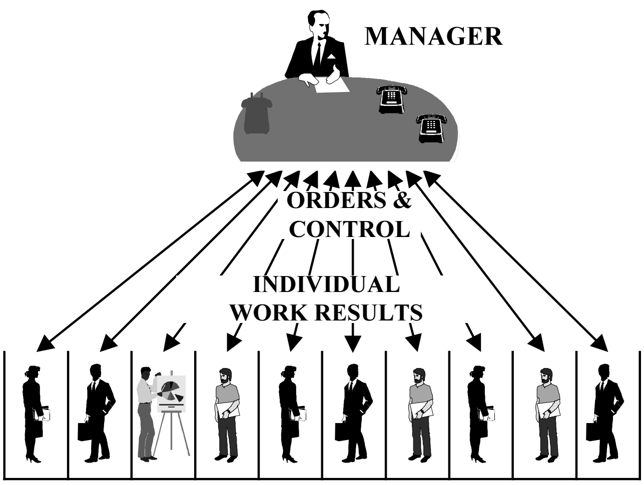
This will result in fundamental changes in the roles and activities of Administrations, and inevitably, their personnel. Personnel will represent an enormously productive real capital, and it will be essential to develop and maintain their competence, to distribute responsibilities as well as decision-making authority to this new corps of skilled employees, to introduce effective, specialised, job-oriented organisations, and to supply high quality work tools, especially software systems and appropriate computer equipment.

The large investments required for future networks and the long-term nature of planning imply that incorrect decisions may be costly or even disastrous. Therefore, sound and effective planning of the network will be of crucial importance- and will be possible thanks to the use of modern, large, and sophisticated planning systems and the accurate processing of large amounts of data.

Network planning should therefore be carried out by a competent, competent, and responsible, integrated group of planners from different specialised fields of knowledge and skill, well-equipped with computing facilities. The cost of such work tools is negligible compared to the output, which comprises:

- large savings in network investment;
- avoidance of incorrect and potentially disastrous decisions.

Many groups and departments are still organised, and work, as shown in Figure 7.9. Well-educated employees work under stiff and patriarchal rules, with no stimulation or motivation, their possible initiatives are not welcomed, they do not cooperate, they do not have individual competence development plans and they spend a lot of time with routine work in which they see no meaning. The output of such an organisation is poor, and the company will hardly survive long in the new competitive market.



1 Brain used to (the mamager)
50% for Creative work
40% for Routine work
10% for Important decisions
0% for Leadership

10 Brains used to (the employees)
50% for Routine work
50% for Useless activities
0% for Creative work
0% for Competence development

RESULT :

Important Decisions	0.1 Brain
Creative Work	0.5 Brain
Competence Development	0 Brain
Leadership	0 Brain
Routine Work	5.4 Brain

Figure 7.9 : The traditional organisation

If this were an organisation for network planning, the result could be a disaster. The modern network planner:

will think in terms of
- Network functions
- Network elements

will design the network considering
- Cost effectiveness
- Flexibility
- Simplicity
- Robustness
- Reliability

should have qualities like
- Analytic thinking
- Creativity
- Team work inclination

should possess knowledge and skills on
- Modern telecommunications
- Network elements
- Network functions
- Telecom services
- Cost structures
- Network planning
- Network design
- Teletraffic engineering
- Optimisation
- Forecasting
- Network evolution
- Use of computers

Figure 7.10 shows one important type of work that a responsible team of specialists could do together and also some of the many data and other prerequisites that they would have to consider.

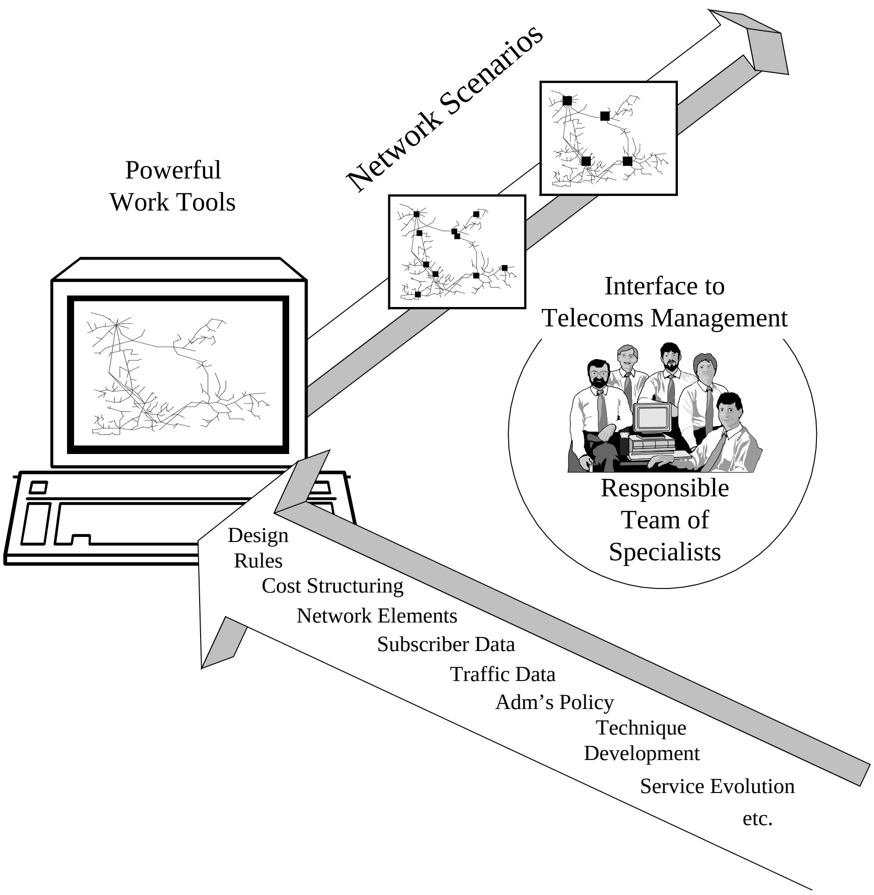


Figure 7.10 : The responsible network planning team

Figure 7.11 demonstrates that such a group of specialists will need a new kind of management which can stimulate them through real leadership. This kind of employee wants to share the responsibility for the decisions, and requires individual competence development plans and continuous training. The message conveyed by this figure is that "brains are money".

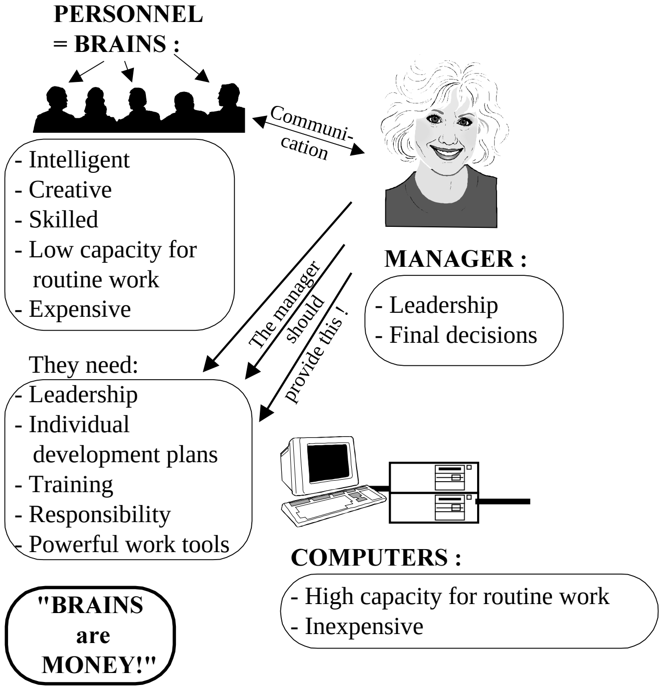


Figure 7.11 : The new leadership

Figure 7.12 shows how a changed type of organisation can improve the output dramatically compared to the traditional one in Figure 7.9 The organisation is now target oriented, which in a way is similar to a project organisation, only that the "project" groups of specialists also belong to the line organisation. The manager now delegates responsibility and authority and stimulates creativity and initiatives. The specialists possess different skills and co-operate, which will create synergy effects. They have adequate work tools such as high speed computers.

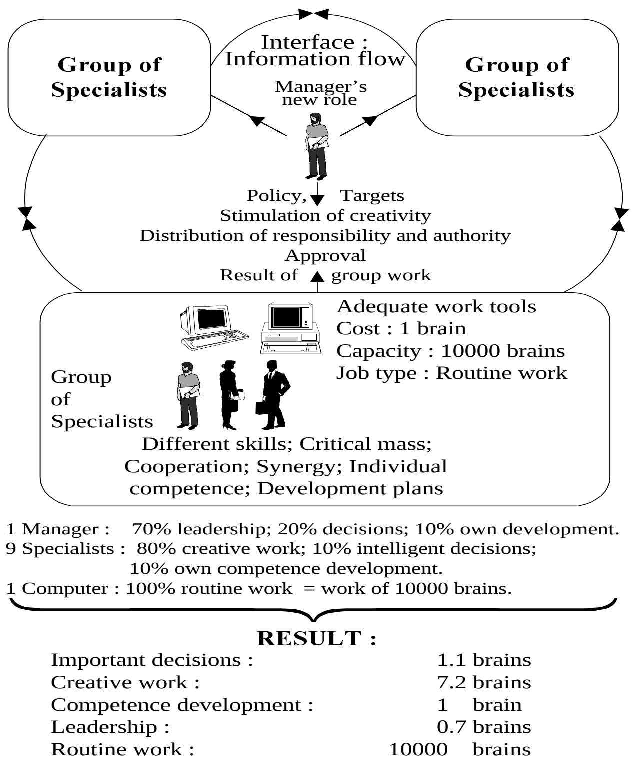


Figure 7.12 : The target oriented organisation

Figure 7.13 shows not an organisation but rather the **Functions** of a **Network Planning Organisation**, the logical flow between functions and the interfaces both to other parts of the **main** organisation and to the **central management**. These interfaces are very important. The central management should provide information about the policy of the company and give general directives so that the network planning group always works according to the general business strategy. The planning group will send forecast and network scenarios to the management for approval, and the management will give the final approval so that the planning group can work out **detailed** plans based on the approved scenarios. The interfaces to the other parts of the organisation must be based on the official authorisation to obtain continuous information from these parts. In the figure, the boundary of the network planning organisation is drawn with dotted lines.

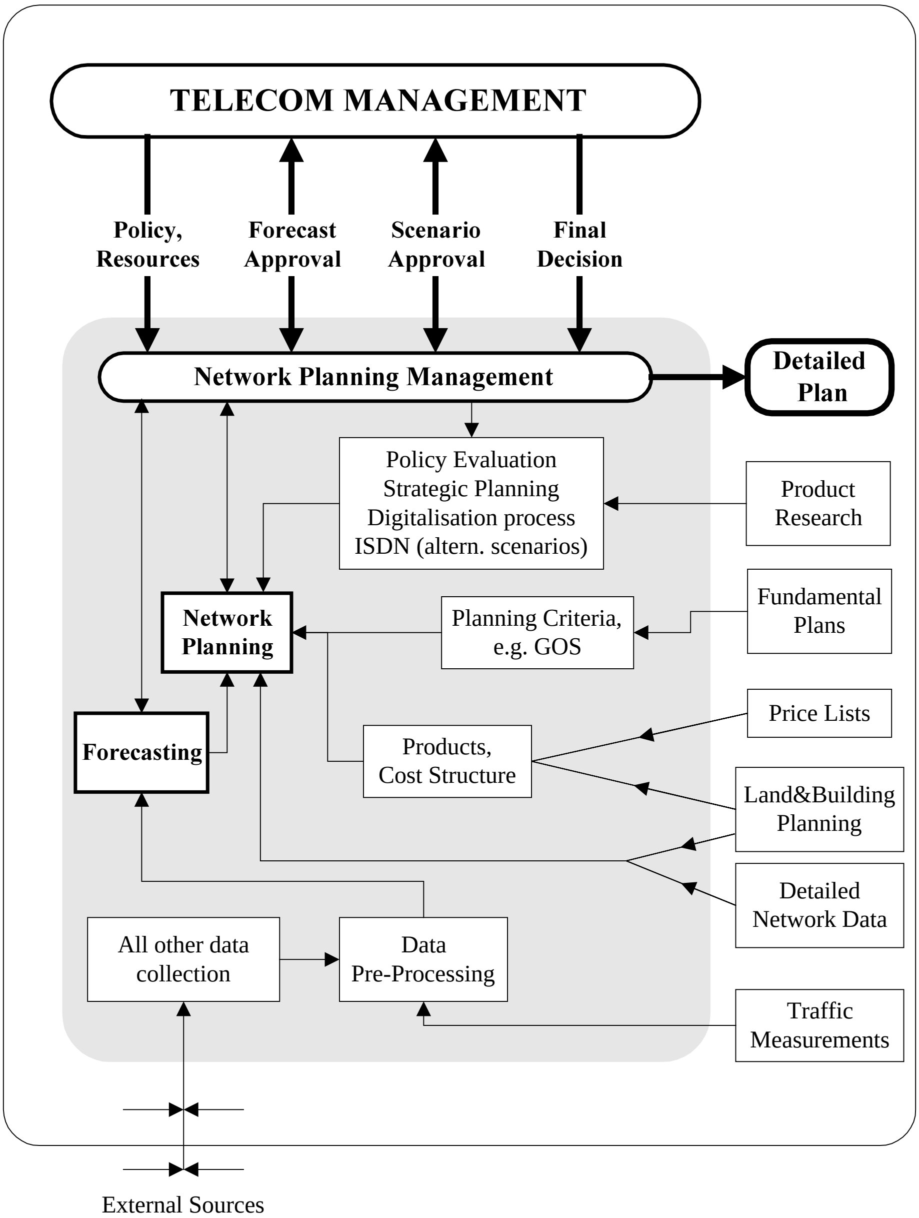


Figure 7.13 :Network planning functions and interfaces

To plan and implement even a small organisation is in fact a project that should be worked out very carefully. A bad start is very difficult to correct later. The top management should be involved, and once the group is established, give it full support.

The following list gives the stages required for the implementation of a typical network planning unit; the stages should be followed sequentially, i.e. 1 ==> 2a ==> 2b ==> 2c etc. It is seen that items 1, 2 and 3 can be resolved through discussions, consultations and decisions, while item 4 consists more of direct **action**. Item 5 should be taken up later, possibly one year after the organisation is implemented.

Project: organisation of a network planning unit

1 Overall responsibilities of the unit

2 The network planning process

a) Definition of planning functions
b) Definition of software tools and necessary equipment
c) Information flow between functions (data)
d) External information flow
e) Decision points

3 Organisation of the unit

a) Decision levels
b) Division into functional work groups
c) Responsibilities of work groups
d) Work flow inside work groups
e) Interfaces between work groups
f) Hierarchical structure of unit
g) Interface towards telecoms management
h) External interfaces
i) Responsibilities of external units
j) Size and skill of work groups
k) Training program

4 Implementation

a) Work groups and unit management
b) Recruitment
c) Start of training
d) Acquisition of computers and other equipment
e) Acquisition of software tools
f) Installation of software; adaptation to local procedures
g) Organisation of data bases
h) Start of data collection
i) Start of data pre-processing
j) Start of forecasting activities
k) Start of network planning

5 Evaluation, revision, approval, future developments (strategy)

7.5 Data bases

Strategic and development plans must be reviewed regularly to take into account various changes in general objectives, external financial resources, policy, equipment etc. For maximal efficiency, master plans for national and local networks should be revised, in principle continuously, but in practice at least every four or five years. However, due to high cost and lack of qualified personnel these plans are typically revised far less frequently. Assumptions underlying the plans may become obsolete, and consequently the plans themselves thus become obsolete.

With an effective and well run computerised **information system**, plans may be updated on a yearly basis. Human intervention is thus reduced to maintaining a comprehensive **data** base with consistent and up-to-date values. Such a permanent inter-active **data base** is the core of an **information system** and is much more powerful than traditional paper documentation.

The tasks in forecasting and network planning require the manipulation of large amounts of data which are characterised by a great variety, a high degree of interaction and frequent changes. Efficient computerised tools are therefore particularly necessary in this field. The iterative nature of many tasks in the overall process reinforces this point.

The traditional approach to computerisation results in files with a rigid structure depending on the particular needs of application programmes. This rigidity leads to multiple data files when the number of programmes increases. The consequences are redundancy of data, which are stored many times, and costly maintenance, because each request for a new application can rarely be satisfied by the previous structure of the available files.

The general purpose of **data bases** is to avoid these drawbacks by providing the end-user with an overall information system that is reliable, consistent, and flexible.

An **information system** is a set of tools, procedures and human resources organised to distribute “the right data to the right person at the right time” for a given field of application, e.g. forecasting and network planning. It should be organised for the Administration as a whole, as it links all the services involved in the concerned field together. An information system plays an essential role in the effectiveness of the organisation, especially for the planning process. A poor information system can lead, for example, to the following difficulties:

- Unreliable results leading to erroneous decisions;
- Missing data, jeopardising decision-making;
- Delayed results which become less or not at all useful;
- Duplicate results from various sources with redundant efforts;
- Inconsistent information provided by different sources;
- Documents of poor quality;
- Expert time wasted on data collection activities.

An **Information system** consists of the following elements:

- **Computer hardware**, personal computers, minicomputers or terminal on main frames;
- **Operating systems** such as MSDOS for personal computers;
- **Data base management systems DBMS**, which are computer software which sort, update, search and output the data contained in data bases in the appropriate form; this software is of general purpose type and can be applied to different domains;
- **Data bases**, which are files, organised in a certain manner, containing all the information describing the real world in a given area according to a model common to a large number of users;
- A **data dictionary**, specifying the format, integrity constraints and the origin of all data;
- A **data base administrator**, responsible for the organisation, reliability, consistency and availability of the data base;
- An **indicator counterpart** in each department or group concerned;

- Software application **end-users**;

- **Computer support**;

- **Operating rules** for the information system, which are decided at the top level of the organisation and which oblige the services to work constantly as a team; these rules must specify the duties and rights of each service as regards the information flow; for instance, which data are input by which service, or what output is to be transmitted by whom, to whom and when;

- An **official terminology** with precise definitions of all terms used in the information system; the same words must correspond to the same things in every part of the organisation; and different things must be called by different words.

The first task to be carried out when implementing an **information system** is the design of the **data base structure**. The points below should be followed:

- Set up a list of the entities on which the structure of the files depends;(Entities are e.g. exchanges, trunk groups, the whole country, provinces, local switching areas etc.)

- Set up a list of all attributes characterising these entities;(Attributes are e.g. name, area, population etc.)

- Set up a list of relationships linking these entities; (A circuit group **links** two exchanges, an exchange is **located** in a building etc.)

- Set up a list of the files, with a key made of one or several attributes used to identify each record of the file;

- Use, for the permanent values, the code of the element of the entity as a key;

- For time-dependent values, this code must be associated with the date to constitute a key; for certain entities it is therefore advisable to have two files.

The structure of the data base and the data dictionary must be managed by only one person: the **Data Base Administrator**. This is compulsory to guarantee the consistency of all the data shared by different departments of the organisation. Alternatively, the administrator's role is to distribute authorisation to users allowed to update or read the different parts of the data base. A large data base represents a huge investment in terms of capital and human effort, so that the security controls must be implemented under the administrator's authority.