INTERNATIONAL TELECOMMUNICATION UNION

TELECOMMUNICATION DEVELOPMENT BUREAU

ITU-D STUDY GROUPS

Document 1/016-E
19 August 1998
Original: English only
DELAYED

FIRST MEETING OF STUDY GROUP 1: GENEVA, 10 - 12 SEPTEMBER 1998
FIRST MEETING OF STUDY GROUP 2: GENEVA, 7 - 9 SEPTEMBER 1998

Question 12/1: Tariff policies, tariff models and methods of determining the cost of national telecommunication services

STUDY GROUP 1

SOURCE: GERMANY

TITLE: AN ANALYTICAL COST MODEL FOR THE LOCAL NETWORK - CONSULTATIVE DOCUMENT - PREPARED BY WIK[1] FOR THE REGULATORY AUTHORITY FOR TELECOMMUNICATIONS AND POSTS

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List of Abbreviations

#	=	number
α	=	factor for the ratio of successful to total call attempts
A	=	traffic offering in Erlangs
Abs_ZWR	=	maximum distance between regenerative repeaters
AbsSchacht	=	average distance between manholes
AFV	=	share of long-distance traffic in total subscriber traffic
AK	=	remote concentrator
AKK_{HK}	=	share of conduit routes in the feeder section
AKK_{VZB}	=	share of conduit routes in the distribution area
AKK_{VK}	=	share of conduit routes in the interoffice network
ASB	=	access area
Asl_analog	=	number of analogue subscriber lines
Asl_digital	=	number of digital subscriber lines (basic rate ISDN access)
Asl_PQ	=	number of subscriber lines in a grid square
Asl_VZB	=	number of subscriber lines in the distribution area
B	=	loss probability
BHCA	=	dynamic traffic load in an average busy hour ("busy hour call attempts")
$BHCA_D$	=	dynamic traffic load in the hour relevant to network capacity dimensioning
BHE	=	traffic volume in an average busy hour ("busy hour Erlang")
BHE_G	=	outgoing traffic
BHE_G_F	=	long-distance traffic (outgoing)
BHE_G_O	=	local traffic (outgoing)
BHE_GK	=	BHE per business customer
BHE_I	=	intraoffice traffic
BHE_K	=	incoming traffic

BHE_K_F	=	long-distance traffic (incoming)
BHE_K_O	=	local traffic (incoming)
BHE_PK	=	BHE per residential customer
BHE_D	=	traffic volume in the hour relevant to network capacity dimensioning
C	=	costs
CP	=	coordination processor
Δp_u	=	average rate of price change for the asset category u
D	=	expected rate of return on equity
DA	=	wire pairs
DA_Asl	=	wire pairs per subscriber line in the drop segment
DSV2	=	2 Mbit/s digital connection
DLU	=	digital line unit
eK	=	equity ratio
EVz	=	Subscriber Distribution Interface (SDI)
EVz_Asl	=	number of SDIs per subscriber line
fK	=	debt ratio
FV_Fkt	=	leased line factor in the interoffice network
FV_Fkt_DA	=	leased line factor in the access network
G_Asl	=	number of trenches per subscriber line
GK_PQ	=	number of business lines in a grid square
GK_VZB	=	number of business lines in a distribution area
GKFkt	=	business customer factor
HT	=	average holding time
HVt	=	main distribution frame
HK	=	feeder cable
K_Tm	=	number of cables per route metre
Kap_CP	=	call processing capacity expressed in BHCA of a local exchange with basic equipment
KBF	=	capital and operating cost factor
KKF	=	capital cost factor
KKS	=	weighted average cost of capital
KVz	=	Feeder-Distribution Interface (FDI)
LA	=	loop length in the branch feeder
LE140	=	140 Mbit/s optical line terminal pairs
LG	=	route length in the distribution area
LH	=	average length of final drop (drop segment)
LL	=	total loop length
LLHK	=	loop length in the feeder cable
LLVZB	=	loop length in the distribution area
LS	=	loop length in the main feeder
LSF	=	peak load factor
LTG	=	line trunk group
LWL	=	optical fibre
M_Asl	=	number of sleeves per subscriber line
m_{ij}	=	number of distribution areas in a quadrant j of an access area i
$MUX_{x/y}$	=	multiplexer pair at a given multiplexer stage
n	=	number of access areas in the local network
N	=	number of lines / channels
ND_u	=	average economic-technical lifetime of the asset category u

OF	=	type of surface
P_Band_m	=	cost of marker tape per metre
P_BHCA	=	cost of an additional 1,000 BHCA traffic load
P_CP	=	base price of the CP in a local exchange
P_DLU	=	cost of a Digital Line Unit (DLU)
P_EVz	=	cost of an SDI
P_GF_m	=	cost of 12-fibre optical fibre cable per metre
P_GrE_m	=	civil engineering costs per metre for buried cable installation
P_GrK_m	=	civil engineering costs per metre for conduit systems
P_HVt_DA	=	cost of MDF per wire pair
P_HVt_Fix	=	base price of an MDF
P_Kabel_fix_m	=	fixed cost per metre of cable
P_Kabel_marginal_m	=	price per metre of wire pair
P_KN	=	cost of a switching network element for 120*2 Mbit/s
P_KVz	=	cost of a Feeder-Distribution Interface (FDI)
P_LTG	=	cost of a Line Trunk Group (LTG)
P_M	=	cost of a tap (sleeve)
P_MUX	=	cost of a multiplexer pair
P_Rohr_m	=	cost of duct per metre
P_Schacht	=	cost of a manhole
P_Schutzhaube_m	=	cost of protective hood per metre
P_SLMA	=	cost of an analogue Subscriber Line Module
P_SLMD	=	cost of a digital Subscriber Line Module
P_ZWR	=	cost of a regenerative repeater
PK_PQ	=	number of residential lines in a grid square
PK_VZB	=	number of residential lines in a distribution area
Q	=	quadrant
R	=	interest rate on debt
Res_Fkt	=	spare capacity factor in the interoffice network
$Res\_Fkt\_DA_{HK}$	=	economic spare capacity factor for wire pairs in the feeder cable
$Res\_Fkt\_DA_{VZB}$	=	economic spare capacity factor for wire pairs in the distribution cable
s	=	number of local exchanges in the local network
SLMA	=	analogue Subscriber Line Module
SLMD	=	digital Subscriber Line Module
SX	=	X coordinate of the core of a distribution area
SY	=	Y coordinate of the core of a distribution area
T	=	effective corporate income tax rate
TAE	=	telecommunications plug and socket
t_a	=	number of remote concentrators attached to $TVSt_a$
TRes_Fkt_DA	=	technical spare capacity factor for wire pairs
TVSt	=	local exchange
VK	=	junction cable
VZB	=	distribution area
VZB-Typ	=	type of distribution area
X_i	=	X coordinate of the main distribution frame
X_{ijk}	=	X coordinate of the feeder-distribution interface of VZB_{ijk}
X_{or}	=	X coordinate of the upper right corner of a distribution area
X_{ul}	=	X coordinate of the lower left corner of a distribution area
Y_i	=	Y coordinate of the main distribution frame

Y_{ijk} = Y coordinate of the feeder-distribution interface of VZB_{ijk}
Y_{or} = Y coordinate of the upper right corner of a distribution area
Y_{ul} = Y coordinate of the lower left corner of a distribution area
ZG = number of ducts
ZWR = regenerative repeater

List of Indices:

a = index of the local exchange, where a = {1...s}
d = index of the main distribution frame, where = $\{0...t_a\}$
i = index of the access area, where i = {1...n}
j = index of the quadrant, where j = {1...4}
k = index of the distribution area, where k = $\{1...m_{ij}\}$
l = index of the wire diameter, where l = {1(0.4mm); 2(0.6mm); 3(0.8mm)}
u = index of the capital asset category, where u = {1...z}

1. Introduction

The German Telecommunications Act (TKG) of 25 July 1996 requires the charges for interconnection and other special network access, along with other charges, to be based on the costs of efficient service provision.

A provider of telecommunications services requiring special network access will purchase intermediate inputs from another company. It is clear that new network operators and other service providers will be reliant on such inputs from Deutsche Telekom AG (DTAG) to a significant extent. This is particularly true in the local loop, as building an alternate network here, delivering calls on the last mile, would take considerable time and would not always make economic sense.

The possibility of purchasing intermediate inputs at cost-oriented prices is designed to ensure that new providers are not unreasonably hampered in their competitive opportunities through a lack of network infrastructure of their own. Where such input is not offered within a competitive framework, regulatory rulings must create a situation mimicking the workings of a competitive market. Hence costs and prices should comply with competitive criteria. This ensures that new infrastructure will only be built where services can then be provided at lower cost than on the basis of the existing network. An economically inefficient bypass of the facilities of the incumbent will be avoided. At the same time, rigorous cost orientation will guarantee that new competitors' service offers are not subsidised by the incumbent provider. Such subsidising would then also lessen the incentive for new operators to invest in their own infrastructure in cases where this promised efficiency gains, in dynamic terms at least. Cost-oriented price regulation within the meaning of this costing approach provides incentives for a regulated network operator to produce efficiently.

The great relevance of interconnection charges to players' costs and revenues and to the evolving dynamics of competition requires the regulator to find a benchmark with reference to which these charges can be determined, ie the cost statements appraised, and which, on account of its simple, clear structure, makes rulings transparent and verifiable in order thus to achieve broad acceptance for them, at least with regard to how they have come about.

Costs of efficient service provision can first be established, as a general rule, with reference to business accounting. The advantage of this approach is that data is, in principle, available and complete. Problematic however is the historical base of cost accounting data that we observe in many areas and that may run counter to the cost efficiency sought, as it is not certain whether the particular company has produced efficiently in the past. Where appropriate, the cost accounting data should be adjusted for inefficiencies. Costs must also be allocated on the principle of causation, where reasonable. Such allocation presupposes the use of activity-based costing, a method that appears suitable primarily in divisions requiring large numbers of staff. Only the so-called non-volume-sensitive common costs that can no longer be allocated should and must be apportioned to the individual products by means of other methods.

From the regulatory point of view, a valuation procedure based solely on cost accounting data is problematic not least because the decisions can only be publicly substantiated to a very limited extent, given the high sensitivity of the data submitted.

Interconnection costs are primarily determined by the capital costs of the fixed assets and related operating costs. Analytical models by means of which network operation is replicated and the costs of individual services or network elements are identified can be used as well as conventional cost accounting to establish these costs, and generally to support telecommunications companies' financial and product strategic policy. Such models are also a useful tool for the Regulatory Authority in preparing and substantiating its rulings.

We will introduce this alternative costing for local network infrastructure in the following chapters. The model described is simple, contemplating solely the essential facilities of a telecommunications network for purposes of special network access, that is to say switched narrowband interconnection and access to the unbundled local loop in the form of copper pairs.[2] It can be easily followed, all the relevant relationships between the input and output parameters being documented and hence accessible to critical debate. It is constructed in such a way as to allow costing on the basis of generic, ie non-company-specific, data but also to allow the inclusion of specific data, where available. Finally, it is sufficiently flexible for the impact of changed parameters to be assessed rapidly. Knowing these changes will enable the parties concerned to judge their possible implications for future regulatory rulings.

The cost model set out on the following pages represents an analytical approach which, on a generally accessible scientific basis, reduces the cost structure of telecommunications (local) networks to the relationships that are fundamental to costing. An open and critical debate is invited on the suitability of this reduction, the aim of such debate being to develop an acceptable methodology on which to base future regulatory rulings on the level of interconnection charges. We realise that the consensus we seek on the methodology cannot also mean a consensus on all the parameters incorporated in the model. Such a consensus, if possible at all, need only be reached in specific cases. Mostly, however, a ruling from the Regulatory Authority will be required here.

The central part of this document is the following two chapters. Chapter 2 gives an overview of the costing methodology, including the network elements depicted, illustrating basic methodological questions, problems and areas for discussion. It becomes clear that a number of conventions concerning a suitable approach are required.

Following this basic description, Chapter 3 then explores in depth the structure of the model developed. Representation of the model is necessarily based on the conventions referred to above, about which searching questions should be asked in the subsequent public consultation procedure. Annex A features a list of topics for discussion, intended to serve as a guide for comments. Annex B lists the input data used in the model, about which data may be requested during the procedure.

2 Copper pairs permit the provision of subscriber lines with a bandwidth of up to 2 Mbit/s (with two pairs).

2. Costing by means of an Analytical Cost Model

Cost models reduce the complex process of producing telecommunications services to a manageable number of essential cost-determining relationships between the factors of production and the service offer. These relationships are defined in both technical and economic terms. The concept *model* implies that the algorithms used to determine the costs will be formulated generically, allowing cost accounting to use the same procedure for a theoretically unlimited number of cases that may differ from each other in respect of the variables underpinning them. It therefore makes sense to draw up a cost model in areas where, as with local networks, a number of individual cases need to be analysed or where parameters such as return on investment, period of depreciation or extent of spare capacity must be investigated with a view to their impact on the results.

The model described here focuses on the costs of the network infrastructure. These are the costs that account for by far the largest part of interconnection and other special network access services. The costs of technical equipment to provide interoperability between networks and the costs of special services to provide, say, a carrier preselection facility are not incorporated in the model, as these cannot be counted as network access services in the stricter sense and cannot therefore be part of the network access charges. The costs of distribution and customer administration in respect of special network access could be regarded as part of the charges in question. However, they are not regarded in this model as they are not determined by the extent to which network elements are used but by the nature of the customer relationship. In a general model addressing network operation, these costs are not accessible. Should allocation by origin not be possible without unreasonable effort, a mark-up on the costs of the network element could be considered.

The cost model does not permit non-volume-sensitive common costs to be established. Such common costs include costs that cannot be allocated on the principle of causation, either directly or indirectly. Common costs are only covered when they are capable of allocation to a group of (infrastructure) services such as, possibly, the cost of housing technical equipment. No reference figures are determinable for common costs arising at other production levels and not capable therefore of being related to the entirety of services addressed by this model. The aim of the model is to allocate costs by causation as direct costs, as far as possible, to the given network elements.

2.1 Long Run Incremental Costs of Service Provision

2.1.1 Long Run Incremental Costs

The Telecommunications Act in conjunction with the Telecommunications Rates Regulation Ordinance of 1 October 1996 calls for rates to be based on the costs of efficient service provision, derived from the long run incremental costs of providing service plus an appropriate mark-up for non-volume-sensitive common costs.

Benchmark for the long run incremental costs is the measure a company applies in deciding whether or not to offer a particular service in the marketplace. It will make sense to do so when the costs incurred in the long run by the decision to produce are at least covered by the revenues achieved.

The costs of an increment are the costs a company incurs in providing a service in addition to a portfolio of other services. They include all the costs directly or indirectly allocable to the service, ie they also include those arising as a result of indivisibilities in producing the increment. As non-volume-sensitive common costs are not taken into account in this study, they should appear in the form of appropriate mark-ups on the incremental costs in order to cover the total costs of the service portfolio.

The long-term nature of the decision to offer a product implies that the company can plan ahead in respect of the total volume of the increment and the capacity required for its production. Hence the increment should be interpreted as the entire marketable output of, in this context, a service offer or a network element.

The aim of price regulation is to establish a competitive measure in those areas where there is either no competition at all or where competition is insufficiently developed. A company operating in an environment of robust competition is forced to select that production process which enables a service to be provided at minimum cost. It must also ensure that no more resources than are absolutely necessary are used in a given production process. It then follows that §3(2) of the Telecommunications Rates Regulation Ordinance can be interpreted as the long run incremental costs being equivalent to the allocable part of the costs of efficient service provision.

The following sections explore this concept of costs as it is made calculable. The concept of long-term as it appears in the legislation implies that companies, in their decisions about production, are not subject to any restrictions imposed upon them say, by irreversible past decisions on investments and hence capacity. Assuming workable competition, a company's pricing flexibility in a situation in which there was unrestricted access to the market would be constrained by the costs of a potential competitor that, by definition, was subject to no restrictions in its choice of production process and decisions on capacity.

Such reference to the costs of an efficient potential new entrant is problematic, however, in that establishing such costs requires extensive knowledge of best practice production process. Yet sound knowledge of the performance and cost structures of innovative technologies will only be available after a certain time has elapsed, in other words after initial deployment in the marketplace and hence also after market entry has occurred.

Conventions representing a consensus on best practice technology as described above and ensuring the availability of sufficiently reliable information on which to base regulatory rulings are required in respect of the technology and network structure underpinning costing. It should also be remembered that the production processes and structures for decisions on offerings should also be relevant in a long-term perspective.

Against the backdrop of these conflicting demands, principles and conventions must be laid down on the basis of which the long run incremental costs of providing the service can then be established. These conventions primarily address the network structure underpinning costing. This encompasses the type, number and location of concentrators and exchanges as well as the kind of transmission and access technologies. It also concerns questions of the valuation and depreciation of the fixed assets, demand levels, capacity utilisation, that is to say spare capacity, and the relevant operating costs.

2.1.2 Costs of the Network Elements

Using the cost modelling described, the costs of the network infrastructure are established in relation to its elements. The telecommunications network is decomposed into elements defined by the functionality provided, such as switching and transmission. Offerings provided within the context of special network access are, by contrast, often described by the combined functionality of several network elements. The assumption is made in costing network access that the individual services are either equivalent to network elements or that their costs can be established by adding the costs of the network elements used. Element-based costing has the advantage that, in a simple and verifiable way, the costs of services can be coupled with the functionally defined elements actually used.

The element-based approach means that incremental costs are regarded as the costs of providing the entire network element quantity for which demand exists. Hence the costs of a network element are established as the difference between the costs of a network including the relevant element and those of a network not providing this element. Indivisibilities in providing the network element are therefore taken into account as a general rule, unlike with a marginal costs approach. The long run average costs of provision of the increment are therefore established with reference to one unit of output of such an element.

Where use of the network elements by various services can be attributed to a common denominator or, more precisely, to a common cost driver, the incremental network element costs must be allocated to these services in the same way. Thus local and long-distance calls use a local exchange in fundamentally the same way, specifically by occupying a channel, including the incoming and outgoing interfaces to the interoffice network and the access network. Identified as a cost driver is then the number of busy hour call minutes. By adopting the element-based approach it is possible for the fixed costs caused by indivisibilities, eg costs of the central processing units of the exchange or costs of trenches and optical fibre cables, not to be inappropriately registered as the common costs of several services but instead as allocable network element costs that, again by causation, ie according to use at peak periods, are allocated to the different services. In this sense the long run incremental costs of the network elements are the costs "common" to different services, but are not non-volume-sensitive common costs whose very distinguishing feature is that allocation by origin is not, in principle, possible.

Yet the existence of common costs at the network element level too cannot be ruled out. These include costs arising through the joint provision of several network elements. They could be the costs of a conduit system jointly used by feeder cables and junction cables. In these cases, consideration should be given to whether a common measure of use cannot be found by means of which the costs can be allocated. This measure could be, for instance, the number of pipes used with reference to which the civil engineering costs are allocated to the network elements. Only when a common measure of use cannot be found or proves unmanageable should other allocation mechanisms be considered.[3]

It must be emphasised again that only those costs that are not directly or indirectly - without unreasonable effort - allocable will be apportioned to the network elements by means of mark-up rates or other methods. In the example given the pipes can be directly allocated to the network elements, so that civil engineering costs, for the main part, will be divided between them.

Finally, it must be pointed out that there is potential for shared use between the elements of the voice telephony network depicted here and other networks. The shared use of buildings and other infrastructural facilities, notably trenches and conduit systems, is an example of such potential.

Shared use of infrastructure is conceivable between telecommunications networks for narrowband services (PSTN) and

- broadband distribution networks (cable TV),
- broadband overlay networks, and
- other utility networks (gas/water/electricity).

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[3] A possible procedure for common costs allocation is the Shapley method, which has the advantage of approximating a negotiating result between the sponsors of various projects about the distribution of common costs incurred. The Shapley value is determined by adopting an approach in which the sequence of projects to be carried out is considered uncertain and hence equally probable. Regarded as projects in this connection are, say, setting up routes for various utility networks. Depending on the sequence in which projects are implemented, different allocable costs are incurred for the individual projects: if only two projects are realised, all the direct and common costs in their entirety are assigned to the project that was implemented first, whereas only the incremental costs are allocated to the subsequent project. All such allocable costs are established for each project, in every possible sequence. The Shapley value is the expected value for the costs allocable to a project in this way. It is a conceivable cost allocation mechanism in particular for all cases in which traditional common cost keys lack the basis, that is to say roughly comparable output volumes. Use of the Shapley method in regulatory practice must be preceded, however, by a greater in-depth analysis of the concept and the potential for its implementation.

As economies of scale or scope can usually be realised such that the volume of investment only rises degressively as capacity is expanded, considerable savings potential can be tapped through the shared use of buildings, trenches and conduit systems. What we have said above applies to the allocation of these costs. The extent of shared use has a significant impact on the costs allocated to the telephone network elements. This is particularly true of outside plant, that is to say the access and the interoffice network.

The explicit modelling of shared infrastructure use between network elements and especially between different networks requires an information base that is not generally available. Any forward-looking approach would have to work on the assumption of joint construction by the network entities with maximum use of economies of scope.

In reality, we would expect the widespread use of potential economies of scope to be counteracted by the transaction costs being too high. On the other hand, however, it is equally unrealistic that economies of scope are not generally used and that supply and waste disposal networks are designed in principle as stand alone networks. Information from the network operators about existing joint production can shed light on the extent of shared use of the infrastructure. If, additionally, cost apportionment arrangements exist, these may be incorporated in the input for the model calculation, where appropriate. This could be done by reducing prices for civil engineering. In these cases, common cost allocation between the different networks will be anticipated by incorporation in the input data.

2.2 Costing Steps

Modelling begins with a definition of the nature and extent of all the services and facilities offered on the basis of the network infrastructure. In the local network these will be provision of subscriber lines, switching and transmission and, where appropriate, leased lines. The quantity to be provided is derived from the number of lines in the local network and from the resultant demand for telephone calls, each of which uses one switch at least. In many cases, transmission devices are also used in the local network. Demand parameters enter the model as exogenous quantities. This has to be considered a simplification, as demand depends on the price asked. To the extent that price itself is based on cost, we have - from the technical point of view - a so-called simultaneous equation problem. Specifying demand as an exogenous quantity is unavoidable when demand, as is the case here, cannot be modelled "simultaneously" as a function of the rates, which in turn are dependent on the costs.

The next step identifies the investment volume required to build a local network infrastructure capable of satisfying demand as defined above. Account must be taken of both technical constraints and the efficient service provision requirement. To accommodate this, the following steps must be carried out - should several production processes and network structures be conceivable - for various technological scenarios and for a number of network structure variants, if determinations have not already been made in advance.

The investment volume identified is valued at the current prices of the capital goods. This reflects the calculations of a new entrant. For a company already operating in or about to operate in a competitive environment that has already taken investment decisions, the replacement cost is the parameter with which it must value the productive capital employed in costing and cost-based pricing, if it is to compete successfully. Using current prices to establish a standard of valuation for costs of efficient service provision will guarantee an economically efficient use of resources, especially because potential decisions on network-based market entry will not be distorted by different costing criteria from those providing and those requiring network access.

The investment values are converted into annualised costs. Account is taken of depreciation and expected return on productive capital employed and current operating costs. This is done with the aid of annualisation factors for depreciation, return on investment and operating costs that are of central importance to the results of operational cost accounting and in the application of analytical cost models. It will not be possible to avoid value judgements especially in fixing the depreciation periods and methods and appropriate returns on investment. While scientific methods can assist in such decision-making, they are no substitute for appraisals that, in a competitive environment, must be made by the management of the company, but here ultimately by the Regulatory Authority. Such decisions can and should be preceded by a debate involving the parties concerned. Additionally, international benchmark data may be consulted.

Annual costs are given for network elements such as subscriber lines, exchanges and transmission lines. Costs of conveyance, that is costs arising from the use of network elements dimensioned for expected traffic demand, are caused by keeping capacity available for peak loads. Hence initially, these costs can only be established as the annual costs of providing capacity, measured roughly as the traffic volume handled, with a certain loss probability, in the busy hour on which the dimensioning is based (busy hour Erlangs). Conversion into costs per minute is effected on the basis of procedures and conventions detailed in section 0.

The costs of interconnection result from the total costs of the network components used. Where appropriate, factors stating the statistical frequency with which a network element is used to provide a defined service should be applied. Costing is then performed in relation to one local network. Where average values are to be established at a higher aggregate level - countrywide, for instance - the network element costs of the separate local networks must be averaged and weighted appropriately on the basis of subscriber statistics or traffic volumes. Where costs are established by sample, the underlying assumption here, it must be guaranteed that the networks contemplated are representative in terms of factors such as line density or number of subscribers.

2.2.1 Definition of Demand

A total of four demand parameters must be determined for the modelling: the demand for subscriber lines, busy hour traffic demand emanating from these, including calls to and from interconnected networks, the number of busy hour call attempts and, where appropriate, the number of leased lines in different sections of the network. Information on all demand variables may be requested from network operators and, where it would appear useful, from other telecommunications service providers. In the following it is assumed, however, that this data is not available initially, so that recourse must be had to generally available data sources.

In identifying demand for subscriber lines, the problem arises that it is not only the number of lines per local network that is relevant; rather, the geographical spread of demand is a central factor in costing the access network. Given the high degree of residential telephone penetration, demographic statistics can serve as a starting point for estimating demand. This data is available for a number of federal states in the form of the so-called *Wohnplatzstatistik* for levels of aggregation according to city districts, enabling a sample that is representative of the demographic structure of the Federal Republic. A complete survey is not possible with the unrestricted data currently available. The number of households identified are assigned to the populated areas within a local network and weighted with subscriber density. Also included are lines used for business purposes, added in the form of mark-up factors and differentiated according to population density, so that subscriber density rises progressively with population density. In accordance with our assumptions, the kind of line has no bearing on the configuration of the access network as both analogue and digital connections can be realised over copper pairs. Differences in cost result from the network termination on the customer's premises and from the line cards at the exchange. These can be established and considered separately.

Regarding statements of anticipated traffic per subscriber line, publicly available statistics or international benchmark data can be used as guides. It is also possible to draw conclusions from the planning targets of the equipment manufacturers. This is true of holding time and the number of call attempts per busy hour. The greater traffic demand from business lines must be taken into account here. The result is that the network nodes in industrial centres will show a disproportionately greater volume of traffic on account of the higher share of business traffic. As nothing is said here about suitable tariff structures for the different services, it is enough to know about aggregated demand in the busy hour and not necessary to know the exact progression of the daily traffic curve. It is important to remember that it is not necessarily demand in the average busy hour but a figure above this, between average peak load and monthly or yearly peak, that may be decisive in dimensioning the switched network. The appropriate level of this mark-up should be subject to debate.

Leased lines must be taken into account in costing, being produced together with the subscriber lines, so that part of the costs of the access network, that is to say the transmission lines, is allocable to them. A pragmatic allocation procedure would consist in leased lines bearing a share of the costs of the access and the interoffice network matching their percentage share at the level of the wire pairs in the access network and at the level of the 2 Mbit/s digital connections in the interoffice network. These shares must be ascertained in the light of experience until data from the network operators is available. Explicit costing for leased lines is not intended.

2.2.2 Investment Volumes for a Generic Network

After the demand parameters have been identified, the nature and extent of the investments required must be determined. This presupposes a definition of a generic network, discussed below.

With forward-looking perspectives, network operators often have choices about which production process to implement. These choices relate primarily to the underlying technology and to the network node locations. Such decisions are interdependent. Given equivalent output, the deciding factor is the costs caused annually by the processes available. Comparing investment totals is not sufficient on account of different depreciation periods and differing levels of operating costs.

A typical decision between various network topologies may be described as follows. Local networks can be built with a large number of network nodes, ie exchanges and remote concentrators and, as a result, shorter line lengths, or with a smaller number of nodes and accordingly longer line lengths. The trade-off between savings in the access network through short cable and line lengths and higher costs for maintenance of the nodes and transmission technology must be borne in mind. Regarding the technology to be deployed in the transmission and in the access network, there are alternatives in the shape of copper cable or optical fibre, chiefly in the feeder cable section.

Establishing minimal cost networks presupposes that complex optimisation problems have been resolved. The greater the degree of freedom, the more complex the procedures for finding solutions will be. Any optimal solution will always be determined by the characteristics of the underlying input parameters. A change in one figure, say the expected rate of return, will have an immediate impact on the optimal solution being sought.

The decision about the degree of freedom allowed in determining the generic network is a decision of principle for the regulator. The two poles between which the convention ultimately chosen will fall are complete network optimisation on the one hand, accommodating all the technologies that have reached deployment maturity, and the complete replication of the existing networks of the regulated company or companies on the other.

No matter what is chosen, it would make sense to guarantee the stability and predictability of the costing methodology in the medium term, even when the input values change, by retaining unaltered for some length of time after its initial definition the generic network and hence the assumed production process, especially with regard to the technology and node locations, for the purpose of price regulation. The impact on efficient service provision costs of changes in the parameters occurring during this period, such as changes in the price of capital goods or in demand, should then be established on the basis of this generic network. This approach will give those concerned confidence about future regulatory action in that the results of bottom up costing, given anticipated changes in parameters, can be calculated in advance. All the same, the generic network must be reviewed at regular intervals, such review having been announced beforehand, to ensure that any changes in the technical, operational and economic framework conditions are taken into suitable account in the network configuration and hence in the costing.

To what extent the DTAG network or that of another network operator represents the generic network must be discussed within the framework of consultation. Specifying the technologies and node locations means that what is to be regarded as a method of efficient service provision is shifted from the results of an optimisation process into the assumptions underlying the model calculations. Hence these constraints must always be clearly marked and made the subject of a critical debate.

Development of the cost model as described below has made it essential, not least for reasons of clear and informative documentation, to agree a number of conventions to this end. Thus the model is not based on any comprehensive optimisation approach. The assumptions about choice of location and technology represent estimates in respect of the production processes that, in the medium term, are efficient and relevant to network planning for switched narrowband conveyance and subscriber lines. The most important assumptions are as follows:

- The locations of exchanges and concentrators are specified in advance, as the potential for restructuring, in the long run, too, is limited, especially as regards the access networks. The location issue would, moreover, be extremely complex as there are a number of choice constraints that would have to be borne in mind. It appears plausible that location choices are basically determined by anticipated subscriber density, so that network nodes are sited mainly in centres of population. Due to the dominating influence of access network costs on the total local network costs, this can be considered as approaching the optimum.
- The access networks will rollout as copper networks, in line with the assumptions. The relevant technology is largely standardised and proven, unlike optical access networks or wireless technologies. Copper wires will continue to provide the numerically dominant type of connection in the existing access networks in the foreseeable future. Even if other options are likely to be provided for customers requiring large bandwidth, copper wire will still be relevant for the majority of residential customers as well as for the small and medium sized business customers in the years ahead.
- Switching is based on digital switching technology. Analogue switching was completely phased out of the DTAG network at the end of 1997 and will play no more part there or at other network operators. Packet switching and transmission using ATM is still in the test and introductory phase. Reliable cost estimates are not therefore possible.

- The interoffice network is built in plesiochronous digital hierachy using optical transmission technology.[4] This produces a star-shaped network between the local exchanges and concentrators and a meshed network between and among the local exchanges themselves.

2.2.3 Cost of Capital

In order to determine the annual costs of providing the network elements the cost of productive capital employed must first be established. The high capital intensity of telecommunications network operation makes this cost block the major factor in the cost of the service offer. The cost of capital is established in three stages. Firstly, the productive capital is valued. Benchmark is the replacement cost of those capital goods that would have to be acquired in a forward-looking approach to provide the functionality of the network element in question. Departure is only made from this convention to the extent that the definition of the generic network provides for the use of other capital goods. Departures from the principle of the latest available technology are justifiable where it becomes clear that large-scale deployment of this technology cannot be expected in the given network in the reference period or where new technologies are being deployed for the main purpose of offering services other than plain telephony now and in the future. These determinations must be transparent and should be made the subject of discussion.

The second stage specifies the depreciation periods and methods for various groups of assets. And finally, the expected return on capital employed must be established.

2.2.3.1 Valuation of Capital Goods: Replacement Cost

Essentially, two different approaches are put forward in response to the question of what basic value to apply in working out the cost of capital: firstly, the purchase cost or cost of production of the capital goods at the time of purchase (historic cost) and secondly, the replacement cost or market value as the price payable at the time of valuation (current cost) in order to replace the existing assets with ones of the same nature and quality, serving an equivalent function, in their new state, ie without consideration of the loss in value that has occurred.

As data on investment expenditure has generally been documented in the past in fixed-asset accounting, the historic cost approach is regarded as the easier of the two to carry out. This is also a fundamental reason why most established telecommunications companies still opt for this method.

However, the decisive argument against valuing assets at historic cost is that it is in clear contradiction to the forward-looking costing desired by the regulator and also regarded as appropriate in a competitive environment. Only costs that are established under forward-looking assumptions can provide a suitable basis for efficient pricing.[5]

Application of the current cost principle is often seen as problematic when there is a decline in the price of the assets over time. This is observed with telecommunications systems in particular, which can rapidly become obsolete. The objection is made that companies must bear 100% of the historic costs in money terms and that prices based on lower current values would not cover these costs. Yet this argument is only valid insofar as it is concerned with price changes that have not been anticipated. The decrease in value caused by anticipated price changes can be written into the annual depreciation by adding the loss in value caused by the price decline to the amount of depreciation

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[4] See footnote 6 on this.

[5] Cf the comments of the committee of experts at the BMPT: "The reason the principle of current cost accounting should be used is because only the current prices and not the historical purchase costs reflect prevailing scarcities and can thus serve as signals for the efficient use of resources." (Federal Ministry of Posts and Telecommunications: Basic Considerations on a Cost Benchmark for the Eligibility for Approval of Monopoly Tariffs, Information Series on Regulation Issues No 10, Bonn, May 1993, p 27).

calculated on the basis of the replacement cost. This yields, in each period, an amount of depreciation composed of the loss in value as a result of the time factor and the loss in value as a result of the price decline.[6]

The aim of the model is to identify what constitutes costs of efficient service provision. It follows that, mindful of the above constraints, only the efficient technologies of those currently deployed in production will be used to underpin costing. Normally, the current prices for these technologies should be available. Difficulties will occur in those cases where the technology underlying the model's assumptions no longer has any place in future investments or is only considered for limited-scope reinvestment. It may be necessary here to establish current prices on the basis of replacement prices or to index the start-up installation prices.[7]

2.2.3.2 Depreciation

The question of a suitable depreciation method is concerned with spreading the value of an asset over the entire period of its economic life during which revenue streams are generated. Hence calculations are based on the actual economic-technical lifetimes of the assets, ie there may be variations in economic life as prescribed by fiscal and commercial law. Expectations are therefore created about the likely economic lifetime of an asset - or, for pragmatic reasons, a class of assets. The depreciation method must then be fixed, whereby four options are possible:

1. Straight-line depreciation is the most common method. It produces depreciation charges that, related to the *real* value of the asset, are constant. When current costs are applied, there are annual changes in the nominal charges, however, on account of price development for the given asset.

2. Variable rates in the real depreciation charges take account of developments that make straight-line depreciation appear inadequate. With the declining balance method of depreciation, the rates are highest at the beginning of the depreciation period and fall from year to year. This method is primarily used when, for reasons of caution, most of the depreciation is to be charged off in the early stages of use.

3. With the increasing balance method of depreciation the reverse holds; the rates are lowest at the beginning of the depreciation period and rise from year to year. This method could be chosen if it was important to show that an asset can only be fully utilised after a certain time, due to the growth in demand anticipated, and depreciation is to be recorded as a function of use. The increasing balance variant is hardly used in accounting practice, however.

4. Under economic depreciation the annual depreciation charge is calculated from the difference between the net present value of the asset at the beginning and end of the period. As the net present value is derived from the total anticipated cash flows from use of the asset, discounted up to the given point in time, all the relevant influences must feed into the calculation. In other words, the expected development of demand, of technological advance, of general price development as well as other factors are relevant determinants of the depreciation rate in this method.

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6 The procedure is comparable in the case of an increase, instead of a decline, in prices; depreciation charges based on replacement costs are reduced by the increase in the value of the asset as a result of the price increase.

7 This does not run counter to the efficiency requirement. For instance, PDH-based equipment was initially used for digital transmission technology. Meanwhile, network rollout and presumably reinvestment, too, when this affects a sufficiently large segment of the network, is effected with the more modern SDH technology. All the same, it is proposed that costing continue to be based on the PDH technology for the offer of narrowband services in the local area in the absence of proof of its inefficiency.

In line with the provisions of fiscal and commercial law, companies mostly use the straight-line or the declining balance method of depreciation in their fixed-asset accounting. Practicability then often dictates that the corresponding figures are used, unchanged, in costing; accordingly, there is no depreciation specifically for cost accounting purposes, ie differing from book depreciation.

Under the aspect of cost allocation that is based as closely as possible on the principle of causation, economic depreciation is generally preferable to the other methods. For a start, it is unrealistic that an asset will always yield its overall potential in rates that are constant from year to year (straight-line depreciation) or in steadily decreasing annual rates (declining balance depreciation). Fluctuations in output over time, triggered, for instance, by changes in demand, will not be recorded. Furthermore, a rigid straight-line or declining balance depreciation would make no allowance for an asset prematurely aging as a result of technical innovation, whereby both its remaining lifetime and its earning power would be diminished. As all these factors are taken into account in economic depreciation, it must be regarded as the most suitable method for allocating asset costs to economic lifetime following the principle of causation as closely as possible.

Yet economic depreciation is very demanding in terms of the data required. If the method is to be used consistently, all the factors affecting the asset (future price development, development of demand, technological advance, etc) would have to be estimated for the remaining lifetime of each and every asset and incorporated in the calculations. Also, this data and these assumptions would have to be revised and possibly adjusted at regular intervals.

Besides the arguments of transparency and practicability we have cited, another point in favour of straight-line depreciation, one of the two traditional methods, being applied to this model is that it closely approximates economic depreciation in practice. This is true when, as we depicted in the previous section, the current cost principle is applied and changes in asset value resulting from price development are taken into account. Assuming that the procurement markets for telecommunications systems have largely competitive structures, we can then assume further that the impact of the above factors on the net present value of an asset has been taken at least into approximate account in the prices. Additionally, straight-line depreciation can be regarded as the average annual depreciation charge over the entire depreciation period. As we are using a generic model for the local network that is representative of the "average" of a large number of local networks, it is appropriate for the model to use the average depreciation charge for all local networks, irrespective of the particular depreciation method used.

If, following this approach, the assets are then valued according to the current cost principle, the average will roughly match the depreciation charge produced by the straight-line method. This charge is presumed to have been adjusted by a figure reflecting the rate of price changes for the asset in question. Adjustment is downwards when the rate of price changes is positive and upwards when it is negative. Accommodating the rate of price changes in the depreciation charge accords with the use of a "real" rate of interest which is required when assets are valued at replacement costs. With a rising asset price the real rate of interest is lower, and with a falling price it is higher than the nominal rate of interest. The latter approach is followed in determining the cost of capital in the model.

Uncertain expectations of future development can also be modelled without the use of the economic depreciation method. This can happen when the depreciation periods are varied for the different asset categories in a number of scenarios. In this way the calculations then reflect that the economic lifetime of an asset can be shortened, say, by technological advance or lengthened as a result of shifts in demand, leading to changes in depreciation charges.

Accordingly we may conclude that straight-line depreciation based on replacement costs is adequate for our modelling purposes. This assessment is borne out by the findings of a comparative study by Oftel[8], in which use of the straight-line method was not found to produce any systematic bias.

2.2.3.3 Expected Return on Investment

Companies usually estimate the cost of interest on the capital tied up in the assets as a fictitious amount. This means that it is not the figures from financial accounting, ie the interest actually paid, that are used; rather, it is assumed that the entire corporate assets are financed by the entire equity and debt capital employed. This idea stems from an opportunity cost concept: although the company has no interest expense on equity employed, it should not be forgotten that it should generate at least an annual rate of return on an alternative investment outlet, so that the equity holders do not go elsewhere. The cost of capital is then derived from the weighted sum of the expected rate of return on equities (before corporate income tax) and the average interest rate on debt.

For some years now, preference has been given to the Capital Asset Pricing Model (CAPM) to determine the expected rate of return, ie the interest rate on equity. Accordingly, the interest rate on equity results from the sum of risk-free interest rate and a risk mark-up. In this model, determining the company-specific risk factor sets high data requirements. An alternative approach for determining the interest rate could therefore be the Dividend Growth Method.[9] This approach, however, also sets high data requirements, as dividend development is estimated for several years in advance. Thus neither model, under the present conditions and from an external viewpoint, is practicable. As an alternative we would propose that the rate of return on equity be determined on the basis of network operator information, ie international comparisons. The rate of return on a risk-free security of average maturity, eg federal loans with a life of 4 to 6 years, can serve as a basis for determining the average interest rate on debt.

The expected return on investment and the depreciation rate are converted into an annuity using the capital recovery factor. The expected return is estimated on the average capital tied up during the economic lifetime of the asset.

2.2.4 Asset-Related Operating Costs

To be added to the direct capital costs of the stock of assets are costs arising from day-to-day operation of the telecommunications network. These are designated as OAM costs (operations, administration and maintenance). They can be recorded in a bottom up model, ie through an analysis of operating strategies, or by establishing factors on the basis of historic relationships between fixed assets and expenditure. Establishing them directly, say, by evaluating operating strategies for various assets such as digital exchanges, is complex. Use of factors set in relation to the investment amount can deliver reasonable approximations. They are derived by calculating the relationships between the company's fixed assets and its asset-related expenditure. Operating cost factors established in this way do not reflect any causal relationships, however, are always historic and may contain operating inefficiencies. This latter weakness would speak in favour of operating cost factors being established for various network operators and suitably weighted.

2.2.4.1 Activity-Based Costing

Deriving OAM costs "bottom up", ie in the same way as the direct capital costs, that is to say on the basis of technical or economic causality, accords with the fundamental approach of analytical cost

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8 Oftel: Network Charges from 1997, Consultative Document, London, December 1996, p 46.

9 Using this approach the rate of return on equity is derived from the formula $D = D_0 / P_0 + g$ (where D_0 = present dividend, P_0 = current share price and g = constant rate of growth of the dividend).

modelling. Proceeding thus allows the costs of efficient network operation to be established. It also allows these costs to be allocated on the principle of causation via an analysis of the cost drivers.

Given the complex workflows underpinning the operation of telecommunications facilities, the operation of a digital exchange for instance, modelling the operating costs with reference to previously identified cost drivers is likely to be tricky. Probably, it can only be accomplished by the systematic implementation of activity-based costing. It is recognised that the different processes taking place within a company will not always be available to the same degree for a detailed cost-driver analysis. In each case a trade-off must be considered between the costs of more precise cost allocation and the insights gained.

2.2.4.2 Historic Costing

The pragmatic and easily available alternative lies in recourse to operators' past expenditure, as far as this is broken down into asset categories, eg digital switching, transmission systems or buried fibre. This expenditure must then be set in relation to the fixed assets and incorporated in the model calculation as operating cost factors. In principle, the fixed assets can be valued at initial or replacement cost. As the model calculation is based on replacement costs, valuing the assets at current costs of modern equivalent assets (MEAs) makes good sense, provided the data available permits this.

Past operating costs, however, are caused by the historic stock of assets, which always covers a variety of degrees of obsolescence. Extrapolating these costs for future periods is therefore permissible only in the absence of better alternatives. On the one hand, technological advance in switching, say, tends to be accompanied by the substitution of operating costs in the form of payroll costs by investments in assets. Hence the operating costs required in the future in this and other areas will be lower than those of the past. On the other hand, however, we may expect, on balance, an increase in nominal operating costs in those areas in which the substitution of labour by capital proceeds more slowly. This applies, for instance, to buried cable infrastructure.

Yet prices for switching and transmission fall over time, whereas prices for cable installation tend to rise. These opposing trends would suggest that the relationship between fixed assets at historic costs and asset-related expenditure can be regarded as an acceptable approximation of forward-looking operating cost factors. Citing reasons for applying such factors to the replacement costs of MEAs is that replacement costs and forward-looking operating costs develop in proportion to one another.

When this method is followed, operating cost factors must be established for several network operators and suitably weighted. One of the best generally available sources of data is the FCC Statistics of Telecommunications Common Carriers (SOCC), an annual compilation of fixed assets, expenditure and a host of other statistics about the major US local telephone companies. This data can be compared with data submitted by companies operating in Germany.

2.2.5 Conventions for Converting Peak Load Costs (Capacity Costs) into Costs per Minute or per Event

The long run incremental costs of the elements of the switched network are the annual costs of providing peak load capacity, that is to say of busy hour Erlangs and busy hour call attempts. These costs are converted into costs per minute or per call set up, based on the convention that the costs of the network element are spread evenly over total output. The model assumes the existence of information on anticipated subscriber traffic in an average busy hour. In order to derive demand for the year as a whole from these traffic values it is necessary to know the relationship between busy hour demand and per day demand and also the relationship between per day demand and per year demand. The peak load capacity costs are then divided by per year demand, expressed, say, in terms of call minutes.

By contrast, rates for network access may well show differentiation with regard to time. This paper is not concerned with a discussion of suitable differentiation, however. We acknowledge that ultimately, agreed, ie approved, charges may contain elements of time differentiation which may be drawn up differently for the different services according to the per day and per week traffic curve. Nevertheless, it must always be ensured that charges for interconnection and other special access to the switched network are based on the costs caused by these services in the busy hour.

2.2.6 Usage Factors

Costs per unit of output, ie minutes or particular events (call set up) are established for each traffic-sensitive network element. The costs of services using more than one network element can be established by adding the costs of the separate elements used. For this purpose we need to identify for each element usage factors that state how many units of output from a given element are used in the production of one unit (ie minute) of interconnection. Usage factors depend on the network structure and on routing in the network.

The local network model described here defines two essential interconnection services, ie switched calls between a subscriber in the local network and an alternative operator: interconnection is provided either at an exchange in the local network or at an exchange in the long-distance network, whereby the traffic is routed from a defined point of interconnection in the local network to the destination exchange (or vice versa) along with the local traffic in a shared transmission medium.

In both cases, a usage factor must be determined for connections between the local exchange and a remote concentrator. This factor is calculated from the ratio of subscriber traffic originating or terminating in an access area connected to a remote concentrator, to the entire local traffic. In the second case, a usage factor must be determined for transmission systems in the local network that are used only when the calling/called party is not connected to the local exchange where the point of interconnection to the long-distance network is sited.

Where appropriate, usage factors must be determined in the same way for connections within the local network. However, a wider and more generalised calculation of usage factors for interconnection would require assumptions about routing not only within the local network but also at the level of long-distance network, which is not addressed in this particular model. Work is currently underway, however, on extending the cost model to the long-distance level.

2.3 Network Elements for Interconnection and Special Network Access

The network architecture described in the following sections, the network elements the architecture contains and how the elements are shaped form the basis of the cost model that is detailed and formalised in Chapter 3. The model as described is underpinned by the assumptions and conventions explored so far and given further concrete shape in what follows.[10] The object of study is generally the local network which can, in principle, be defined in various ways. The convention of working from existing network structures dictates that the point of reference will then be the network boundaries imposed by the provider, that is first and foremost DTAG. A sample calculation is assumed possible in respect of generating average values for the costs of the separate network elements for an operator's local networks in their totality. This sample is intended to be

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[10] This basic approach reflects in part the local network model as set out by Gabel and Kennet. Cf Gabel, David und Mark Kennet: Estimating the cost structure of the local telephone exchange network, Study for the NRRI (National Regulatory Research Institute, Columbus, Ohio), October 1991.

representative of the various network structures that are relevant to the level of interconnection costs.

2.3.1 General Network Architecture

The modelling approach we are describing assumes a local telecommunications network dimensioned for the provision of call oriented, narrowband services. This encompasses all services supported by a reference 64 kbit/s channel. The facility provided by the elements of the switched network is an end-to-end 64 kbit/s channel between the exchange of the calling and that of the called party. Subscribers not directly connected to a local exchange will have their calls begin and end at the first concentrating element of the network. This element is designated the remote concentrator or remote digital line unit. Switching functions are performed by digital exchanges. Optical fibre is used for transmission in the interoffice network. The long-distance level is not explicitly addressed. It is assumed that long-distance traffic is transferred at the local exchange and routed in the interoffice network with the local traffic over a shared transmission medium.

The facility provided by the elements of the access network is a permanent, subscriber-specific link between the network termination point at the customer's premises and the first concentrating element of the telecommunications network, realised over a copper network.

The technology deployed is therefore construed as given and will not undergo any further optimisation.

The provision of leased lines in addition to switched services can also be taken into account. No separate costing is undertaken for them. However, part of the costs of transmission lines and the access network may be allocable, since leased lines are assumed to be provided in conjunction with switched services. The share of costs allocable is estimated according to the share of wire pairs for leased lines in the access network in the total number of wire pairs and also according to the share of 2 Mbit/s leased lines in the total number of 2 Mbit/s digital connections in the interoffice network. The costs of switching equipment are not affected by the provision of leased lines.

The following sections describe the local network elements, underscoring those factors thought to have a significant impact on the costs computed. The relevance of purchase prices and of capital and operating cost factors is not stressed for each and every element. It applies generally to all elements described.

2.3.2 Access Network

The access network serves to provide transmission functionality between the terminal equipment and the termination point of the outside plant before the first concentration point, set up either at a local exchange or at a remote concentrator unit. As no concentrating units are addressed, the access network can be dimensioned independently of the individual user's traffic demand. A basic cost driver is the demand for lines in their geographical spread. The average costs of a subscriber line in the local network are fundamentally affected by subscriber density. High subscriber density enables economies of density particularly in infrastructural terms; conduit systems and trenches can be well utilised and loop lengths to the first concentration point are relatively short. Precise costing presupposes knowledge of geographical line distribution at a heavily disaggregated level. Local networks with the same average subscriber density may show substantial differences in costs on account of different settlement patterns, for instance greater or lesser line concentration in centres of population.

Other factors affecting subscriber line costs are the prices of materials and civil engineering, ie the prices for various kinds of installation (and their respective shares), which may also vary with the type of terrain and with the type of surface reconstruction. Regarding civil engineering costs, it would seem appropriate to take the averages of all the local networks studied. How this averaging is performed must be made transparent.

The access network is decomposed horizontally into the distribution network and the feeder cable network. The feeder cable network terminates on the line side with the main distribution frame. The feeder-distribution interface separates the feeder cable and the distribution network. The distribution network can be broken down further into the distribution cable network in the strict sense and the drop segment. The interfaces here are taps in the distribution cable. Also to be included in the costing is the in-house cabling including the plug and socket, whose interface with the drop segment is formed by the general network termination point in the shape of the subscriber distribution interface. Depending on the nature of the questions asked, the costs of exchange components that can be allocated by causation to the subscriber lines in addition to the access network may also feature in the study of subscriber line costs. Important in this context are the subscriber line interface modules, or line cards.

2.3.2.1 Distribution Network

The distribution network refers to the connection between the general network termination point on or at the subscriber's premises in the form of the subscriber distribution interface and the nearest cross-connection point at the ground level feeder-distribution interface. The in-house cabling providing the connection between the subscriber distribution interface and the socket should be looked at separately. Drops run from the subscriber distribution interface to the distribution cable, normally laid to follow the path of the street. Several drops are concentrated in a tap (sleeve) taking them on to the distribution cable. The distribution cables terminate at the feeder-distribution interface where they are connected to the feeder cable wires. Each feeder-distribution interface defines a particular distribution area. The surface area and layout of the distribution areas are determined in the model by editing subscriber line demand in its geographical dimension. The area of a local network is divided into square distribution areas with sides of 600m. In areas of high subscriber density the distribution areas are divided into two (600m x 300m) or four (300m x 300m). How the wire, cable and trench lengths are calculated is set out in Chapter 3.

Critical factors for the level of costs in the distribution network are the type of installation (buried cable, underground cable, aerial cable), the average length of drop, the number of lines that can be realised in one drop and the kind of surface to be reconstructed in the case of underground installation. All the parameters cited can be determined at the local network level and additionally differentiated according to subscriber density in the distribution area into a current total of three categories representing rural, suburban and urban areas. Finally, spare capacity in the form of unused wire pairs must be taken into account. Also important is the degree to which there is shared use of drops, trenches and underground systems between distribution and other cables such as coaxial cables for cable TV. The model does not take explicit account of shared use of the infrastructure by different network elements or networks, but contemplates the separate elements or network sections independently of one another and of other network structures. The potential for shared infrastructure use can currently be accommodated by price variations, for instance for civil engineering services.

2.3.2.2 Feeder Cable Network

The feeder-distribution interface and the main distribution frame are connected by feeder cable. Each main distribution frame and associated feeder cable and distribution cable network represents an access area. The basic cost factors correspond, with the initial exception of the drops, to those of the distribution area. Added to this is the fact that the entire length of the feeder cable network, unlike that of the distribution network, is determined by the location of the main distribution frames. Hence it is necessary to decide whether the locations (and the number of locations) should be determined, endogeneous to the model, as the result of cost minimisation rules or whether existing locations should instead provide the reference for the cost calculations. Both approaches can be followed in the modelling. The modelling described in Chapter 3 is based on given network structures and therefore presupposes that the locations of the main distribution frames in the local networks studied are known and can be used as the basis for the calculations of length. In the context of shared infrastructure use, interoffice cables are also relevant in the feeder section.

The structure of the feeder network is represented as follows. Each access area is divided into four squares, along whose bisectors a feeder cable route runs. At the distribution area level cables branch off at right angles from the feeder cable route, terminating at the feeder-distribution interfaces. The feeder cable network shows a tree topology. See section 3.1.6 for details of the relevant length calculations.

2.3.3 Local Exchange and Remote Concentrators

Feeder cables terminate in distribution frames from which the wire pairs are routed to the main distribution frame located at an exchange or a remote concentrator. The main distribution frame forms a cross-connection point connecting to the line cards, by means of junction cables, the wire pairs attached to the terminal equipment. The costs of the main distribution frame and the line cards can be fully allocated to the individual subscribers. Line cards are attached to digital line units in which traffic is concentrated on 2 Mbit/s digital connections with 30 user-information channels operating at 64 kbit/s. By virtue of their concentrator function the digital line units are, from the subscriber's point of view, the first traffic-sensitive equipment of the telephone network. The main distribution frame and the concentrators may be located at the exchange or dislocated from this. Remote concentrators are connected to the exchange by means of optical fibre. The uniform interface with the switching network is provided by the line trunk group, invariably located at the local exchange.

The switching network enables the incoming and outgoing channels to be connected in line with the calling party's wishes. Again, the line trunk group forms the interface with the 2 Mbit/s lines of the interoffice network between exchanges. The concentrators, line trunk groups and interoffice network elements are dimensioned as a function of traffic offered in the busy hour. Dimensioning is based on a loss probability by means of which the number of 2 Mbit/s lines required for a given amount of traffic offered is calculated with the aid of the Erlang loss formula.

Call set up takes place in the exchange. The signalling information is evaluated by one or more microprocessors, including control software. Here, the cost driver is not the expected holding time but the expected number of call attempts including those in which call set up to the called party is not completed.

The total costs of the switch are therefore determined by the number of subscribers connected and by the traffic these subscribers generate. Also relevant are the costs of housing, air conditioning, power supply and installation structures (false floors, racks) that cannot be apportioned either directly or in most cases, indirectly, to the cost drivers cited. Co-located with the local exchange or the remote concentrator unit is also equipment serving transmission purposes. Hence these costs are not part of the long run incremental costs of the given network elements. All the same, they should be taken into due account in the usage charges.

2.3.4 Transport between Remote Concentrator and Local Exchange

It is assumed that concentrator units dislocated from the exchange are connected to just one local exchange in a star-shaped topology. High-usage routes between remote concentrators are not looked at, as no switching functions are performed at the concentrator locations. Hence the entire traffic is routed over the local exchange. Transmission is by means of optical fibre. The transmission rate is 140 Mbit/s. This implies that the electrical 2 Mbit/s signals are multiplexed into a 140 Mbit/s stream before being converted into optical signals. At the exchange, the reverse route is taken down to the electrical 2 Mbit/s level. Opting for such transmission can lead to low effective capacity utilisation when the number of subscribers is very small or subscriber traffic figures are low. But on average, several thousand subscribers can be connected to the local exchange via remote concentrators, so that the deployment of optical fibre is justified in a forward-looking approach. It is also assumed that leased lines will feature in the transmission system, thus increasing the demand for 2 Mbit/s digital connections.

Aside from the terminal equipment, ie multiplexers and optical line terminals, the structure of the transmission line in terms of outside plant has a bearing on the costs. What was said about the various sections of the access network also applies here with regard to the costs of civil engineering and possible apportionment between the network elements.

2.3.5 Switched Transport between Local Exchanges

Any study of local network costs must include the interoffice network whenever the local network has more than one exchange. The interoffice network is relevant to the costs of interconnection services when transfer from a competitor's network takes place not at the local exchange of the called/calling party but at an exchange on a higher hierarchical level, so that transmission lines are possibly used within the local network.

Costing proceeds as follows for traffic remaining within the local network. It is assumed that the local network exchanges are fully meshed both at the level of the 2 Mbit/s digital connections and at the level of the cables, transmission systems and infrastructure. Traffic volumes on the connections are calculated by, firstly, the outgoing traffic of an exchange being reduced by the share classified as long-distance traffic. This share is fixed at the local network level. The traffic remaining in the local network is divided among the local exchanges according to its relative weight in total subscriber traffic. Consequently, some of the traffic remains in the exchange area of the calling subscriber. The number of 2 Mbit/s digital connections between two exchanges is calculated according to total traffic handled plus a share of the leased lines, whereby there is always symmetry in the incoming and the outgoing traffic between two exchanges owing to the underlying assumptions of traffic distribution. Additionally, the possibility of alternative routing in the event of the failure of a direct route can be taken into account in its impact on the costs of providing the service by increasing the number of 2 Mbit/s digital connections required between two points. This means a less effective degree of utilisation of the transmission facilities.

With a large number of exchanges within a local network, assuming a fully meshed state can lead to the costs of efficient service provision being overstated, as a direct physical link between all the exchange locations may not be justifiable even when the failsafe aspect is given high priority. It is difficult to assess the amount by which the costs could be overstated in any given instance. The local network reaches a critical size as from 4 or 5 exchanges. This number will easily be reached in many large local networks. Here, the investments in infrastructure and in transmission facilities will possibly have to be scaled back suitably so that the shared use of transmission systems and infrastructure by several logical connections can be recorded.

2.3.6 Switched Transport between Local Exchange and Local Network Boundary

Since it is only elements of the local network that are addressed in the model set out here, it is necessary to find a suitable definition for the boundary with the long-distance network, the next level. It is assumed that incoming and outgoing long-distance traffic is routed within the local network together with the local traffic, in shared transmission systems. The interface with the long-distance network is either an exchange with long-distance switching functions co-located with a local exchange, or a likewise co-located transmission facility representing the termination of a transmission link to a long-distance exchange. Solely the costs of transport in the local network are recorded. Assuming a co-located long-distance exchange, these costs will correspond to the costs of the transmission segment between the long-distance and the local exchange.

3. The Logic of Costing

This section details how the costs of local network elements are determined. Particular significance is attached to describing the various calculation steps as generally as possible, irrespective of whether the model is actually implemented as a computer programme or a spreadsheet. The perspective of an external observer is adopted in the modelling process in order to develop the basic relationships between input and output parameters that are relevant to local network costs. This is done on the basis of generally available economic and technical knowledge and, as far as possible, generally available data. This approach allows model calculations to be made without necessarily having recourse to company-specific information. Where information is submitted by companies affected by regulatory rulings, it can, if appropriate, be integrated in the modelling or included as an input parameter in the calculations.

3.1 Preliminary Work to Determine the Investment Volume

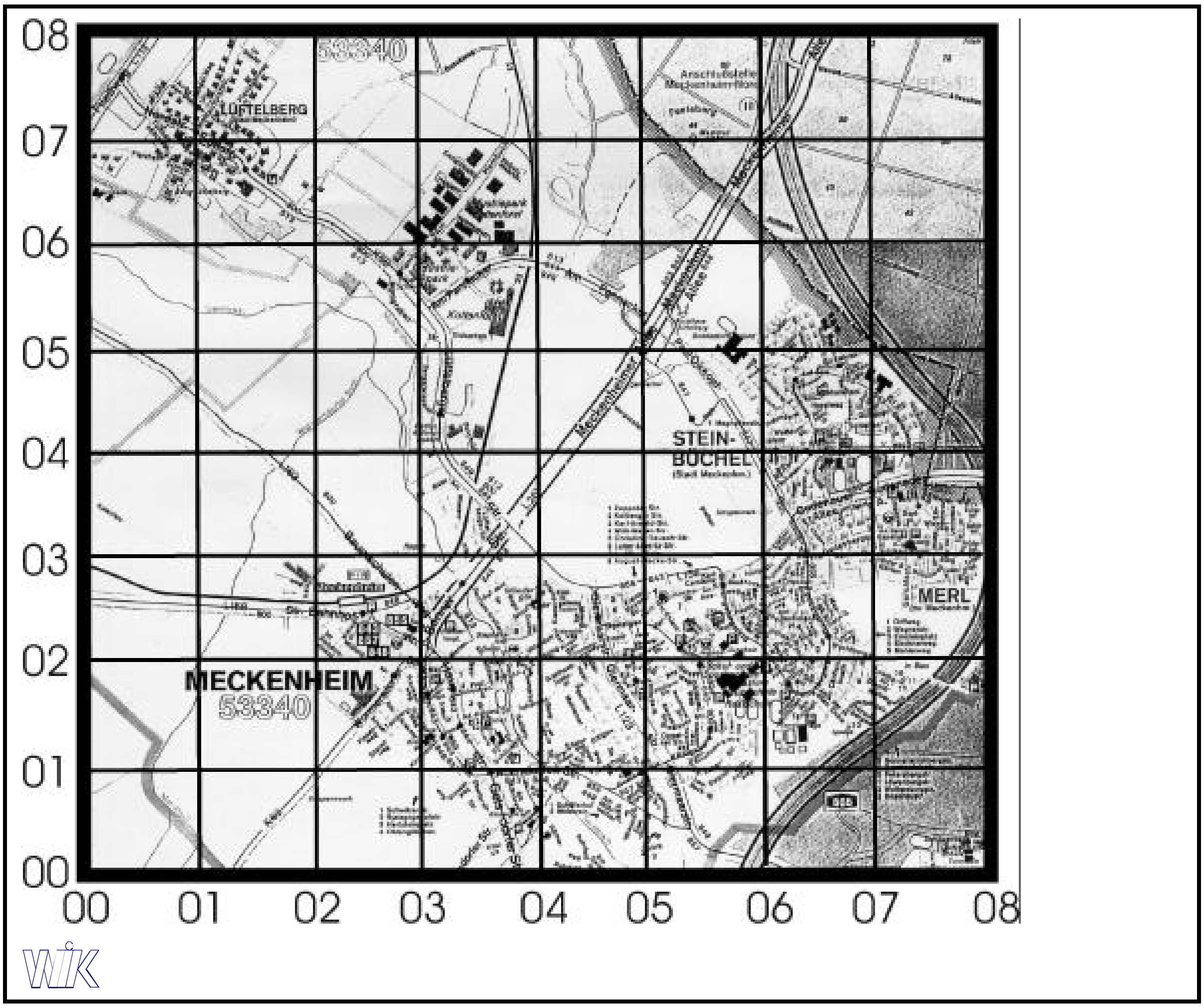
Costing the network elements is based on a number of steps, described separately for more clarity. These steps include for instance the allocation of subscriber lines to distribution areas, feeder sections, main distribution frames and local exchanges. In addition, 2 Mbit/s equivalents are determined for transmission links in the local network and capital and operating cost factors identified. Specifically, this means the following:

- dividing the local network area into distribution areas (VZB) (section 3.1.1);
- establishing the demand for subscriber lines in the individual distribution areas (section 3.1.2);
- dividing the distribution areas into types (section 3.1.3);
- allocating distribution areas to main distribution frame sites to determine access areas (ASB) (section 3.1.4);
- allocating the distribution areas of each ASB to feeder sections (quadrants) (section 3.1.5);
- calculating the lengths of feeder and distribution cables (section 3.1.6);
- establishing the wire pair diameters to be used in the access network (section 3.1.7);
- establishing the number of wire pairs in different network sections (section 3.1.8);
- establishing the traffic volume for access areas (section 3.1.9);
- establishing the traffic relations between nodes in the local network (section 3.1.10);
- establishing the number of DSV2 digital connections for transmission in the local network (section 3.1.11);
- establishing the lengths of junction cables (section 3.1.12);
- and finally, establishing the capital and operating cost factors (section 3.1.13).

3.1.1 Dividing the Local Network Area into Distribution Areas

Cost calculation is based on individual local networks. Here, the geographic boundaries of an operator's local network or other limits, eg municipal boundaries, may serve as a benchmark. A grid with sides of 600m x 600m is applied to the whole local network area. Each grid square represents a possible distribution area. The lower left corner of the grid is interpreted as a coordinate origin, allowing each point of the local network to be identified by its horizontal and vertical distance to the origin. Fig 3.1.1-A shows such a grid schematically.

Figure 3.1.1-A: Division of a Local Network Area into Grid Squares



3.1.2 Establishing the Demand for Subscriber Lines in the Individual Distribution Areas

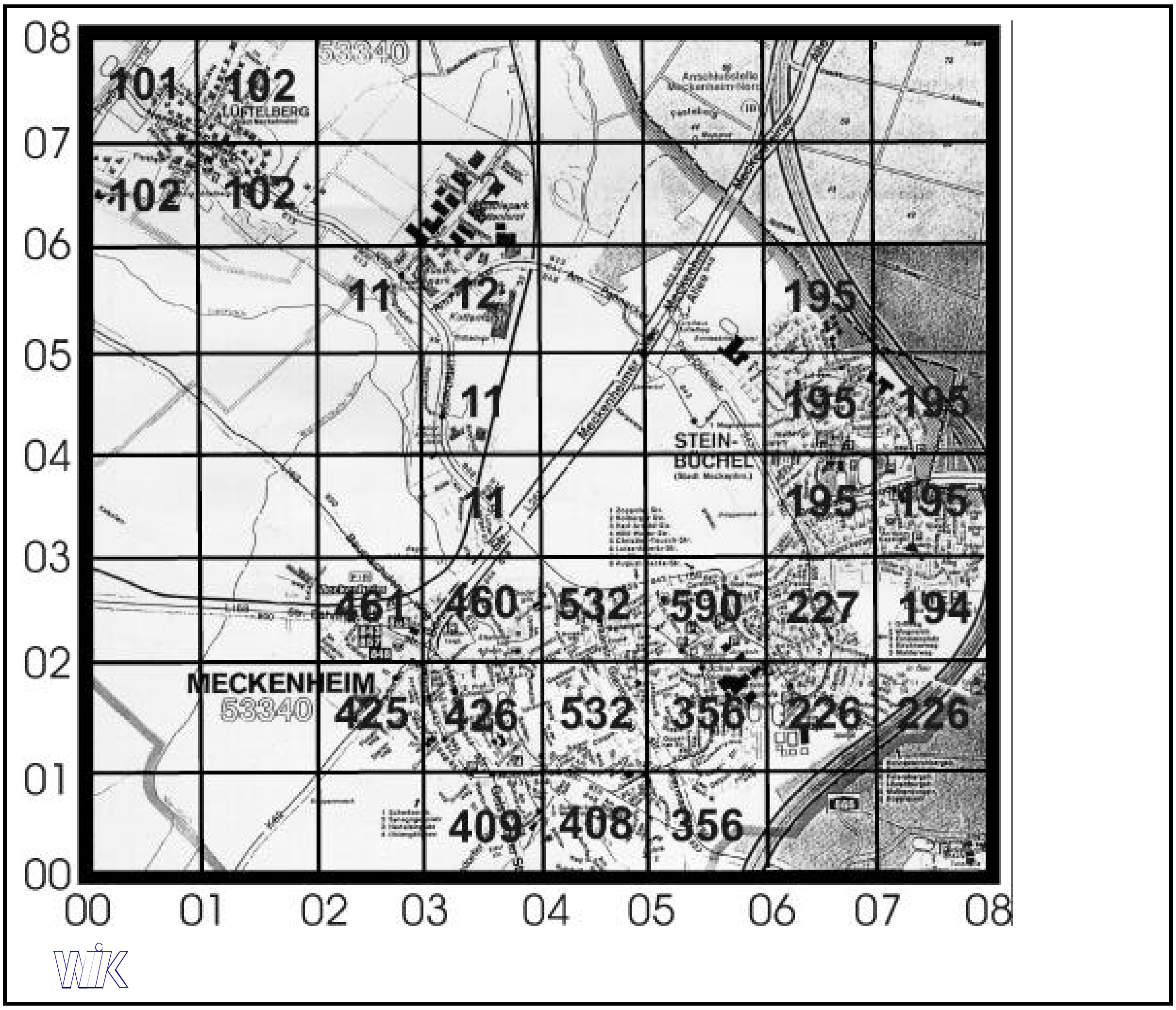
Demand for subscriber lines is established on the basis of demographic statistics on the number of private households, the so-called *Wohnplatzstatistik*, corresponding roughly to city districts.[11] Such districts are identified in the local network plan. Built-up grid squares are then determined for each district. The number of private households per district is distributed equally among the squares marked as built-up. It is assumed that the demand for residential telephone lines corresponds to the number of private households
(cf Fig 3.1.2-A).

[11] This data is currently available to WIK for the federal state of North Rhine-Westphalia.

Table 3.1.2-a: Extract from the *Wohnplatzstatistik*

Administrative District	**Private Households**
Meckenheim, Stadt	7,267
Lüftelberg	407
Merl-Steinbüchel	1,169
Alt Merl-Lehmwiese	679
Meckenheim-Stadtkern	590
Meckenheim-Südwest	851
Meckenheim-Süd	817
Meckenheim-Giermaarstr./Dechan	1,064
Meckenheim-Neue Mitte	921
Meckenheim-Mitte Ost	712
Meckenheim-Industriegebiet	57

Figure 3.1.2-A: Allocation of Residential Subscriber Lines to Grid Squares



The total number of subscribers per grid square is ascertained by adding the number of residential customers to the number of business customers.

The number of business customers is estimated as a function of the number of residential customers by means of a user-defined factor. At present, a business customer factor of 10% for grid squares having fewer than 250 residential lines and 30% for grid squares having 250 to 500 residential lines serves as a working hypothesis. With further increasing density of residential lines, an additional rise in the business customer factor is considered possible. However, to avoid overestimating the number of business lines especially in areas of high residential population density, the number of these lines is set at 250 for grid squares having more than 500 residential lines. The following then applies:

$$\begin{aligned} Asl\_PQ &= PK\_PQ + GK\_PQ \\ GK\_PQ &= \begin{bmatrix} \mid PK\_PQ \cdot GKFkt \mid \text{for } PK\_PQ < 500 \\ \mid 250 \mid \text{for } PK\_PQ \geq 500 \end{bmatrix} \\ GKFkt &= \begin{bmatrix} \mid 0{,}1 \mid \text{for } 0 \leq PK\_PQ < 250 \\ \mid 0{,}3 \mid \text{for } 250 \leq PK\_PQ < 500 \end{bmatrix} \end{aligned} \qquad (3.1.2\text{-}1)$$

where:

Asl_PQ = number of subscriber lines in a grid square

PK_PQ = number of residential lines in a grid square

GK_PQ = number of business lines in a grid square

GKFkt = business customer factor

Determining mark-up factors serves to identify a plausible spread of telephone lines over the area. The number of subscribers in the local network considered may be derived from adding the values of all the grid squares. Where network operator data is available in the same disaggregated form, it may be used. Where data solely on the number of subscriber lines is available for the whole of the local network, appropriate adjustments can be made by means of a linear increase or decrease in the demand data initially assumed for the grid squares. This implies that the assumed spread of lines over the area is maintained.

In further calculations, one grid square represents one distribution area, provided that the subscriber density ascertained does not exceed a particular threshold. This threshold is currently fixed at 600 subscriber lines per distribution area. Where more than 600 lines are allocated to a grid square, the square is divided into two distribution areas. In case the number of lines per distribution area is still more than 600, it is further divided. Hence grid squares with an established number of subscribers of more than 1,200 are divided into four distribution areas with sides of 300m x 300m.

3.1.3 Dividing the Distribution Areas into Types

As a next step, the distribution areas are divided into types. These types allow a number of input parameters to be differentiated by their characteristics.[12] This division is based on subscriber density in the grid square to which the distribution areas relate, ie where they are located. A difference is made between three types:

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[12] The value of the type variable affects for instance the way cables are laid, spare capacity factors and the parameters of the drop segment.

$$\text{VZB-Typ} = \begin{bmatrix} |\ 1\ |\ \text{for Asl\_PQ} \geq 600 \text{ (urban)} \\ |\ 2\ |\ \text{for } 200 \leq \text{Asl\_PQ} < 600 \text{ (suburban)} \\ |\ 3\ |\ \text{for Asl\_PQ} < 200 \text{ (rural)} \end{bmatrix} \quad (3.1.3\text{-}1)$$

where:

VZB-Typ = type of distribution area

Asl_PQ = number of subscriber lines in a grid square

3.1.4 Allocating Distribution Areas to Access Areas

Following the division of grid squares with high subscriber density, the local network is then divided into access areas. Each access area is defined by the existence of a main distribution frame (HVt), connected either directly to an exchange or to a remote concentrator unit.[13] Generally, a local network is divided into several access areas. Allocation of the distribution areas to access areas (ie to main distribution frames) may be prescribed. Where this is not the case, each distribution area is allocated to the nearest main distribution frame site. The orthogonal distances between the core of the distribution area and the main distribution frame site are crucial, for they ensure that each distribution area is allocated to the main distribution frame where the distance in cable metres is minimised, given the assumed access area topology (cf section 3.1.5). The coordinates of the core of a particular distribution area may initially be derived as follows:

$$SX = \frac{X_{or} + X_{ul}}{2} \qquad SY = \frac{Y_{or} + Y_{ul}}{2} \quad (3.1.4\text{-}1)$$

where:

SX = X coordinate of the core of a distribution area

SY = Y coordinate of the core of a distribution area

X_{ul} *= X coordinate of the lower left corner of a distribution area*

Y_{ul} *= Y coordinate of the lower left corner of a distribution area*

X_{or} *= X coordinate of the upper right corner of a distribution area*

Y_{or} *= Y coordinate of the upper right corner of a distribution area*

---

[13] The main distribution frame sites must be indicated by the operator if - as assumed here - its network structure is to underpin calculations.

The allocation of a distribution area to a main distribution frame and hence to an access area is derived as follows:

$$\text{VZB} \in \text{ASB}_i, \text{ where the following applies: } \text{HVt}_i \left(\min\left[\left| X_i - SX \right| + \left| Y_i - SY \right| \right] \Big|_{i=1}^{n} \right)$$

(3.1.4-2)

where:

VZB = *distribution area*

ASB_i = *access area i*

HVt_i = *main distribution frame in ASB i*

i = *index of the access area, where i = {1...n}*

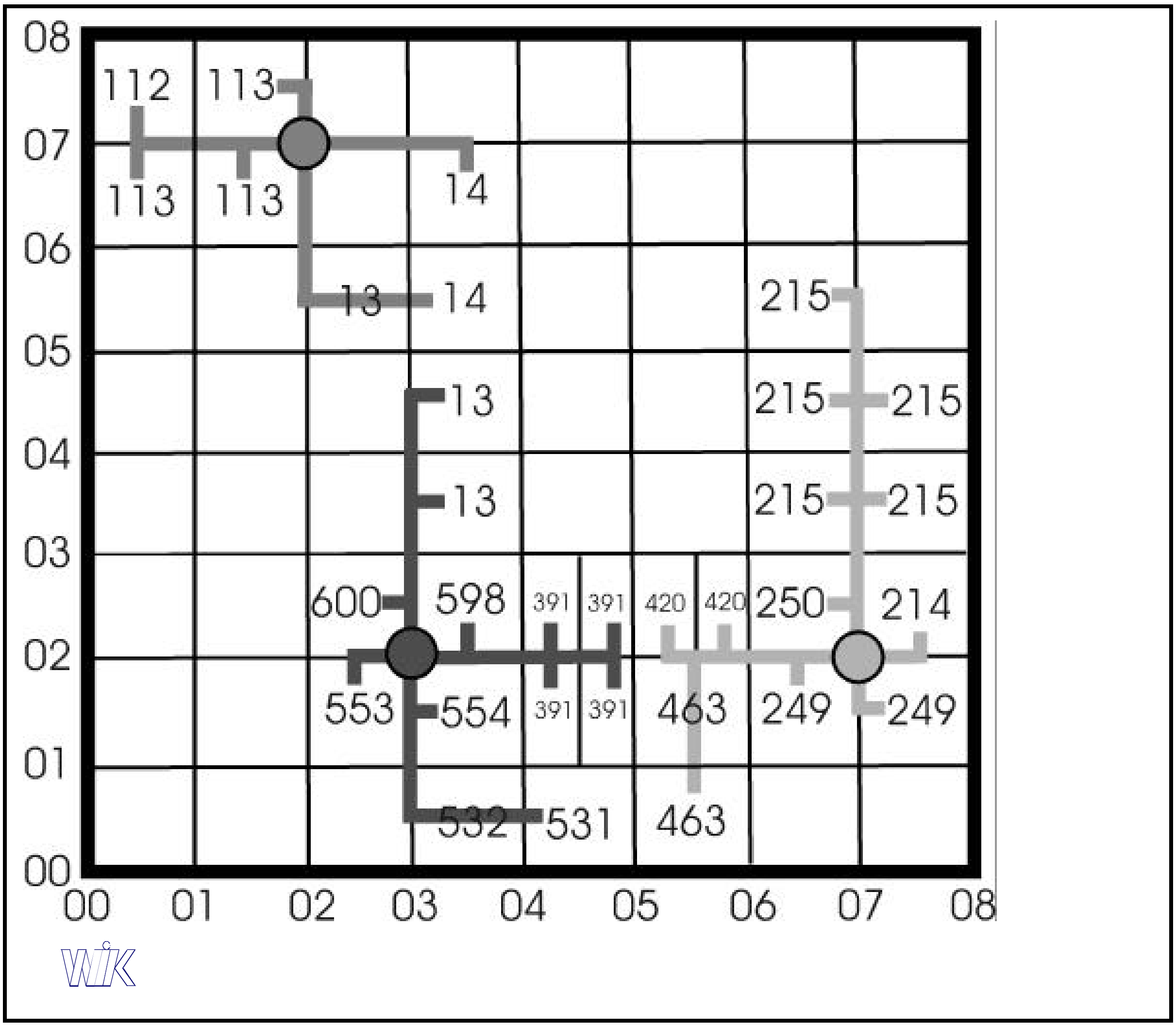
X_i = *X coordinate of the main distribution frame*

Y_i = *Y coordinate of the main distribution frame*

In this way the access areas are defined and each distribution area allocated precisely to an access area.

Figure 3.1.4-A shows how the above steps are implemented in the model. Depicted is the allocation of the distribution areas to access areas (cf section 3.1.4) and feeder sections (cf section 3.1.5) as well as the division of high density distribution areas into two (cf section 3.1.2).

Figure 3.1.4-A: Structure of a Local Network Contemplated in the Model



3.1.5 Allocating Distribution Areas to Feeder Sections

The following assumption is made in respect of the feeder network topology. Starting from the main distribution frame, the whole access area is divided into four feeder sections in the form of quadrants. The distribution areas are allocated to the quadrants as described in the following. Distribution areas are always allocated to the quadrant where the core (SX, SY) of the distribution area is located. If the core is located exactly on the quadrant boundary, it is allocated to the nearest quadrant clockwise. The following then applies:

$$j = \begin{bmatrix} |\ 1\ |\ \text{for } SY > SX + (Y_i - X_i) \text{ and } SY \geq -SX + (Y_i + X_i) \\ |\ 2\ |\ \text{for } SY \leq SX + (Y_i - X_i) \text{ and } SY > -SX + (Y_i + X_i) \\ |\ 3\ |\ \text{for } SY < SX + (Y_i - X_i) \text{ and } SY \leq -SX + (Y_i + X_i) \\ |\ 4\ |\ \text{for } SY \geq SX + (Y_i - X_i) \text{ and } SY < -SX + (Y_i + X_i) \end{bmatrix} \qquad (3.1.5\text{-}1)$$

where:

j = *index of the quadrant, where j = {1...4}*

SX = *X coordinate of the core of a distribution area*

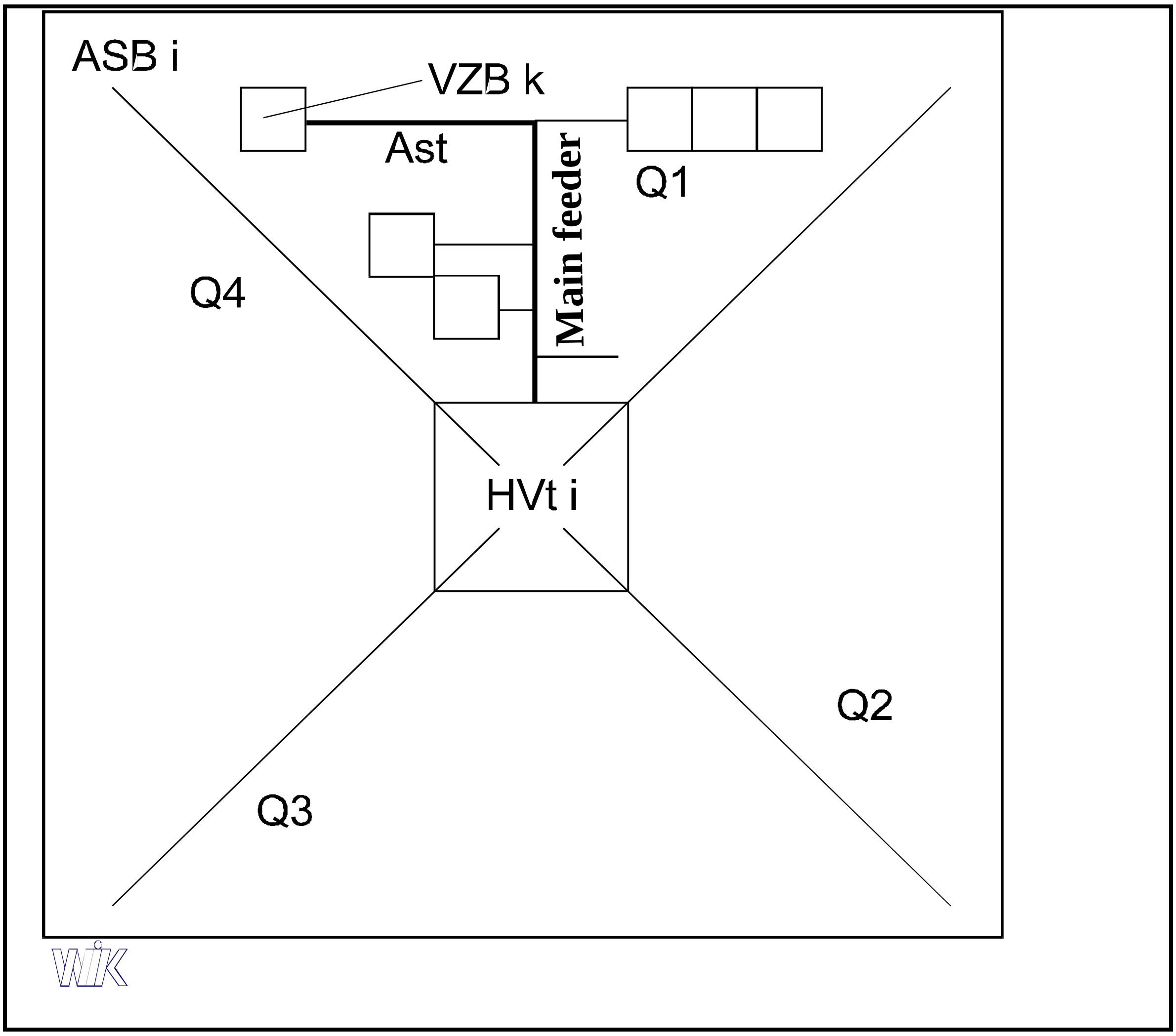
SY = *Y coordinate of the core of a distribution area*

X_i = *X coordinate of the main distribution frame*

Y_i = *Y coordinate of the main distribution frame*

In respect of the access network topology it is assumed that one feeder route runs along the bisector of each quadrant in the direction of the four cardinal points; these are called main feeders. The individual distribution areas of the respective quadrant are attached to the main feeders by feeder routes branching off at right angles, the so-called branch feeders. Each branch feeder terminates at the feeder-distribution interface. This interface is a cross-connection point and separates the feeder network from the distribution network. Fig 3.1.5-A shows the stylised structure of an access area.

Figure 3.1.5-A: Structure of an Access Area



Hence it follows that each distribution area is defined by allocation to an access area, to an access area quadrant and its serial number index within the quadrant. The indexing used in the following reads:

ASB_i = *access area i, where i = {1...n}*

HVt_i = *main distribution frame in the* ASB_i*, where i = {1...n}*

Q_{ij} = *quadrant j in the* ASB_i*, where j = {1...4}*

VZB_{ijk} = *distribution area k in* Q_j *of* ASB_i*, where* $k = \{1...m_{ij}\}$

k = *index of the distribution area, where* $k = \{1...m_{ij}\}$

3.1.6 Calculating the Lengths of the Feeder and Distribution Networks

Once the distribution areas have been allocated to the quadrants, the coordinates of the feeder-distribution interfaces can be calculated. These are determined by the position of the distribution area relative to the attached main distribution frame. In line with the assumptions, the feeder-distribution interface is, as a general rule, located in the middle of the distribution area edge, closer to and parallel to the main feeder.

The coordinates of the feeder-distribution interface (X_{ijk},Y_{ijk}) hence are as follows:

$$X_{ijk} = \begin{bmatrix} \left| SX_{ijk} \right| \text{ for } j = 2 \text{ or } j = 4 \\ \left| X_{or_{ijk}} \right| \text{ for } (j = 1 \text{ or } j = 3) \text{ and } SX_{ijk} < X_i \\ \left| X_{ul_{ijk}} \right| \text{ for } (j = 1 \text{ or } j = 3) \text{ and } SX_{ijk} > X_i \end{bmatrix} \qquad (3.1.6\text{-}1)$$

$$Y_{ijk} = \begin{bmatrix} \left| SY_{ijk} \right| \text{ for } j = 1 \text{ or } j = 3 \\ \left| Y_{or_{ijk}} \right| \text{ for } (j = 2 \text{ or } j = 4) \text{ and } SY_{ijk} < Y_i \\ \left| Y_{ul_{ijk}} \right| \text{ for } (j = 2 \text{ or } j = 4) \text{ and } SY_{ijk} > Y_i \end{bmatrix}$$

where:

X_{ijk} = X coordinate of the feeder-distribution interface of VZB_{ijk}

Y_{ijk} = Y coordinate of the feeder-distribution interface of VZB_{ijk}

3.1.6.1 Calculating the Lengths of the Feeder Network

The route length of the main feeder is calculated for each quadrant of an access area and that of the branch feeder for each distribution area by means of the feeder-distribution interface coordinates. The route length of the main feeder of each quadrant depends on the distances between the distribution areas and the main distribution frame of the access area. As it is assumed that the feeder cables of a quadrant run over a joint route in the main feeder, their length is determined by the distribution area that requires the maximum route length for connection in the main feeder section.

$$LS_{ij} = max\left(LS_{ijk}\right)\Big|_{k=1}^{m_{ij}} \qquad (3.1.6\text{-}2)$$

whereby the following applies:

$$LS_{ijk} = \begin{bmatrix} \left| Y_i - Y_{ijk} \right| \text{ for } j = 1 \text{ or } 3 \\ \left| X_i - X_{ijk} \right| \text{ for } j = 2 \text{ or } 4 \end{bmatrix} \qquad (3.1.6\text{-}3)$$

where:

LS = loop length in the main feeder

The branch feeder length for each distribution area is finally built from the following formula:

$$LA_{ijk} = \begin{bmatrix} \left| X_i - X_{ijk} \right| \text{ for } j = 1 \text{ or } 3 \\ \left| Y_i - Y_{ijk} \right| \text{ for } j = 2 \text{ or } 4 \end{bmatrix} \qquad (3.1.6\text{-}4)$$

where:

LA = loop length in the branch feeder

The route lengths in the feeder section form the basis for costing civil engineering and for establishing the cable and conductor lengths.

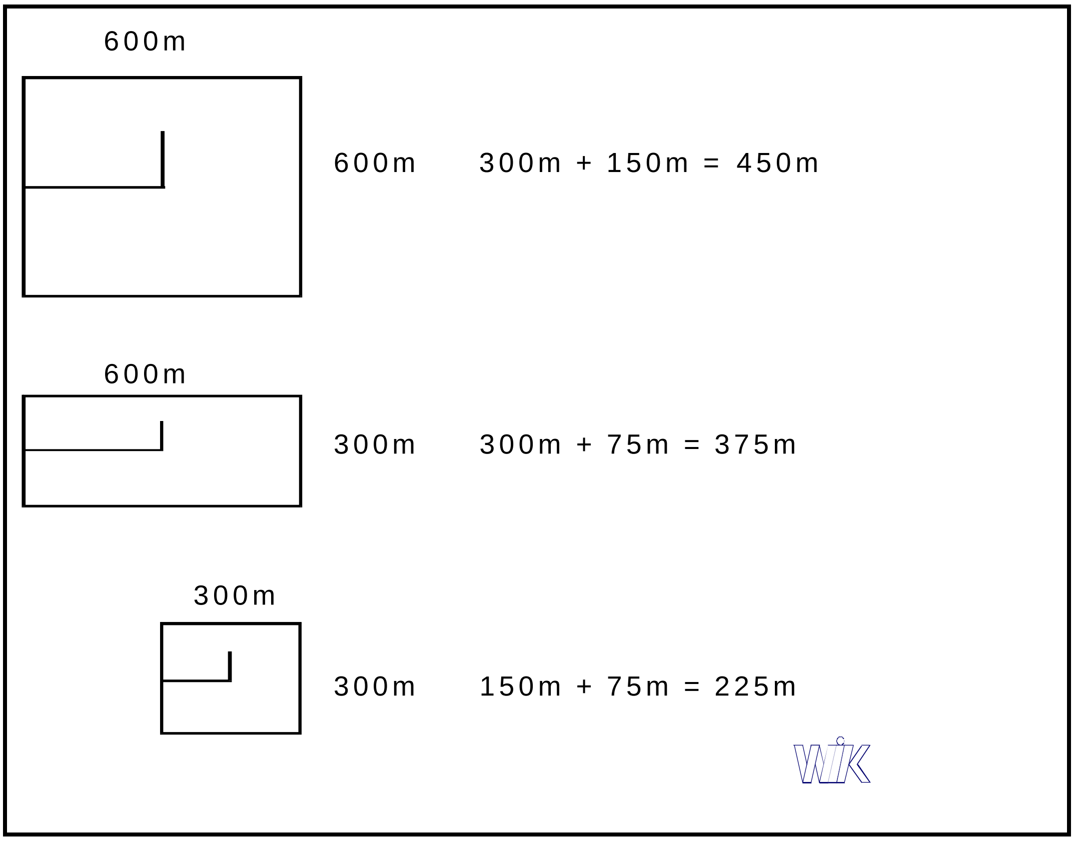
3.1.6.2 Calculating the Lengths of the Distribution Network

While the position of individual distribution areas in the local network can be determined on the basis of statistical data and appropriate maps, no additional data is available that could shed light on the spread of subscriber lines in the distribution areas. This is why the relevant distances in the distribution area are computed in a simplified manner with an equal spread of subscriber lines assumed. The orthogonal distance between average subscriber and feeder-distribution interface is ascertained as follows:

$$\frac{|x_{or} - x_{ul}|}{2} + \frac{|y_{or} - y_{ul}|}{4} \text{ for } j = 1 \text{ or } 3$$
$$\frac{|y_{or} - y_{ul}|}{2} + \frac{|x_{or} - x_{ul}|}{4} \text{ for } j = 2 \text{ or } 4 \qquad (3.1.6\text{-}5)$$

Fig 3.1.6-A illustrates this calculation.

Figure 3.1.6-A: Average Distance between Subscriber and Feeder-Distribution Interface



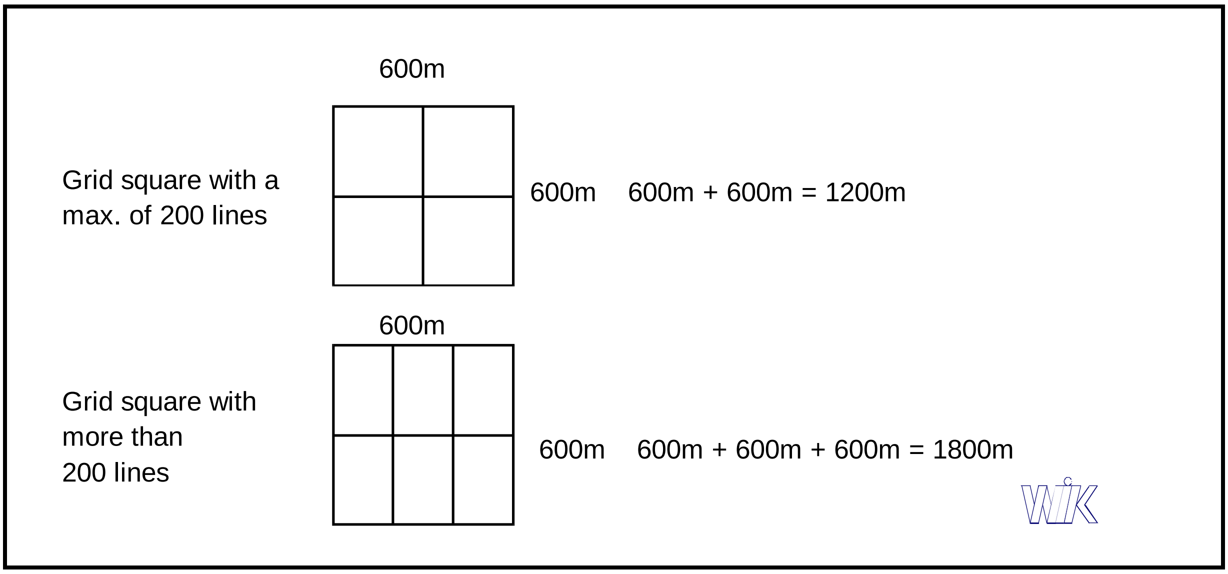
The average distance between subscriber and feeder-distribution interface corresponds to the average length of a wire pair in the distribution cable:

$$LLVZB_{ijk} = \begin{bmatrix} |\,0{,}450\,| \text{ for } X_{or_{ijk}} - X_{ul_{ijk}} = 0{,}600 \text{ and } Y_{or_{ijk}} - Y_{ul_{ijk}} = 0{,}600 \\ |\,0{,}375\,| \text{ for } X_{or_{ijk}} - X_{ul_{ijk}} = 0{,}300 \text{ and } Y_{or_{ijk}} - Y_{ul_{ijk}} = 0{,}600 \\ |\,0{,}375\,| \text{ for } X_{or_{ijk}} - X_{ul_{ijk}} = 0{,}600 \text{ and } Y_{or_{ijk}} - Y_{ul_{ijk}} = 0{,}300 \\ |\,0{,}225\,| \text{ for } X_{or_{ijk}} - X_{ul_{ijk}} = 0{,}300 \text{ and } Y_{or_{ijk}} - Y_{ul_{ijk}} = 0{,}300 \end{bmatrix} \qquad (3.1.6\text{-}6)$$

LLVZB = loop length in the distribution area

The length of the cable routes required in a distribution area depends mainly on the size of this area. It is assumed that the distribution network is rolled out in a topology comparable to that of the feeder network. Starting from a main feeder, branch feeders run parallel to roads and at right angles to the edge of the distribution area. The distance between the branching points corresponds to the average distance between two road junctions. As a general rule, the distribution network has the same length, relative to a grid square. Since grid squares with a density of more than 600 subscriber lines are subdivided into smaller distribution areas, the length of the distribution network is also divided into two or four. An exception is made for grid squares with low subscriber density where a less dense distribution network is assumed (cf Fig 3.1.6-B). More differentiated modelling of the distribution network is subject to the availability of detailed data on the settlement structure.

Figure 3.1.6-B: Structure of Cable Routes



Total route length is thus as follows:

$$LG_{ijk} = \begin{bmatrix} \left| 1{,}200 \right| & \text{for } 0 \le Asl\_PQ < 200 \\ \left| 1{,}800 \right| & \text{for } 200 \le Asl\_PQ < 600 \\ \left| 0{,}900 \right| & \text{for } 600 \le Asl\_PQ < 1200 \\ \left| 0{,}450 \right| & \text{for } Asl\_PQ \ge 1200 \end{bmatrix} \qquad (3.1.6\text{-}7)$$

where:

Asl_PQ = number of subscriber lines in a grid square

LG_{ijk} = route length in the distribution area

3.1.7 Establishing the Necessary Copper Pair Diameters

As the copper price is a decisive cost factor in the use of telecommunications cables, conductor diameters should be as small as possible from the economic perspective. Conductor resistance increases with conductor length. With telecommunications applications a specific conductor resistance may not be exceeded overall. Where a subscriber line exceeds a particular length, it should therefore be provided partly or completely with larger diameter conductors. Available are conductors with the following diameters: l = 0.40 mm, l = 0.60 mm and l = 0.80 mm. The shares of the cable types to be used must be determined for each loop length. Decisive in this connection is total conductor length from the main distribution frame to the customer location in the distribution area. It is assumed that the conductor at the main distribution frame starts with the smaller conductor diameter in each case. It is also assumed that, within the distribution cable, there is no changeover from one diameter to the next, even if calculations might allow such a changeover point to be located there. In these cases this point is at the feeder-distribution interface.

The following formulae are derived from information in the *Lehrbuch der Fernmeldetechnik*.[14]

Total loop length to an average customer of a VZB_{ijk} is as follows:

$$LL_{ijk} = LS_{ijk} + LA_{ijk} + LLVZB_{ijk} \qquad (3.1.7\text{-}1)$$

where:

LL = *total loop length*

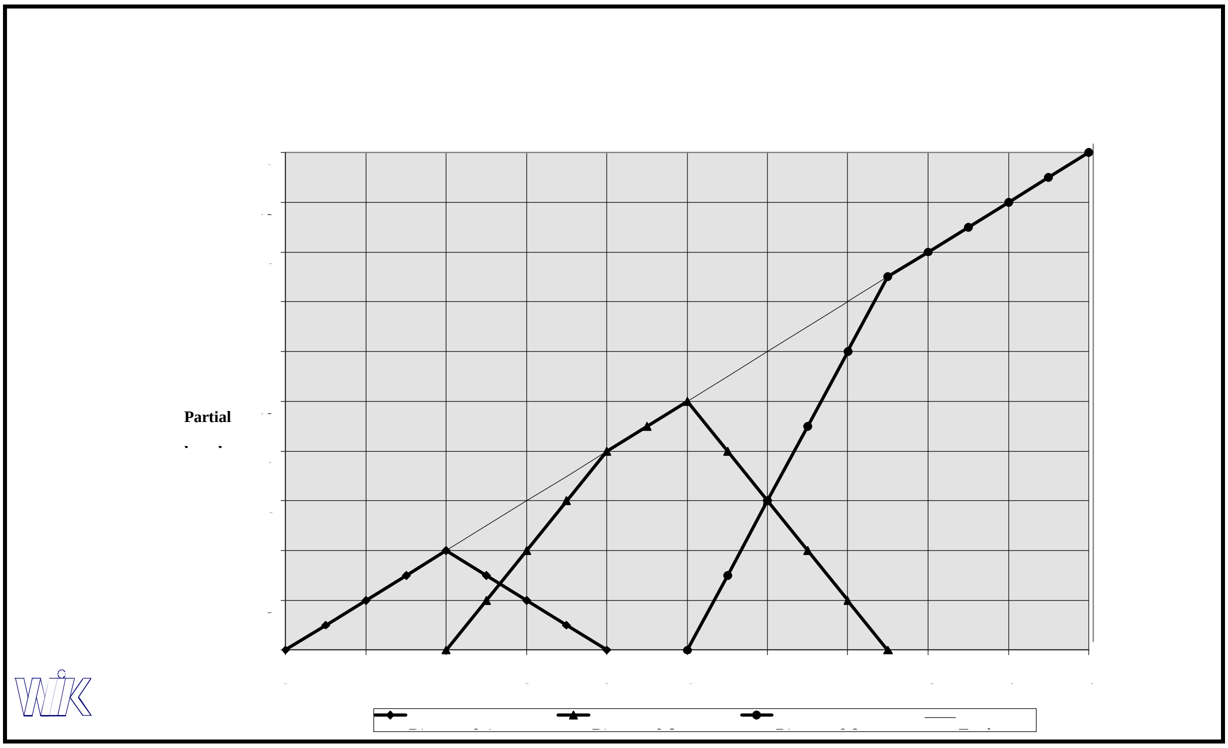
LS = *loop length in the main feeder*

LA = *loop length in the branch feeder*

LLVZB = *loop length in the distribution area*

14 Bergmann. K. (Begr.) and Slabon, R.W. (editors): Lehrbuch der Fernmeldetechnik, 5th edition, Berlin 1986. Where network operators use different cable types, the calculations must be modified accordingly.

Figure 3.1.7-A: Conductor Diameters Used



Proceeding from the above assumptions, the lengths of conductors with diameters of 0.4, 0.6 and 0.8mm in the feeder section are as follows:

For $0{,}0\text{km} < LL_{ijk} \leq 4{,}0\text{km}$:

$$LLHK_{ijkl} = \begin{bmatrix} \left| LL_{ijk} - LLVZB_{ijk} \right| \text{ for } l = 0{,}40 \\ \left| 0 \right| \text{ for } l = 0{,}60 \\ \left| 0 \right| \text{ for } l = 0{,}80 \end{bmatrix} \qquad (3.1.7\text{-}2)$$

For $4{,}0\text{km} < LL_{ijk} \leq 8{,}0\text{km}$ and $LLVZB_{ijk} \leq \left(LL_{ijk} \cdot (2) - 8 \right)$:

$$LLHK_{ijkl} = \begin{bmatrix} \left| LL_{ijk} \cdot (-1) + 8 \right| \text{ for } l = 0{,}40 \\ \left| \left(LL_{ijk} \cdot (2) - 8 \right) - LLVZB_{ijk} \right| \text{ for } l = 0{,}60 \\ \left| 0 \right| \text{ for } l = 0{,}80 \end{bmatrix}$$

For $4{,}0\text{km} < LL_{ijk} \leq 8{,}0\text{km}$ and $LLVZB_{ijk} \geq \left(LL_{ijk} \cdot (2) - 8 \right)$:

$$LLHK_{ijkl} = \begin{bmatrix} \left| \left(LL_{ijk} \cdot (-1) + 8 \right) - \left(LLVZB_{ijk} - \left(LL_{ijk} \cdot (2) - 8 \right) \right) \right| \text{ for } l = 0{,}40 \\ \left| 0 \right| \text{ for } l = 0{,}60 \\ \left| 0 \right| \text{ for } l = 0{,}80 \end{bmatrix}$$

For $8{,}0\text{km} < LL_{ijk} \leq 10{,}0\text{km}$:

$$LLHK_{ijkl} = \begin{bmatrix} |\,0\,|\ \text{for } l = 0{,}40 \\ |\,LL_{ijk} - LLVZB_{ijk}\,|\ \text{for } l = 0{,}60 \\ |\,0\,|\ \text{for } l = 0{,}80 \end{bmatrix}$$

For $10{,}0\text{km} < LL_{ijk} \leq 15{,}0\text{km}$ and $LLVZB \leq \left(LL_{ijk} \cdot (3) - 30\right)$:

$$LLHK_{ijkl} = \begin{bmatrix} |\,0\,|\ \text{for } l = 0{,}40 \\ |\,LL_{ijk} \cdot (-2) + 30\,|\ \text{for } l = 0{,}60 \\ |\,\left(LL_{ijk} \cdot (3) - 30\right) - LLVZB_{ijk}\,|\ \text{for } l = 0{,}80 \end{bmatrix}$$

For $10{,}0\text{km} < LL_{ijk} \leq 15{,}0\text{km}$ and $LLVZB \geq \left(LL_{ijk} \cdot (3) - 30\right)$:

$$LLHK_{ijkl} = \begin{bmatrix} |\,0\,|\ \text{for } l = 0{,}40 \\ |\,\left(LL_{ijk} \cdot (-2) + 30\right) - \left(LLVZB_{ijk} - \left(LL_{ijk} \cdot (3) - 30\right)\right)\,|\ \text{for } l = 0{,}60 \\ |\,0\,|\ \text{for } l = 0{,}80 \end{bmatrix}$$

For $15{,}0\text{km} < LL_{ijk}$

$$LLHK_{ijkl} = \begin{bmatrix} |\,0\,|\ \text{for } l = 0{,}40 \\ |\,0\,|\ \text{for } l = 0{,}60 \\ |\,LL_{ijk} - LLVZB_{ijk}\,|\ \text{for } l = 0{,}80 \end{bmatrix}$$

where:

LL = *total loop length*

LLHK = *loop length in the feeder cable*

LLVZB = *loop length in the distribution area*

l = *copper pair diameter in mm, where l = {0,4; 0,6; 0,8}*

As there is no changeover point in the distribution cable, conductor diameter within a distribution area is simply a function of total conductor length:

$$l = \begin{bmatrix} |\,0{,}40\,|\ \text{for } 0{,}0\text{km} \leq LL_{ijk} < 4{,}0\text{km} \\ |\,0{,}60\,|\ \text{for } 4{,}0\text{km} \leq LL_{ijk} < 8{,}0\text{km} \\ |\,0{,}80\,|\ \text{for } LL_{ijk} \geq 8{,}0\text{km} \end{bmatrix} \qquad (3.1.7\text{-}3)$$

3.1.8 Establishing the Number of Wire Pairs

The number of pairs per subscriber line is of great importance when the following costs are determined. The number of wire pairs (DA) laid is always larger than the number of wires actually used to provide subscriber lines, as

- not all wires can be used, ie spare capacity must be included for pairs that become unusable over time,

- additional spare capacity must be included for possible growth in demand,
- pairs are also used for the provision of leased lines.

Applicable to the number of subscriber lines per distribution area as identified above is, first of all, a factor reflecting the expected growth in demand during the economic lifetime of the local loop investment. Due regard must be given here to the scope provided by multiple use of wire pairs, for instance by digitisation (ISDN). Then comes a factor for leased line demand und finally, one for spare capacity.

Leased line factor and demand-driven (economic) spare capacity factor may be differentiated, where required, between feeder, distribution and drop segments and between the different types of distribution area.

$$DA_{HK_{ijk}} = Asl\_VZB_{ijk} \cdot Res\_Fkt\_DA_{HK} \cdot FV\_Fkt\_DA \cdot TRes\_Fkt\_DA$$
$$DA_{VZB_{ijk}} = Asl\_VZB_{ijk} \cdot Res\_Fkt\_DA_{VZB}(VZB-Typ) \cdot FV\_Fkt\_DA \cdot TRes\_Fkt\_DA$$

(3.1.8-1)

where

$DA_{HK_{ijk}}$ = *number of wire pairs in the feeder section for* VZB_{ijk}

$DA_{VZB_{ijk}}$ = *number of wire pairs in the distribution area* VZB_{ijk}

Asl_VZB_{ijk} = *number of subscriber lines in* VZB_{ijk}

$Res\_Fkt\_DA_{HK}$ = *economic spare capacity factor for DA in the feeder cable*

$Res\_Fkt\_DA_{VZB}$ = *economic spare capacity factor for DA in the distribution cable*

TRes_Fkt_DA = *technical spare capacity factor for DA*

FV_Fkt_DA = *leased line factor in the access network*

The following, moreover, needs to be defined directly:

DA_Asl(VZB-Typ) = *number of wire pairs per subscriber line in the drop segment*

3.1.9 Establishing the Traffic Volume for Access Areas

To dimension traffic-sensitive investment, data on the traffic volume in remote concentrators and local exchanges is required. A distinction is made between static traffic volume, measured in Erlangs (E), and dynamic traffic load, measured in call attempts (CA). In both cases data on the traffic volume must be provided for the hour considered relevant to network capacity dimensioning.

The following computations are based in the first place on incoming and outgoing traffic values in an average daily busy hour. A distinction is made between residential and business customers. Traffic demand, specified in busy hour Erlangs (BHE), is determined for each access area by adding the subscriber traffic.

$$BHE_i = \sum_{j=1}^{4} \sum_{k=1}^{m_{ij}} \left(PK\_VZB_{ijk} \cdot BHE\_PK + GK\_VZB_{ijk} \cdot BHE\_GK \right) \qquad (3.1.9\text{-}1)$$

where:

BHE_i = *traffic volume in* ASB_i

BHE_PK = *BHE per residential customer*

BHE_GK = *BHE per business customer*

PK_VZB_{ijk} = *residential customers in* VZB_{ijk}

GK_VZB_{ijk} = *business customers in* VZB_{ijk}

To determine dynamic traffic load, ie the number of call attempts during the busy hour, total holding time must be divided by average holding time in order to determine the number of successful calls first. This figure must be divided by a factor corresponding to the share of successful call attempts in the total number of call attempts. The following applies in a general form:

$$BHCA = \frac{BHE \cdot 60}{HT} \cdot \frac{1}{\alpha} \qquad (3.1.9\text{-}2)$$

where:

BHCA = *dynamic traffic load in an average busy hour*

BHE = *traffic volume in an average busy hour*

HT = *average holding time*

a = *factor indicating the ratio of successful to total number of call attempts*

These values must then be increased by a factor which takes into account that dimensioning the capacity of the network is based on a value higher than the average daily peak load. This ensures that weekly and monthly peak loads can also be handled with an acceptable grade of service.

$$BHE_D = BHE \cdot LSF \qquad (3.1.9\text{-}3)$$

$$BHCA_D = BHCA \cdot LSF$$

where:

BHE_D, $BHCA_D$ = *traffic volume or dynamic traffic load in the hour relevant to network capacity dimensioning*

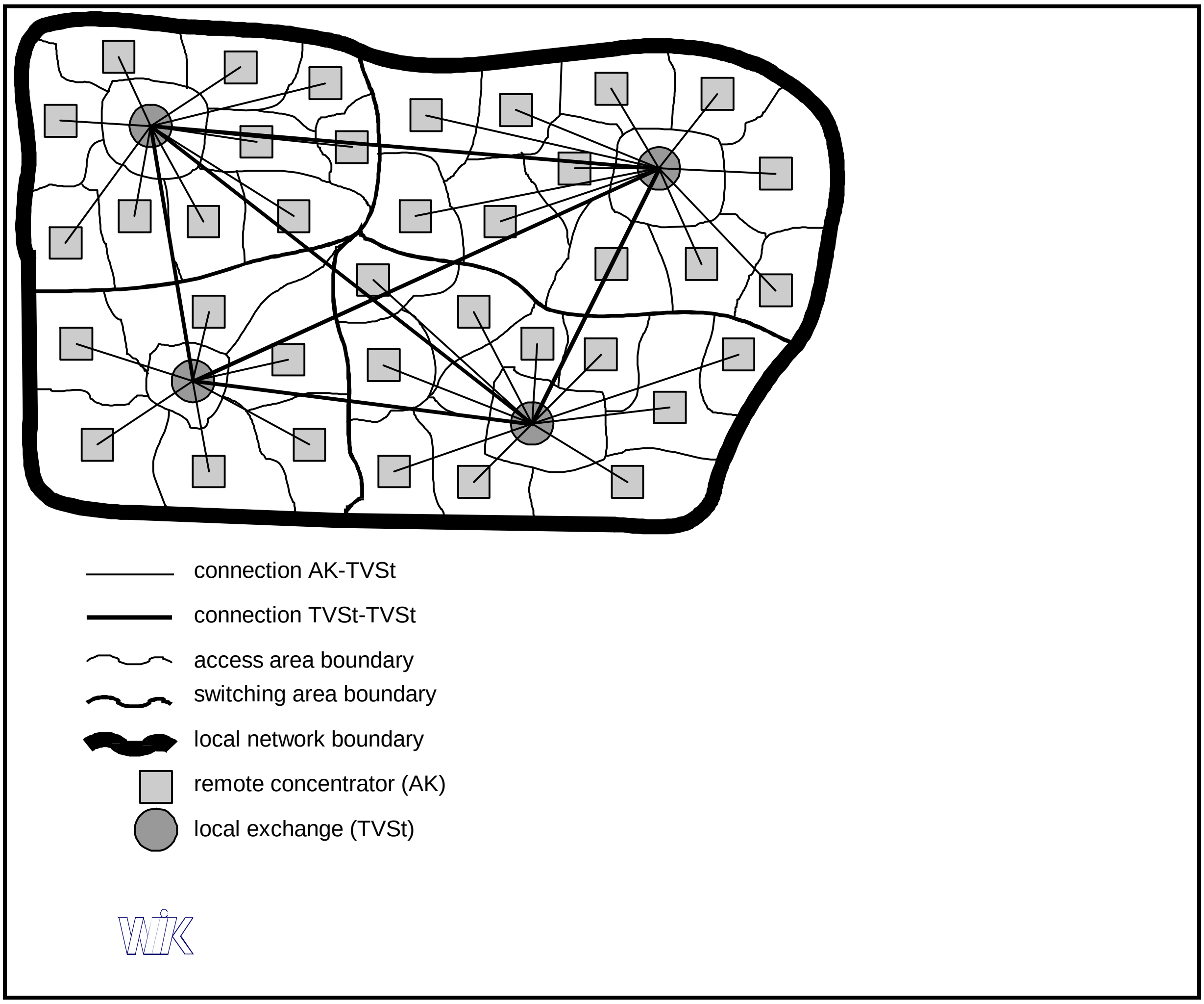
LSF = *peak load factor*

The values thus identified for the average holding time of a subscriber line and the average number of call attempts per busy hour are the basis for calculating traffic volumes in the elements of the telecommunications network that are dimensioned on a traffic-sensitive basis. A difference is made between an average (daily) busy hour and a busy hour relevant to dimensioning network capacity for the following reason. The average busy hour is used to determine expected annual demand, while the busy hour that is relevant to dimensioning network capacity is used, as the term suggests, to determine investments in the traffic-sensitive part of the telecommunications network. The next step establishes traffic relations between network nodes as well as the relevant equivalent of the 2 Mbit/s (DSV2) connections.

3.1.10 Establishing the Logical Traffic Relations between Network Nodes

Establishing the traffic volumes in the switching nodes, in the interoffice network and between remote concentrators and associated exchanges requires prior identification of the main distribution frame co-located with a local exchange. In line with the assumptions, the remaining main distribution frames are co-located with a remote concentrator. In addition, remote concentrators must be allocated to local exchanges (cf Fig 3.1.10-A).

Figure 3.1.10-A: Stylised Structure of a Local Network



The following calculations assume such determinations. Hence each access area (ASB)/main distribution frame (HVt) is allocated either to a local exchange (TVSt) or to a remote concentrator (AK), and each remote concentrator to a local exchange. The following then applies:

ASB_{a0} = *ASB of the local exchange a, where a = {1...s}*

ASB_{ad} = *ASB of the remote concentrator of local exchange a, where a = {1...s} and d = {1...*t_a*}*

3.1.10.1 Connections between Remote Concentrators and Local Exchange

Assuming that internal connections are not established in remote concentrators (AK), all subscriber traffic is routed via the local exchange (TVSt). The volume of traffic carried to the local exchange can thus be established by adding the subscriber traffic in the access area, routed via the concentrator.

$$\mathrm{BHE}_{\mathrm{AK}_{\mathrm{ad}}|\mathrm{TVSt}_{\mathrm{a}}} = \mathrm{BHE}_{\mathrm{ad}}, \text{ where } d \neq 0 \qquad (3.1.10\text{-}1)$$

where:

$BHE_{AK_{ad}|TVSt_a}$ = *traffic between remote concentrator*$_{ad}$ *and TVSt*$_a$

BHE_{ad} = *subscriber traffic in the ASB*$_{ad}$

3.1.10.2 Connections between Local Exchanges

Based on the symmetry assumption, outgoing traffic may be determined as half the total traffic.

$$BHE\_G_{ad} = \frac{BHE_{ad}}{2} \qquad (3.1.10\text{-}2)$$

where:

BHE_G = outgoing traffic

It is assumed that a certain share of the outgoing subscriber traffic, determined at local network level, will be classified as long-distance traffic, ie with a destination in a different local network.

$$BHE\_G\_O_{ad} = BHE\_G_{ad}\,(1-AFV) \qquad (3.1.10\text{-}3)$$

$$BHE\_G\_F_{ad} = BHE\_G_{ad}\,AFV \qquad (3.1.10\text{-}4)$$

where:

BHE_G_F = long-distance traffic (outgoing)

BHE_G_O = local traffic (outgoing)

BHE_G_{ad} = *traffic in an ASB*$_{ad}$ *(outgoing)*

AFV = share of long-distance traffic in total subscriber traffic

(1-AFV) = share of local traffic in total subscriber traffic

The total volume of traffic of a local exchange is built from the sum total of subscriber traffic from all access areas directly or remotely attached to such an exchange. The intraoffice traffic of a local exchange, ie traffic not conveyed to another local exchange, corresponds to its relative share in total outgoing local traffic. This reflects the assumption that all conceivable connections between two local network subscribers are equally probable. Local traffic to a different local exchange is calculated accordingly. Traffic from the local exchanges to the trunk exchange may be derived from the sum total of the outgoing long-distance traffic of the access areas attached via the local exchanges.

Local traffic:

$$BHE\_G\_O_{TVSt_x|TVSt_y} = \sum_{d=0}^{t_x} BHE\_G\_O_{xd} \cdot \frac{\sum_{d=0}^{t_y} BHE\_G\_O_{yd}}{\sum_{a=1}^{s}\sum_{d=0}^{t_a} BHE\_G\_O_{ad}} \qquad (3.1.10\text{-}5)$$

Long-distance traffic:

$$BHE\_G\_F_{TVSt_x\,|\,FVSt} = \sum_{d=0}^{t_x} BHE\_G\_F_{xd} \qquad (3.1.10\text{-}6)$$

where:

a = *index of the TVSt, where a = {1...s}*

s = *number of TVSt in the local network*

d = *index of the HVt, where d = {0...t_a}*

t_x = *number of AK attached to TVSt$_x$*

d=0: *HVt of TVSt*

d Î {1...t_a}: *HVt of AK*

x Î {1...s}: *index of a TVSt*

y Î {1...s}: *index of a TVSt*

This serves as a basis for developing the traffic matrix shown in Table 3.1.10-a.

Table 3.1.10-a: Traffic Matrix of Local, Intraoffice and Long-Distance Traffic

Desti nation / Origin	$TVSt_1$	$TVSt_2$	...	$TVSt_a$	FVSt
$TVSt_1$	$BHE\_G_{TVSt_1\|TVSt_1}$	$BHE\_G_{TVSt_1\|TVSt_2}$	...	$BHE\_G_{TVSt_1\|TVSt_a}$	$BHE\_G_{TVSt_1\|FVSt}$
$TVSt_2$	$BHE\_G_{TVSt_2\|TVSt_1}$	$BHE\_G_{TVSt_2\|TVSt_2}$	...	$BHE\_G_{TVSt_2\|TVSt_a}$	$BHE\_G_{TVSt_2\|FVSt}$
:	:	:		:	:
$TVSt_a$	$BHE\_G_{TVSt_a\|TVSt_1}$	$BHE\_G_{TVSt_a\|TVSt_2}$	...	$BHE\_G_{TVSt_a\|TVSt_a}$	$BHE\_G_{TVSt_a\|FVSt}$
FVSt	$BHE\_G_{FVSt\|TVSt_1}$	$BHE\_G_{FVSt\|TVSt_2}$	...	$BHE\_G_{FVSt\|TVSt_a}$	0

where:

$BHE\_G_{TVSt_x|TVSt_y}$ = *outgoing traffic from TVSt$_x$ to TVST$_y$*

$BHE\_G_{TVSt_x|TVSt_x}$ = *intraoffice traffic of TVSt$_x$*

$BHE\_G_{TVSt_x|FVSt}$ = *long-distance traffic of TVSt$_x$*

Total outgoing local traffic in a local exchange may be derived from:

$$BHE\_G\_O_{TVSt_x} = \sum_{a=1}^{s}\left(BHE\_G_{TVSt_x|TVSt_a}\right)_{\text{with } a \neq x} \qquad (3.1.10\text{-}7)$$

Total outgoing long-distance traffic in a local exchange may be derived from:

$$BHE\_G\_F_{TVSt_x} = BHE\_G_{TVSt_x|FVSt} \qquad (3.1.10\text{-}8)$$

Total incoming local traffic in a local exchange may be derived from:

$$BHE\_K\_O_{TVSt_x} = \sum_{a=1}^{s}\left(BHE\_G_{TVSt_a|TVSt_x}\right)_{\text{with } a \neq x} \qquad (3.1.10\text{-}9)$$

Total incoming long-distance traffic in a local exchange may be derived from:

$$BHE\_K\_F_{TVSt_x} = BHE\_G_{FVSt|TVSt_x} \qquad (3.1.10\text{-}10)$$

Total intraoffice traffic in a local exchange may be derived from:

$$BHE\_I_{TVSt_x} = BHE\_G_{TVSt_x|TVSt_x} \qquad (3.1.10\text{-}11)$$

Finally, total traffic in a local exchange may be derived from:

$$BHE_{TVSt_x} = BHE\_G\_O_{TVSt_x} + BHE\_K\_O_{TVSt_x} + BHE\_I_{TVSt_x} + BHE\_G\_F_{TVSt_x} + BHE\_K\_F_{TVSt_x} \qquad (3.1.10\text{-}12)$$

The total dynamic traffic load of a local exchange is as follows:

$$BHCA_{TVSt_x} = \frac{BHE_{TVSt_x} \cdot 60}{HT} \cdot \frac{1}{\alpha} \qquad (3.1.10\text{-}13)$$

3.1.11 Establishing the Number of DSV2 Digital Connections for Transmission in the Local Network

After total traffic demand between two network nodes has been determined, the next step establishes the number of 2Mbit/s digital connections (DSV2) to be used between the nodes. Each DSV2 connection includes 30 user-information channels operating at 64 kbit/s plus two channels for signalling and management functions.

The required number of DSV2 connections is calculated by means of the Erlang loss formula. This indicates the number of channels required to implement a prescribed traffic offering with a given loss probability. The Erlang loss formula is built as follows:

$$B = \frac{\frac{A^N}{N!}}{\sum_{K=0}^{N} \frac{A^K}{K!}} \qquad (3.1.11\text{-}1)$$

where:

B = loss probability

A = traffic offering in Erlangs

N = number of lines/channels

Table 3.1.11-a shows the maximum traffic offered to a bundle of DSV2 connections, given different loss probabilities.

Table 3.1.11-a: Traffic Table (Example)

Traffic Offering A		Loss Probability		
Number of channels	Number of DSV2	B=0,005	B=0,01	B=0,05
N=30	1	19,03	20,34	24,80
N=60	2	44,76	46,95	54,57
N=90	3	71,76	74,68	85,01
N=120	4	99,38	102,96	115,77
N=150	5	127,40	131,58	146,71
N=180	6	155,68	160,42	177,76
N=210	7	184,16	189,42	208,89
N=240	8	212,79	218,56	240,09
N=270	9	241,55	247,80	271,33
N=300	10	270,41	277,13	302,62
N=330	11	299,35	306,52	333,93
N=360	12	328,37	335,98	365,27
N=390	13	357,45	365,49	396,63
N=420	14	386,59	395,04	428,01
N=450	15	415,78	424,63	459,40
N=480	16	445,01	454,27	490,81
N=510	17	474,28	483,93	522,23
N=540	18	503,58	513,62	553,66
N=570	19	532,92	543,34	585,10
N=600	20	562,29	573,08	616,55
N=630	21	591,69	602,84	648,00
N=660	22	621,11	632,62	679,47
N=690	23	650,55	662,42	710,94
N=720	24	680,02	692,24	742,41
N=750	25	709,51	722,08	773,89
N=780	26	739,01	751,92	805,38
N=810	27	768,53	781,79	836,87
N=840	28	798,07	811,67	868,36
N=870	29	827,63	841,56	899,86
N=900	30	857,20	871,46	931,36

The calculations for transmission systems assume that the required number of DSV2 connections is based on a traffic table as set out above with a given loss probability. The interoffice network that underpins costing in this model provides for direct routes between two nodes, without overflow routes being taken into account. This means that direct routes are also final routes. It follows that traffic rejected by a group of circuits is in fact lost and does not flow into another group. When the number of connections is determined, this assumption must be taken into account by applying a lower loss probability value than for overflow systems, in which direct routes can be well utilised due to the acceptance of high losses. The loss probability value used in the model should be chosen so as to allow realisation of the ultimately desired grade of service.

The number of DSV2 connections between a local exchange $TVSt_x$ and another local exchange $TVSt_y$ is calculated as follows:

$$\#DSV2_{TVSt_x|TVSt_y} = \text{rounded up}\left(\frac{N(A;B) \text{where } A = BHE\_G\_O_{D_{TVSt_x|TVSt_y}} + BHE\_G\_O_{D_{TVSt_y|TVSt_x}}}{30}\right)$$

(3.1.11-2)

The number of DSV2 connections between a local exchange $TVSt_x$ and a trunk exchange FVSt, is calculated as follows:

$$\#DSV2_{TVSt_x|FVSt} = \text{rounded up}\left(\frac{N(A;B) \text{ where } A = BHE\_G\_F_{D_{TVSt_x}} + BHE\_K\_F_{D_{TVSt_x}}}{30}\right) \quad (3.1.11\text{-}3)$$

To conclude, the total number of DSV2 connections in the interoffice network can be calculated for a TVSt as follows:[15]

$$\#DSV2_x = \sum_{a=1}^{s}\left(\#DSV2_{TVSt_x|TVSt_a}\right)_{mit\ a \neq x} + \#DSV2_{TVSt_x|FVSt} \quad (3.1.11\text{-}4)$$

The following applies in respect of connections between remote concentrator and local exchange. Subscriber traffic is concentrated on digital line units (DLUs). Each DLU has 4 x 2 Mbit/s ends. It follows that, initally, the number of DLUs per remote concentrator can be ascertained by means of the Erlang formula. The number of DSV2 connections carried over the transmission system is derived from the number of DLUs multiplied by four. Hence the number of DLUs per access area and the number of DSV2 connections for attachment to the relevant local exchange of access areas connected to remote concentrators are calculated as follows:

$$\#DLU_{ad} = \text{rounded up}\left(\frac{BHE_{D_{ad}}}{A(N;B) \text{ mit } N = 120}\right)$$

$$\#DLU_a = \sum_{d=0}^{t_a} \#DLU_{ad} \quad (3.1.11\text{-}5)$$

$$\#DSV2_{ad} = 4 \cdot \#DLU_{ad}, d \neq 0$$

where:

$\#DLU_{ad}$ = number of digital line units in an access area ad

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[15] It should not be forgotten that transmission equipment need not be provided for the necessary connections between a local exchange and the point of interconnection to the long-distance network in cases where the two are co-located. But in these cases, too, the incoming/outgoing long-distance traffic is relevant to the number of network-facing line trunk groups (LTGs).

#DLU$_{ad}$ = number of digital line units in a switching area a

#DSV$_{ad}$ = number of DSV2 connections between AK$_{ad}$ and the relevant TVSt

3.1.12 Establishing the Lengths of Junction Cables

The lengths of junction cables between remote concentrator (AK) and local exchange (TVSt) are calculated as follows:

$$AK_{ad}\_TVSt_a = \left|X_{AK_{ad}} - X_{TVSt_a}\right| + \left|Y_{AK_{ad}} - Y_{TVSt_a}\right| \qquad (3.1.12\text{-}1)$$

where:

AK = remote concentrator

TVSt = local exchange

d = index of the remote concentrator, where d = {1...t$_a$}

The junction cable lengths between and among local exchanges are computed as follows:

$$TVSt_x\_TVSt_y = \left|X_x - X_y\right| + \left|Y_x - Y_y\right| \qquad (3.1.12\text{-}2)$$

3.1.13 Establishing the Capital and Operating Cost Factors

The capital and operating cost factors (KBF) for the various asset categories indicate in terms of a percentage of the current replacement cost of the assets used the costs incurred annually for these assets. They are determined as a sum total of the operating cost factor (BKF) and the capital cost factor (KKF) which, as a capital recovery factor, covers both depreciation and the expected return on investment.

$$KBF_u = BKF_u + KKF_u \qquad (3.1.13\text{-}1)$$

where:

u = index of the asset category, where u = {1...z}

The specific capital cost factors are computed by means of the usual formula for the capital recovery factor, the general cost of capital being adjusted by the asset-specific rate of price changes as described in section 2.2.3.2.

$$KKF_u(KKS, \Delta p_u, ND_u) = \frac{KKS - \Delta p_u}{1 - \frac{1}{(1 + KKS - \Delta p_u)^{ND_u}}} \qquad (3.1.13\text{-}2)$$

where:

KKS = cost of capital

Dp$_u$ = average rate of price change for the asset category u

ND$_u$ = average economic-technical lifetime of the asset category u

The cost of capital is built as a weighted average of the rate of return on equity and the interest rate on debt.

$$KKS(eK,fK,D,T,R) = \frac{eK \cdot D}{1-T} + fK \cdot R \qquad (3.1.13\text{-}3)$$

where:

eK = *equity ratio*

fK = *debt ratio (interest-bearing debt only)*

D = *expected rate of return on equity*

T = *effective corporate income tax rate*

R = *interest rate on debt*

In addition to the equity ratio eK, the debt ratio fK, the expected rate of return on equity D, the effective corporate income tax rate T and the interest rate on debt R, the operating cost factors, the average rate of price changes and the lifetimes of the individual asset categories must be determined exogenously. It is proposed that the interest rate on debt be fixed on the basis of the return on risk-free medium-term securities, eg federal loans with 4 to 6 years to maturity. The rate of return on equity could be determined on the basis of the Capital Asset Pricing Model (CAPM) or the Dividend Growth Model. As described in section 2.2.3.3 neither approach can be implemented currently due to the high data requirements set. Recourse to network operator data or international comparisons is therefore needed. The list of topics for discussion (Annex A) includes a question to this effect.

The model covers the following asset categories:

Table 3.1.13-a: Asset Categories

Category	Designation of the KBF
Buildings	$KBF_{Gebäude}$
Supplementary equipment	$KBF_{Ausstattung}$
Transmission equipment	$KBF_{Übertragungstechnik}$
Switching equipment	$KBF_{Vermittlung}$
Underground copper cable	$KBF_{Röhrenkabel}$
Underground fibre cable	$KBF_{GF-Röhrenkabel}$
Buried copper cable	$KBF_{Erdkabel}$
Buried fibre cable	$KBF_{GF-Erdkabel}$
Drop segment	$KBF_{Endkabel}$
Conduit systems	KBF_{Kanal}
In-house cabling	$KBF_{Endstellenkabel}$

3.2 Costing the Subscriber Line Network

3.2.1 Costs of the Feeder Network

Costs are calculated for each quadrant of an access area. Hence the costs of the feeder cable (C_{HK}) of the entire local network are the sum total of the costs of the feeder cables of all the access areas in the local network and all the quadrants of the access areas:

$$C_{HK} = \sum_{i=1}^{n} \sum_{j=1}^{4} C_{HK_{ij}} \qquad (3.2.1\text{-}1)$$

where:

i = index of the access area where i = {1...n}

n = number of access areas in the local network

j = index of the quadrant where j = {1...4}

In costing the feeder cable, the level of infrastructure, ie trenches and conduit systems, the level of cables and the level of conductors are looked at separately. This approach defines three reference parameters – route metres, cable metres and conductor metres - for the various asset categories. From the topological perspective, the level of the infrastructure and the level of the cables can be described as forming a tree-and-branch system. The conductor level (wire pairs), by contrast, displays a star-shaped structure because, in accordance with our assumptions, a dedicated conductor to the main distribution frame is allocated to every subscriber. This separation reflects the fact that economies of density can be realised at the infrastructure level and the cable level, but not at the conductor level. Hence the formula for the costs of the feeder network of a quadrant is as follows:

$$C_{HK_{ij}} = C_{infrastructure_{ij}} + C_{cable_{ij}} + C_{conductor_{ij}} \qquad (3.2.1\text{-}2)$$

3.2.1.1 Costs of Infrastructure

The infrastructure is costed separately for the main feeder and the individual branch feeders. It is assumed that each main feeder ends at the level of the farthest distribution area. In this segment the infrastructure is shared by the cables of all distribution areas. By contrast, each distribution area is connected to the main feeder via a separate branch feeder. Hence it is assumed that there is no shared use by the cables in the separate distribution areas. This is a reasonable compromise with regard to the savings realised as a result of shared use of infrastructure, a compromise assuming, on the one hand, maximum use of economies of scope in the main feeder and, on the other, complete renunciation of the use of economies of scope in the branch feeders. The infrastructure costs per quadrant are derived from the costs of the main feeder plus the sum total of the costs of the branch feeders over all the distribution areas of the quadrant:

$$C_{infrastructure_{ij}} = C_{infrastructure\ main\ feeder_{ij}} + \sum_{k=1}^{m_{ij}} C_{infrastructure\ branch\ feeder_{ijk}} \qquad (3.2.1\text{-}3)$$

where:

k = index of the distribution area, where k = {1...m_{ij}}

m_{ij} = number of distribution areas in a quadrant j of an access area i

3.2.1.1.1 Costs of Civil Engineering

The infrastructure costs are divided into two components, materials and civil engineering. The underlying reason is to enable disaggregation of the cost components and to ensure maximum flexibility. Hence further modelling can take account of several network elements or networks sharing the infrastructure by separating the civil engineering costs as a potential block of common costs from the direct costs of materials:

$$C_{infrastructure\ main\ feeder_{ij}} = C_{trench\ main\ feeder_{ij}} + C_{materials\ main\ feeder_{ij}} \qquad (3.2.1\text{-}4)$$

$$C_{infrastructure\ branch\ feeder_{ijk}} = C_{trench\ branch\ feeder_{ijk}} + C_{materials\ branch\ feeder_{ijk}}$$

The civil engineering costs, in turn, are broken down into civil engineering costs for buried cables and civil engineering costs for setting up conduit systems. The different methods of laying cables incur different costs of investment per metre. Moreover, different capital and operating cost factors are applied to the investment sum totals.[16] At this stage, aerial cable installations could also be considered; these, however, have been excluded from the approach presented on the assumption that the access network is extended below ground without exception.

$$C_{trench\ main\ feeder_{ij}} = C_{trench\ main\ feeder\ conduit_{ij}} + C_{trench\ main\ feeder\ buried\ cable_{ij}} \qquad (3.2.1\text{-}5)$$

$$C_{trench\ branch\ feeder_{ijk}} = C_{trench\ branch\ feeder\ conduit_{ijk}} + C_{trench\ branch\ feeder\ buried\ cable_{ijk}}$$

16 Civil engineering investments in the conduit, in particular, are written off over a longer period of time than the investments in buried cables.

The civil engineering costs can now be attributed to parameters, either given as direct input or calculated elsewhere:

$$C_{trench\ main\ feeder\ conduit_{ij}} = LS_{ij} \cdot AKK_{HK} \cdot P\_GrK\_m(ZG_{HK};OF_{HK}) \cdot KBF_{Kanal}$$
$$C_{trench\ main\ feeder\ buried\ cable_{ij}} = LS_{ij} \cdot (1 - AKK_{HK}) \cdot P\_GrE\_m(OF_{HK}) \cdot KBF_{\mathrm{Erdkabel}} \quad (3.2.1\text{-}6)$$
$$C_{trench\ branch\ feeder\ conduit_{ijk}} = LA_{ijk} \cdot AKK_{HK} \cdot P\_GK\_m(ZG_{HK};OF_{HK}) \cdot KBF_{Kanal}$$
$$C_{trench\ branch\ feeder\ buried\ cable_{ijk}} = LA_{ijk} \cdot (1 - AKK_{HK}) \cdot P\_GE\_m(ZG_{HK};OF_{HK}) \cdot KBF_{Erdkabel}$$

where:

AKK_{HK} = *share of conduit routes in the feeder section*

ZG_{HK} = *number of ducts in the conduit systems*

OF_{HK} = *type of surface in the feeder segment*

KBF = *capital and operating cost factor*

LS_{ij} = *loop length in the main feeder*

P_GrK_m = *civil engineering costs per metre for conduit systems*

P_GrE_m = *civil engineering costs per metre for buried cable installation*

The variable "share of conduit" indicates the share of conduit systems in the cable routes. Hence (1-AKK_{HK}) is the share of buried cable routes. This share is established at local network level for all feeder routes. The civil engineering costs of conduit systems are a function of the number of ducts and the share of the different surfaces to be reconstructed. A duct is defined as a PVC duct with a diameter of about 10cm. The number of ducts underpinning the cost calculations is established at local network level and must therefore be considered an average value for the feeder cable routes.

The type of surface is a factor greatly affecting the costs of civil engineering because surface reconstruction accounts for a considerable, but greatly varying, share of the overall costs. It is assumed that the average civil engineering costs per metre can be found if the costs for the restoration of green areas, asphalt and interlocking pavers, the most common types of surface, are known and if weight shares in overall route kilometres are attributed to them. Hence the variable "type of surface" (OF) must be seen as a vector which includes these weight shares and the corresponding civil engineering costs. The civil engineering costs per metre of conduit systems are a function of the number of ducts and of the share in the route kilometres of the respective surfaces to be reconstructed. In the case of buried cables it is proposed that a uniform trench size be taken as a basis and only variations in the type of surface be considered.

It is clear that the type of terrain also has an impact on the base costs of civil engineering. The costs modelled should, therefore, reflect a degree of difficulty which can be considered representative. It should be emphasised that all input parameters can be determined at local network level. In principle then, it is possible to map the geological characteristics of any local network, provided the necessary information is available. Yet thought should be given here to where averaging should be performed in advance, ie not as part of the model calculations. While it would seem necessary, especially with reference to geography and demand distribution, to take averages on the basis of modelling results and not modelling assumptions, this does not seem necessary for other input parameters such as civil engineering costs. No relevant information will be lost if calculations are based on values representative of the region studied.

3.2.1.1.2 Costs of Materials

Investment in materials plays a role primarily for conduit systems. Materials for buried cables are not considered at the infrastructure level but at the cable level. Regarding this investment, a distinction is made between ducts and manholes, whereby the installation costs must always be included. Investment in manholes is computed on the basis of the number of manholes, determined by the average distance between two manholes and by the type of manhole. The type of manhole should be chosen so that it accords with the assumed number of ducts. This means if a six-bore conduit system is the basis for calculation, the size of the manhole should allow six cables to be pulled in. Hence it follows:

$$C_{materials\ main\ feeder\ _{ij}} = C_{ducts\ main\ feeder\ conduit_{ij}} + C_{manholes\ main\ feeder\ conduit_{ij}}$$

$$C_{materials\ branch\ feeder_{ijk}} = C_{ducts\ branch\ feeder\ conduit_{ijk}} + C_{manholes\ branch\ feeder\ conduit_{ijk}}$$

$$C_{ducts\ main\ feeder\ conduit_{ij}} = LS_{ij} \cdot AKK_{HK} \cdot P\_Rohr\_m \cdot ZG_{HK} \cdot KBF_{Kanal}$$

$$C_{manholes\ main\ feeder\ conduit_{ij}} = \frac{LS_{ij} \cdot AKK_{HK}}{AbsSchacht} \cdot P\_Schacht\left(ZG_{HK}\right) \cdot KBF_{Kanal} \qquad (3.2.1\text{-}7)$$

$$C_{ducts\ branch\ feeder\ conduit_{ijk}} = LA_{ijk} \cdot AKK_{HK} \cdot P\_Rohr\_m \cdot KBF_{Kanal} \cdot ZG_{HK}$$

$$C_{manholes\ branch\ feeder\ conduit_{ijk}} = \frac{LA_{ijk} \cdot AKK_{HK}}{AbsSchacht} \cdot P\_Schacht\left(ZG_{HK}\right) \cdot KBF_{Kanal}$$

where:

P_Rohr_m = cost of duct per metre

P_Schacht = cost of a manhole

AbsSchacht = average distance between manholes

3.2.1.2 Costs of Cables

At the cable level, the costs considered are those for which the reference parameter is metres of cable laid. On the one hand they include the implicit fixed investments per cable metre, that is to say the price of the cable sheath. They are determined for cables with different numbers of wires through linear regression over the costs per metre. The fixed costs correspond to the intercept of the axis, whereas the gradient of the regression line indicates the costs of an additional wire pair per metre. The costs of protective hoods and marker tape are added, whereby it is the cable metres and not the route metres that constitute the relevant reference parameter. Protective hoods and marker tape play a role only in the case of buried cables whereby protective hoods are not required along the whole cable length.[17] The basis for calculating the length of the cables is, first of all, the length of the routes in the respective quadrants. The underlying assumption is that feeder cables, starting from the main distribution frame, keep tapering and that, in the so-called branch sleeve, the wire pairs needed to connect the distribution areas are taken from the main feeder cable. In many cases, however - and this applies especially to the main feeder - several cables will be laid in parallel in a trench or a conduit system, the reason being a large number of subscribers whose wire pairs can no longer be accommodated in a cable, or the fact that conductors with different diameters are needed. For reasons of cost it may also be preferred to lay a cable in one piece instead of connecting two cables. It is possible in the model calculations to establish the number of cables for the branch feeders and

[17] For the sake of simplicity, this should be reflected in the calculations by reducing the costs per metre.

for each segment of the main feeder on the basis of the number of wire pairs and the maximum number of wires per cable needed in each individual case. The following calculations, however, draw on a factor which is multiplied by the route length for the purpose of establishing the length of the cable; hence this factor should correspond to the average number of cables in the main or the branch feeder. Comments are invited on the extent to which this simplified calculation method is deemed sufficient.

It is assumed that the costs of laying cables, ie in trenches and ducts, and the costs of jointing cables vary depending on the number of wire pairs. Hence it is the wire pair metres and not the cable metres that are taken as the relevant reference parameter. A difference is made between buried cables and underground cables because they are governed by different capital and operating cost factors. In case significant differences are later encountered which are not expected at present, it is necessary to distinguish between the costs of cables placed directly in the ground and the costs of cables laid in conduits, which, otherwise, are identical in terms of the number and diameter of wires.

$$C_{cable_{ij}} = C_{cable\,main\,feeder_{ij}} + \sum_{k=1}^{m_{ij}} C_{cable\,branch\,feeder_{ijk}} \qquad (3.2.1\text{-}8)$$

$$C_{cable\,main\,feeder_{ij}} = LS_{ij} \cdot AKK_{HK} \cdot P\_Kabel\_fix\_m \cdot K\_Tm_{main\,feeder} \cdot KBF_{Röhrenkabel} + LS_{ij} \cdot \left(1 - AKK_{HK}\right)$$
$$\cdot (P\_Kabel\_fix\_m + P\_Schutzhaube\_m + P\_Band\_m) \cdot K\_Tm_{main\,feeder} \cdot KBF_{Erdkabel}$$

$$C_{cable\,branch\,feeder_{ijk}} = LA_{ijk} \cdot AKK_{HK} \cdot P\_Kabel\_fix\_m \cdot K\_Tm_{branch\,feeder} \cdot KBF_{Röhrenkabel} + LA_{ijk} \cdot \left(1 - AKK_{HK}\right)$$
$$\cdot (P\_Kabel\_fix\_m + P\_Schutzhaube\_m + P\_Band\_m) \cdot K\_Tm_{branch\,feeder} \cdot KBF_{Erdkabel}$$

where:

P_Kabel_fix_m = fixed cost per metre of cable

K_Tm = number of cables per route metre

P_Schutzhaube_m = cost of protective hood per metre

P_Band_m = cost of marker tape per metre

k = index of the distribution area, where k = {1...m_{ij}}

m_{ij} = number of distribution areas in a quadrant j of an access area i

3.2.1.3 Costs of Conductors

As the access network is star-shaped at the wire pair level, costs may be calculated for each distribution area step by step, without shared use being taken into consideration. Again, a difference is made between buried and underground cable segments, primarily to enable the application of different capital and operating cost factors. In addition, a distinction is made between the various conductor diameters. Owing to the resistance of the copper wires being determined by their diameter, it is no longer sufficient with longer distances between main distribution frame and subscriber, to use wires with the minimum diameter (currently 0.40mm) to install a subscriber line. Instead, when distance increases, wires with a diameter of 0.60mm and 0.80mm are used, initially only for sections and then along the total length of the subscriber line. Usually, a maximum of two different diameters is used per subscriber line. Hence cost calculations must also add up the various diameters and their share in the cable. How the share of conductor diameters used is calculated is set out in section 3.1.7. The result is the parameter LL_{ijkl} which indicates how many metres of the line connecting a customer in a specific distribution area have a specific conductor diameter. This means:

$$C_{conductor_{ij}} = \sum_{k=1}^{m_{ij}} \sum_{l=1}^{3} C_{conductor_{ijkl}} \qquad (3.2.1\text{-}9)$$

$$C_{conductor_{ijkl}} = LL_{ijkl} \cdot AKK_{HK} \cdot P\_Kabel\_marginal\_m(l) \cdot DA_{HK_{ijk}} \cdot KBF_{Röhrenkabel}$$
$$+ LL_{ijkl} \cdot (1 - AKK_{HK}) \cdot P\_Kabel\_marginal\_m(l) \cdot DA_{HK_{ijk}} \cdot KBF_{Erdkabel}$$

where:

k = *index of the distribution area, where k = {1...m_{ij}}*

m_{ij} = *number of distribution areas in a quadrant j of an access area i*

l = *index of the wire diameter, where l = {1, 2, 3}*
l=1 equals 0.4 mm; l=2 equals 0.6 mm; l=3 equals 0.8 mm

P_Kabel_marginal_m = *price per metre of wire pair*

$DA_{HK_{ijk}}$ = *number of wire pairs in the feeder cable of a distribution area*

The marginal costs of a cable indicate the costs of a wire pair per metre. They correspond to the gradient of the regression line ascertained on the basis of the costs of different cables with a different number of wires. It must be noted that the marginal costs of the cable must include not only the net costs of materials but also an element for cable laying, because the costs of cable laying per metre rise as the number of wires increases. Cable laying costs also include the costs of the connecting sleeves. Comments are invited on whether the wire pair metre is the appropriate reference parameter to reflect the costs of sleeves, or whether other reference parameters mentioned (eg cable metre or route metre), or yet other reference parameters still to be introduced should be selected.

3.2.2 Costs of the Distribution Network

The distribution network connects the termination point of the general network - located usually in the subscriber distribution interface on or at the customer's premises - to the nearest cross-connection point in the access network, which provides access to the feeder network through the feeder-distribution interface installed at ground level. Within the distribution network the costs of the drop segment between the distribution cable and the subscriber distribution interface are looked at separately (cf section 3.2.3). The in-house cabling from the subscriber distribution interface to the socket (TAE) must also be costed
(cf section 3.2.4). However, as the costs of in-house cabling vary greatly with the specific circumstances prevailing at the location of the subscriber line, we recommend that this cost element be looked at in only a general way in the absence of more detailed information.

The size of a distribution area varies with subscriber density. Distribution areas tend to be smaller when subscriber density is high. This is reflected in the model which looks at three different sizes of distribution area. Starting from a standard size of 600 x 600m per grid square, the distribution areas are divided into two or four if the predetermined number of subscriber lines is exceeded. Each distribution area has a feeder-distribution interface which connects all the subscriber lines in the distribution area with the feeder cable.[18] The wire pairs which run from the feeder-distribution interface and have a star-shaped structure, are laid in cables and trenches forming a tree-and-branch system. The diagram below shows the stylised structure of a distribution area.

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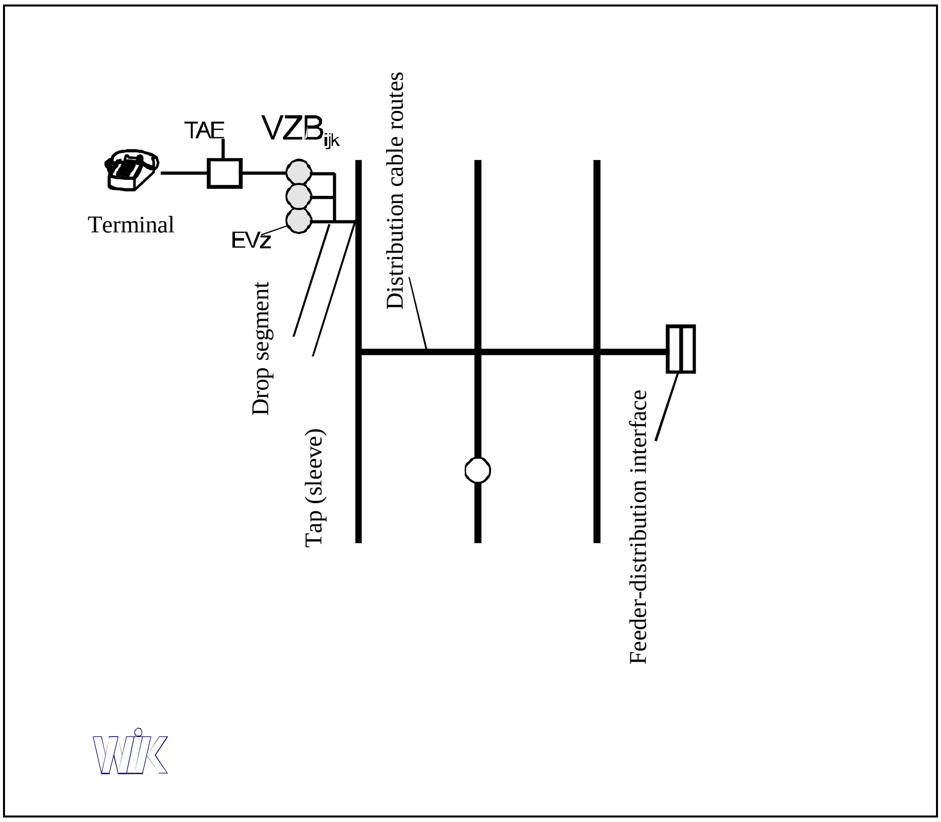
[18] The few cases in which customers located near a main distribution frame are connected directly and not through a cross-connection point in the form of a feeder-distribution interface are not covered here.

Figure 3.2.2-A: Stylised Structure of a Distribution Network



he overall costs of the distribution network (C_{VZB}) are built up from the costs of the individual distribution areas.

$$C_{VZB} = \sum_{i=1}^{n} \sum_{j=1}^{4} \sum_{k=1}^{m_{ij}} C_{VZB_{ijk}} \qquad (3.2.2\text{-}1)$$

i = *index of the access area where i = {1...n}*

j = *index of the quadrant where j = {1...4}*

k = *index of the distribution area where k = {1..*m_{ij}*}*

m_{ij} = *number of distribution areas in a quadrant j of an access area i*

Just like the costs of the feeder network, the costs of a distribution area are made up of the total costs of infrastructure, conductors and cables. On top of this are the costs for connecting the subscriber to the distribution network (drop segment network, final drop), which are considered separately. The costs of the feeder-distribution interfaces are added to the costs of the infrastructure. Otherwise the formulae, with the exception of the formula for costing the drop segment network, follow the same logic as those for costing the feeder cables. The variables determining the composition of the surfaces to be reconstructed, the share of conduit routes and number of ducts they contain as well as the spare capacity and leased line factors in the distribution cable can be indicated separately for each of the three categories of density. In general, we may assume that the share of conduit systems in the distribution network is smaller than in the feeder network, and will keep diminishing as subscriber density falls:

$$C_{VZB_{ijk}} = C_{infrastructure_{ijk}} + C_{cable_{ijk}} + C_{conductor_{ijk}} + C_{drop\ segment_{ijk}} \qquad (3.2.2\text{-}2)$$

3.2.2.1 Costs of Infrastructure

$$C_{infrastructure_{ijk}} = C_{trench_{ijk}} + C_{materials_{ijk}} + C_{feeder\ distribution\ interface_{ijk}} \qquad (3.2.2\text{-}3)$$

3.2.2.1.1 Costs of Civil Engineering

$$C_{trench_{ijk}} = C_{trench\ conduit_{ijk}} + C_{trench\ buried\ cable_{ijk}} \qquad (3.2.2\text{-}4)$$

$$C_{trench\ conduit_{ijk}} = LG_{ijk} \cdot AKK_{VZB}(VZB - type) \cdot P\_GrK\_m\left(ZG_{VZB}(VZB\text{-}type); OF_{VZB}(VZB - Typ)\right) \cdot KBF_{Kanal}$$

$$C_{trench\ buried\ cable_{ijk}} = LG_{ijk} \cdot \left(1 - AKK_{VZB}(VZB - type)\right) \cdot P\_GrE\_m\left(OF_{VZB}(VZB - type)\right) \cdot KBF_{Erdkabel} \qquad (3.2.2\text{-}5)$$

where:

LG = route length in the distribution area

AKK_{VZB} = share of conduit routes in the distribution area

ZG_{VZB} = average number of ducts in the conduit systems in the distribution area

OF_{VZB} = type of surface in the distribution area

KBF = capital and operating cost factor

3.2.2.1.2 Costs of Materials

$$C_{materials_{ijk}} = C_{ducts\ VZB\ conduit_{ijk}} + C_{manholes\ VZB\ conduit_{ijk}} \qquad (3.2.2\text{-}6)$$

$$C_{ducts\ VZB\ conduit_{ijk}} = LG_{ijk} \cdot AKK_{VZB}(VZB - Typ) \cdot P\_Rohr\_m \cdot ZG_{VZB}(VZB - Typ) \cdot KBF_{Kanal} \qquad (3.2.2\text{-}7)$$

$$C_{manholes\ VZB\ conduit_{ijk}} = \frac{LG_{ijk} \cdot AKK_{VZB}}{AbsSchacht} \cdot P\_Schacht\ (ZG_{VZB}(VZB\text{-}Typ)) \cdot KBF_{Kanal} \qquad (3.2.2\text{-}8)$$

3.2.2.1.3 Costs of the Feeder-Distribution Interface

$$C_{feeder\ distribution\ interface_{ijk}} = P\_KVZ \cdot KBF_{conduit} \qquad (3.2.2\text{-}9)$$

P_KVz = cost of a feeder-distribution interface

3.2.2.2 Costs of Cables

$$C_{cable_{ijk}} = LG_{ijk} \cdot AKK_{VZB}(VZB-Typ) \cdot P\_Kabel\_fix\_m \cdot K\_Tm_{VZB} \cdot KBF_{Röhrenkabel} + LG_{ijk} \cdot (1-AKK_{VZB}(VZB-Typ)) \cdot (P\_Kabel\_fix\_m + P\ Band\_m + P\_Schutzhaube\_m) \cdot K\_Tm_{VZB} \cdot KBF_{Erdkabel}$$

(3.2.2-10)

3.2.2.3 Costs of Conductors

$$C_{conductor_{ijk}} = LLVZB_{ijk} \cdot AKK_{VZB} \cdot P\_Kabel\_marginal\_m(l) \cdot DA_{VZB_{ijk}} \cdot KBF_{Röhrenkabel} + LLVZB_{ijk} \cdot (1-AKK_{VZB}) \cdot P\_Kabel\_marginal\_m(l) \cdot DA_{VZB_{ijk}} \cdot KBF_{Erdkabel} \quad (3.2.2\text{-}11)$$

$DA_{VZB_{ijk}}$ = *number of wire pairs in the distribution area* VZB_{ijk}

3.2.3 Costs of the Drop Segment Network

The drop segment network is defined as the connection between buildings in which there are one or more subscribers, and the distribution cable, usually laid in public land. What counts is the costs of the subscriber distribution interface. This is used as an element of the termination point of the general network (APL) and connects the access network to the cabling inside the building (in-house cabling), the junction cable to the distribution cable (drop segment) and the tap (sleeve) of the distribution cable, where the wire pairs for the subscriber line are taken from the distribution cable. Costing is difficult because costs per subscriber line vary greatly, mainly with the type of building. Significant cost factors are, on the one hand, the average length of connection, derived from the distance between the building and the distribution cable, ie usually the distance to the next street, and on the other, the number of subscribers per building, which determines the extent to which costs may be reduced through shared use of the subscriber distribution interface, trenches, cables and taps. Development density and the type and size of building yield significant economies of density. Such economies may be reflected by differentiating the variables mentioned - lines per subscriber distribution interface, per drop segment, per tap and finally length of drop segment - by type of distribution area and thus currently by three categories of subscriber density. Further differentiation would seem helpful only if there is sufficiently refined data to hand. The costs of the drop segment, in turn, are determined by the cost drivers trench length, cable length and conductor length.

$$C_{drop\ segment\ _{ijk}} = C_{tap_{ijk}} + C_{subscriber-distribution\ interface_{ijk}} + C_{trench\ connection_{ijk}} + C_{cable\ connection_{ijk}} + C_{conductor\ connection_{ijk}}$$

(3.2.2-12)

$$C_{tap_{ijk}} = M\_Asl(VZB\text{-}Typ) \cdot Asl\_VZB_{ijk} \cdot P\_M \cdot KBF_{Endkabel} \qquad (3.2.2\text{-}13)$$

$$C_{subscriber-distribution\ interface_{ijk}} = EVz\_Asl(VZB\text{-}Typ) \cdot Asl\_VZB_{ijk} \cdot P\_EVz \cdot KBF_{Endkabel}$$

(3.2.2-14)

$$C_{trench\ drop\ segment_{ijk}} = G\_Asl(VZB-Typ) \cdot Asl\_VZB_{ijk} \cdot LH(VZB-Typ) \cdot P\_GE\_m\left(OF\right) \cdot KBF_{Endkabel}$$

(3.2.2-15)

$$C_{cable\ drop\ segment_{ijk}} = G\_Asl(VZB-Typ) \cdot Asl\_VZB_{ijk} \cdot LH(VZB-Typ) \cdot P\_Kabel\_fix\_m \cdot KBF_{Endkabel}$$

(3.2.2-16)

$$\begin{aligned} \mathrm{C}_{conductor\ drop\ segment_{\mathrm{ijk}}} = {} & \mathrm{DA\_Asl(VZB\text{-}Typ) \cdot Asl\_VZB_{ijk} \cdot LH(VZB-Typ)} \cdot \\ & P\_Kabel\_marginal\_m(l) \cdot KBF_{Endkabel} \end{aligned} \qquad (3.2.2\text{-}17)$$

where:

P_M = cost of a tap

P_EVz = cost of a subscriber distribution interface

M_Asl = number of sleeves per subscriber line (M_Asl £ 1, ie a value of 0.1 means that an average of 10 lines is connected via one sleeve.)

EVz_Asl = subscriber distribution interfaces per subscriber line (see above)

G_Asl = number of trenches per subscriber line (see above)

DA_Asl = number of wire pairs per subscriber line

LH = average length of final drop

VZB-Typ = type of distribution area

3.2.4 Costs of In-House Cabling

On account of high line specificity, the connection between the subscriber distribution interface and the socket (TAE) cannot be costed precisely in a generic model. Hence we would propose using three values to reflect the average investment cost per access in the three subscriber density categories defined. It then follows:

$$C_{in\text{-}house\ cabling} \sum_{i=1}^{n} \sum_{j=1}^{4} \sum_{k=1}^{m_{ij}} C_{in\text{-}house\ cabling_{ijk}} \qquad (3.2.2\text{-}18)$$

$$C_{in\text{-}house\ cabling_{ijk}} = Asl\_VZB_{ijk} \cdot \left(P\_EndStk\ (VZB-Typ)\ +\ P\_TAE\right) \cdot KBF_{Endstellenkabel}$$

(3.2.2-19)

3.2.5 Costs of the Main Distribution Frame

The costs of the main distribution frame are modelled as a linear function of the wire pairs in the feeder cable. A fixed component covers the costs of housing the main distribution frame and the costs of the rooms needed for cabling into the building of the exchange or the concentrator unit.

$$C_{HVt} = \sum_{i=1}^{n} C_{HVt_i} \quad (3.2.2\text{-}20)$$

$$C_{HVt_i} = P\_HVt\_Fix \cdot KBF_{Gebäude} + P\_HVt\_DA \sum_{j=1}^{4} \sum_{k=1}^{m_{ij}} DA_{HK_{ijk}} \cdot KBF_{Ausstattung} \quad (3.2.2\text{-}21)$$

where:

P_HVt_Fix = *base price of the main distribution frame*

P_HVt_DA = *cost of the main distribution frame per wire pair*

$DA_{HK_{ijk}}$ = *number of wire pairs in the feeder cable for the subscriber lines in the distribution area* VZB_{ijk}

3.3 Costing Switching Equipment

The costs of the switching units at local network level are made up of the costs of the local exchange (TVSt) and the costs of the remote concentrators, which constitute remotely located functional units of the local exchange. Nevertheless it is advisable to cost the concentrator units separately, because the costs of accommodation, etc are incurred at every site and the indivisibilities of investment must be taken into consideration. The formulae below and the relevant module designations relate to the Siemens EWSD system (Digital Electronic Switching System).[19]

For the purpose of costing it is necessary to know the access areas that are connected to the various local exchanges either directly or via remote concentrators. The assumption is that the remote concentrators are allocated to just one exchange. It is also assumed that this allocation is known (cf section 3.1.10). It can then be taken as a basis for dividing a local network into one or more exchange areas. In this context, exchange areas are defined as the combined access areas for which switching functions are carried out in one and the same local exchange. Hence it follows:

$$C_{exchange} = \sum_{a=1}^{s} C_{VB_a} \quad (3.3\text{-}1)$$

$$C_{VB_a} = C_{local\ exchange_a} + \sum_{d=1}^{t_a} C_{remote\ concentrator_{ad}} \quad (3.3\text{-}2)$$

where C_{VB} = *costs of an exchange area*

3.3.1 Costs of the Local Exchange

Costing the local exchange is based on the assumption that three major cost drivers can be identified, specifically the number of subscribers directly connected, ie the subscribers in the own access area, holding time of the incoming and outgoing channels and the number of call attempts (events). Apart from this, costs are incurred which cannot be attributed directly to any of the cost drivers mentioned, such as the costs for housing the exchange, power supply, air conditioning and the like. The following then applies:

$$C_{TVSt} = C_{access} + C_{usage} + C_{building\ and\ equipment} \quad (3.3.1\text{-}1)$$

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19 See Siemens AG (editor): Technische Systembeschreibung für EWSD-Version 11, o.J. and Siemens AG (editor): Technische Unterlage VE-Ausbau und Verkehrsleistungsdaten für die EWSD-Versionen 11 u. 12, 1997. It is assumed that the costs of the EWSD system will be largely similar to those of System S12, also used by DTAG.

3.3.1.1 Access-Related Costs

First, assessment of the access-related costs is described briefly.[20] No distinction is made in costing the subscriber line network between types of access, it being assumed that both analogue and ISDN basic rate access lines can be realised over a copper wire pair without any changes to outside plant. However, the line termination (line card) in the exchange is differentiated by types of access. The costs of the subscriber line interface modules can be expressed as costs per analogue line or per ISDN basic rate line.

The EWSD system uses two elements as interface units for analogue (SLMA) and ISDN basic rate access lines (SLMD), both capable of connecting 16 subscribers. Hence the access-related non-traffic sensitive total costs of the local exchange (TVSt) are:

$$C_{access} = Asl\_analog_{a0} \cdot \frac{P\_SLMA}{16} \cdot KBF_{Vermittlung} + Asl\_digital_{a0} \cdot \frac{P\_SLMD}{16} \cdot KBF_{Vermittlung} \qquad (3.3.1\text{-}2)$$

where:

Asl_analog = *number of analogue subscriber lines in the access area of the local exchange*

Asl_digital = *number of digital subscriber lines in the access area of the local exchange*

P_SLMA = *cost of an analogue subscriber line module (SLMA)*

P_SLMD = *cost of a digital subscriber line module (SLMD)*

3.3.1 2 Usage-Based Costs

Usage-based costs can be related to traffic demand, expressed in Erlangs, and also to the number of call attempts (CA):

$$C_{usage_a} = C_{Erlang_a} + C_{CA_a} \qquad (3.3.1\text{-}3)$$

3.3.1.2.1 Holding-Time-Sensitive Costs

Holding-time-sensitive costs are derived from the provision of channels in the switching network, in the digital line units (DLU) and in the access and network-facing line trunk groups (LTG), determined by busy hour traffic volume:

$$C_{Erlang_a} = C_{DLU_a} + C_{LTG\ subscriber_a} + C_{LTG\ network_a} + C_{switching\ network_a} \qquad (3.3.1\text{-}4)$$

The first step is to identify the necessary number of digital line units (DLU). Each DLU has a limited number of slots for subscriber line interface modules, which means that there is a binding upper limit to the number of subscribers per DLU, independent of the traffic volume.[21] The main function of the DLU is to concentrate outgoing subscriber traffic on 2 Mbit/s multiplex lines. Each DLU provides 120 user-information channels to the switching network in the form of 4 x 2 Mbit/s. Based on subscriber traffic and on the Erlang loss formula, the necessary number of DLUs per access area is identified in section 3.1.11.

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[20] Access-related costs of the local exchange must be taken into account in costing access. They are neither part of the interconnection costs, nor of the costs of access to the subscriber line at the point of unbundling in the main distribution frame.

[21] In the case of Version 11 55 SLMAI/SLMD this ceiling is 880 subscribers.

Hence it follows:

$$C_{DLU_a} = \# DLU_a \cdot P\_DLU \cdot KBF_{Vermittlung} \qquad (3.3.1\text{-}5)$$

where

P_DLU = cost of a digital line unit

Two digital line units are both connected crosswise to two line trunk groups (LTG) which provide the uniform interface to the switching network. This arrangement means that the number of subscriber-facing line trunk groups corresponds to the number of digital line units at the exchange plus the digital line units for connection of the remotely located digital line units:[22]

$$C_{LTG\ subscriber_a} = \sum_{d=0}^{t_x} \# DLU_{ad} \cdot P\_LTG \cdot KBF_{Vermittlung} \qquad (3.3.1\text{-}6)$$

where:

P_LTG = cost of a line trunk group

Line trunk groups also provide the interface to the interoffice network, ie to installations for transmission to and from other exchanges. Each LTG provides interfaces for 4 x 2Mbit/s junction lines (DSV2). To ascertain the number of network-facing LTGs per exchange it is necessary to determine the number of DSV2s connected to the local exchange for the purpose of handling the external traffic of the exchange, ie traffic coming from or going to another exchange. The method for establishing the number of DSV2s for connections within the local network and for connections to the long-distance network is described in section 3.1.10. Hence it follows:

$$C_{LTG\ network_a} = \# DSV2_a \cdot P\_LTG \cdot KBF_{Vermittlung} \qquad (3.3.1\text{-}7)$$

The incoming and outgoing channel is connected through in the switching network, which performs this function by changing the position of a 64 kbit/s channel within a multiplex line and by changing the multiplex line while retaining the time slot of the channel (space stage). The combination of time and space stages more or less ensures full accessibility, ie an incoming channel can be connected to any outgoing channel.

The basic configuration of the switching network in the EWSD system offers a switching capacity of 120 x 2 Mbit/s. This configuration is extended in steps of a further 120 x 2 Mbit/s, up to a maximum capacity of 1920 x 2 Mbit/s.

The necessary number of 2 Mbit/s lines in the switching network can be found by adding the subscriber and network-facing line trunk groups (LTG) and multiplying the result by 4, since each LTG can take 4 x 2 Mbit/s. As a next step the number of switching network elements is obtained by dividing the 2 Mbit/s lines by 120 and then rounding them up in order to allow for indivisibilities:

$$C_{switching\ network_a} = rounded\ up\left[\left(\# LTG_{subscriber_a} + \# LTG_{network\ a}\right) \cdot 4 \div 120\right] \cdot P\_KN \cdot KBF_{Vermittlung} \qquad (3.3.1\text{-}8)$$

where:

P_KN = cost of a switching network element

[22] LTGs for subscribers not connected via a DLU may be added, but this is not taken into account here.

3.3.1.2.2 Event-Sensitive Costs

In digital switching centres it is a microprocessor, in the EWSD context called a coordination processor (CP), that searches for a free channel in the switching network in order to meet the caller's request for connection.[23] The functions performed by this processor include the evaluation of signalling information, path selection and through-connection in the switching network, routing or tariffing and charging. These tasks are fulfilled one by one for every call attempt. Hence the capacity of a microprocessor-controlled exchange is determined by the number of busy hour call attempts, which also include call attempts not resulting in complete call set-up to the subscriber. Total holding time, however, is of minor relevance to the processor capacity required. The dynamic performance of an exchange is therefore expressed in busy hour call attempts (BHCA). These can be established by dividing subscriber traffic, expressed in minutes, by average holding time and dividing the result by a factor for unsuccessful call attempts (cf section 3.1.10). It must be taken into account that intraoffice calls mean one call set-up only; therefore, only outgoing intraoffice traffic per subscriber is taken into consideration in order to avoid duplicated counts.

It is assumed that, for reasons of indivisibilities, investment in call processing capacity is fixed, provided the requirements made of dynamic performance are low. Above a certain BHCA threshold, processor control will need to be stepped up gradually by additional hardware and adapted software**.** The EWSD system can be expanded in steps of 1000 BHCA. As the provision of call processing capacity depends on the interaction of a variety of elements and control software, the detailed recording of which entails great expense, we would propose, as a pragmatic alternative to the usual approach, determining the volume of event-sensitive investment in a similar fashion to the system manufacturers, ie quoting prices not for individual elements but for call processing functionality as a whole.

Total event-sensitive investment is then as follows:

$$C_{CP} = \begin{bmatrix} \left| P\_CP \cdot KBF_{Vermittlung} \right| \; für\ BHCA_{D_{TVSt_a}} \leq Kap\_CP \\ \left| \left(P\_CP + rounded\ up\left(\frac{BHCA_{D_{TVSt_a}} - Kap\_CP}{1000} \right) \cdot P\_BHCA \right) \cdot KBF_{Vermittlung} \right| \\ for\ BHCA_{D_{TVSt_a}} > Kap\_CP \end{bmatrix} \quad (3.3.1\text{-}9)$$

where:

P_CP = *base price of processor control*

BHCA_TVSt = *traffic load of a local exchange*

P_BHCA = *cost of an additional 1000 BHCA call processing capacity*

Kap_CP = *call processing capacity expressed in BHCA of an exchange with basic equipment*

3.3.1.3 Costs of Housing and Equipping Exchanges

Finally, the costs that cannot be attributed directly to any of the cost drivers mentioned must be taken into account. These include costs incurred for investments in housing, power supply including stand-by power supply, air conditioning, terminals for maintenance and operation, spare parts, repair shop equipment, office equipment, furniture, etc. It is assumed that these investments can be expressed in absolute figures per local exchange. The capital and operating cost factors applied

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[23] Strictly speaking, a coordination processor consists of several processors performing different functions.

should reflect the longer economic lifetime, on average, of buildings and supplementary equipment than of the other hardware and software in the exchange. The costs of housing and equipping exchanges are then as follows:

$$C_{building+equipment_{TVSt}} = P\_housing_{TVSt} \cdot KBF_{Gebäude} + P\_equipment_{TVSt} \cdot KBF_{Ausstattung}$$

(3.3.1-10)

3.3.2 Costs of Remote Concentrators

In principle, remote concentrators are costed in the same way as the exchanges. It is not necessary therefore to detail the calculation formulae here. Line cards (SLMA/SLMD) and digital line units (DLU) are remotely located. Line trunk groups (LTG) are located exclusively in the local exchange. In accordance with our assumptions, the concentrators do not perform any switching functions so that usage-sensitive costs are reduced to the costs of the digital line units. As less space is required and fewer functions have to be performed, the costs of housing and equipment are lower than those for a local exchange (TVSt):

$$C_{AK} = C_{access\,AK} + C_{Erlang_{AK}} + C_{building+equipment_{AK}} \qquad (3.3.2\text{-}1)$$

where:

$$C_{building+equipment_{AK}} = P\_housing_{AK} \cdot KBF_{Gebäude} + P\_equipment_{AK} \cdot KBF_{Ausstattung} \qquad (3.3.2\text{-}2)$$

3.4 Costing the Transmission Paths in the Local Network

3.4.1 Connections between Remote Concentrator and Local Exchange

As remote concentrators do not perform any switching functions, all subscriber traffic is routed to the allocated local exchange via optical fibre. Hence it is not necessary to distinguish between connections whose source and sink is in the same access area, and connections to other access areas. Transmission systems can be split into terminal equipment (multiplexers and optical line terminals), regenerative repeaters and outside plant which, as in the access area, can be divided into the levels of infrastructure, cables and conductors. In the following the assumption is made that the number of fibres per cable is fixed so that only the cable level need be looked at. The remote concentrators are connected to one exchange only so that the network has a star-shaped structure at all levels. The costs of connecting the concentrators in the entire local network are expressed as follows:

$$C_{transport} = \sum_{a=1}^{s} \sum_{d=1}^{t_a} C_{transport_{ad}} \qquad (3.4.1\text{-}1)$$

$$C_{transport} = C_{transmission\ equipment} + C_{ZWR} + C_{outside\ plant} \qquad (3.4.1\text{-}2)$$

3.4.1.1 Costs of Transmission Equipment

The costs of transmission equipment at both ends of a connection can be broken down into the costs of multiplexers and those of line terminals. Assuming that optical fibres are used for transmission, it is then necessary to transform the 2 Mbit/s signals into a 140 Mbit/s stream. To this end, the PDH technology is required to go through several steps of the multiplexer hierarchy (2/34 Mbit/s and 34/140 Mbit/s) at both ends of the connection. First of all, the total subscriber traffic of a remote concentrator is transformed into the equivalent of 2 Mbit/s. As connections are provided between the DLU and the LTG, the number of 2 Mbit/s lines (DSV2s) is derived from the number of DLUs multiplied by 4 plus another DSV2 for the provision of leased lines in accordance with a given factor.

If necessary, this value can be increased again to allow for spare capacity in the transmission network (cf section 2.3.5).[24] This means:

$$C_{transmission\ equipment\ ad} = (\#MUX_{2/34} \cdot P\_MUX_{2/34} + \#MUX_{34/140} \cdot P\_MUX_{34/140} + \#LE140 \cdot P\_LE140) \cdot KBF_{Übertragungstechnik} \quad (3.4.1.\text{-}3)$$

where:

$$\#MUX_{2/34} = rounded\ up\left(\frac{\#DSV2_{ad} \cdot FV\_Fkt \cdot Res\_Fkt}{16}\right)$$

$$\#MUX_{34/140} = rounded\ up\left(\frac{\#MUX_{2/34}}{4}\right) \quad (3.4.1\text{-}4)$$

$$\#LE140 = \#MUX_{34/140}$$

where:

$\#MUX_{x/y}$ = *number of multiplexer pairs at a given multiplexing stage*

#DSV2 = number of DSV2s

#LE140 = number of 140 Mbit/s line terminal pairs

$P\_MUX_{x/y}$ = *cost of a multiplexer pair at a given multiplexing stage*

P_LE140 = cost of 140 Mbit/s line terminal pairs

FV_Fkt = leased line factor on the DSV2

Res_Fkt = spare capacity factor on the DSV2

3.4.1.2 Costs of Regenerative Repeaters

Longer transmission paths require regenerative repeaters (ZWR) at regular intervals:

$$C_{ZWR} = \begin{bmatrix} \left| rounded\ up\left(\frac{AK_{ad}\_TVSt_a}{Abs\_ZWR}\right) \cdot P\_ZWR \cdot KBF_{Übertragungstechnik} \right| für \frac{AK_{ad}\_TVSt_a}{Abs\_ZWR} \geq 1 \\ \left| 0 \right| for \frac{AK_{ad}\_TVSt_a}{Abs\_ZWR} < 1 \end{bmatrix} \quad (3.4.1\text{-}5)$$

where:

$AK_{ad}\_TVSt_a$ = *distance between remote concentrator and local exchange*

P_ZWR = cost of a regenerative repeater

Abs_ZWR = maximum distance between regenerative repeaters

3.4.1.3 Costs of Outside Plant

The costs of outside plant are derived from the costs of cable installation and the costs of the optical fibre cable.

$$C_{outside\ plant} = C_{infrastructure} + C_{cable} \quad (3.4.1\text{-}6)$$

24 DLUs not fully used are disregarded here.

3.4.1.3.1 Costs of Infrastructure

The costs of infrastructure are built up from the distance between remote concentrator and local exchange. Assumptions must also be made on cable installation and costs per metre as a function of surface and type of terrain.

$$C_{infrastructure} = C_{trench} + C_{materials} \qquad (3.4.1\text{-}7)$$

$$C_{trench} = C_{trench\ conduit} + C_{trench\ buried\ cable} \qquad (3.4.1\text{-}8)$$

$$C_{trench\,cable} = AK_{ad}\_TVSt_a \cdot AKK_{VK} \cdot P\_GrK\_m(ZG_{VK};OF_{VK}) \cdot KBF_{Kanal}$$
$$C_{trench\,buried\,cable} = AK_{ad}\_TVSt_a \cdot \left(1 - AKK_{VK}\right) \cdot P\_GrE\_m(OF_{VK}) \cdot KBF_{GF\_Erdkabel} \qquad (3.4.1\text{-}9)$$

$$C_{materials} = C_{ducts} + C_{tape/\ protective\ hoods} + C_{manholes} \qquad (3.4.1\text{-}10)$$

$$C_{ducts} = AK_{ad}\_TVSt_a \cdot AKK_{VK} \cdot P\_Rohr\_m \cdot ZG_{VK} \cdot KBF_{Kanal}$$
$$C_{manholes} = \frac{AK_{ad}\_TVSt_a \cdot AKK_{VK}}{Abs\_Schacht} \cdot P\_Schacht\left(ZG_{VK}\right) \cdot KBF_{Kanal}$$
$$C_{tape/\ protective\ hoods} = AK_{ad}\_TVSt_a \cdot (1 - AKK_{VK}) \cdot (P\_Band\_m + P\_Schutzhaube\_m) \cdot KBF_{GF\_Erdkabel} \qquad (3.4.1\text{-}11)$$

where:

AKK_{VK} = share of conduit routes in the junction cable

3.4.1.3.2 Costs of Cables

It is assumed that monomode fibre cables with 12 fibres are used in an optical fibre system. The costs per metre must reflect laying and splicing. The costs of cables are then expressed as:

$$C_{cable} = AK_{ad}\_TVSt_a \cdot AKK_{VK} \cdot P\_GF\_m \cdot KBF_{GF\_Röhrenkabel} + AK_{ad}\_TVSt_a \cdot (1 - AKK_{VK}) \cdot P\_GF\_m \cdot KBF_{GF\_Erdkabel} \qquad (3.4.1\text{-}12)$$

where:

P_GF_m = costs of optical fibre per metre

The costs established thus are apportioned to switched connections and leased lines according to the DSV2 provided.

3.4.2 Connections between Exchanges in the Local Network

The cost drivers already described for connections between remote concentrator and local exchange are relevant to transport between local exchanges. Required beforehand, however, is determination of the traffic relations within the local network. First of all, subscriber traffic is divided into traffic remaining within the area served by the exchange, ie calling and called party are within the same exchange area. The remaining traffic can be described as external traffic, either going to a subscriber in the same local network or leaving the local network. The conventions set out below then determine the logical network. A given share of total expected subscriber traffic is declared as external traffic (long-distance traffic). This traffic is routed to a point within the local network, serving as a point of interconnection to the long-distance network. In accordance with our assumptions, this interconnection point is co-located with a local exchange. The remaining local traffic is apportioned to the local exchange according to the share of the subscriber traffic of an exchange in the subscriber traffic of the local network as a whole. Symmetry between outgoing and incoming traffic is assumed. The exchanges of the local network are fully meshed at the logical level, ie a local connection is not switched more than twice: in the local exchange in the area of origin and in the local exchange in the area of destination.

Based on the logical traffic relations the physical network is designed as follows. The logical connections between two local exchanges match a transmission system between the network nodes which is dimensioned on the basis of direct traffic plus leased lines. Also taken into account in the interoffice network are 565 Mbit/s optical fibre systems, used if more than one 140 Mbit/s system would otherwise be needed. In accordance with our assumptions, long-distance traffic is routed together with the local traffic, on a shared transmission system, to a local exchange co-located with the point of interconnection to the long-distance network. Cost calculations are then, for the most part, similar to the above costing of connections between concentrator and local exchange. Hence it follows:

$$C_{interoffice\ network} = \sum C_{interoffice\ connection_{x|y}} \quad (3.4.2\text{-}1)$$

$$C_{interoffice\ connection_{x|y}} = C_{terminal\ equipment} + C_{repeater} + C_{outside\ plant} \quad (3.4.2\text{-}2)$$

3.4.2.1 Costs of Transmission Equipment

$$C_{terminal\ equipment_{x|y}} = (\#\ MUX_{2/34} \cdot P\_\ MUX_{2/34} + \#\ MUX_{34/140} \cdot P\_\ MUX_{34/140} + \#\ MUX_{140/565} \cdot P\_\ MUX_{140/565} + \#\ LE140 \cdot P\_\ LE140 + \#\ LE565 \cdot P\_\ LE565) \cdot KBF_{Übertragungstechnik}$$

(3.4.2-3)

where:

$$\#\ MUX_{2/34} = rounded\ up\left(\frac{\left(\#\ DSV2_{x/y} + \#\ DSV2_{x/FVSt}\right) \cdot FV\_\ Fkt \cdot Res\_\ Fkt}{16}\right)$$

$$\#\ MUX_{34/140} = rounded\ up\left(\frac{\#\ MUX_{8/34}}{4}\right)$$

$$\#\ MUX_{140/565} = rounded\ up\left(\frac{\#\ MUX_{34/140}}{4}\right)\ for\ \#\ MUX_{34/140} > 1,\ 0\ otherwise \quad (3.4.2\text{-}4)$$

$$\#\ LE140 = \begin{bmatrix} \left|\ \#\ MUX_{34/140}\right|\ for\ \#\ MUX_{34/140} = 1 \\ \left|\ 0\ \right|\ for\ \#\ MUX_{34/140} > 1 \end{bmatrix}$$

$$\#\ LE565 = \#\ MUX_{140/565}$$

3.4.2.2 Costs of Regenerative Repeaters

$$C_{ZWR} = \begin{bmatrix} \left|\ rounded\ up\left(\frac{TVSt_x\_TVSt_y}{Abs\_\ ZWR}\right) \cdot P\_\ ZWR \cdot KBF_{Übertragungstechnik}\ \right|\ for\ \frac{TVSt_a\_TVSt_b}{Abs\_\ ZWR} \geq 1 \\ \left|\ 0\ \right|\ for\ \frac{TVSt_a\_TVSt_b}{Abs\_\ ZWR} < 1 \end{bmatrix}$$

(3.4.2-5)

3.4.2.3 Costs of Outside Plant

3.4.2.3.1 Costs of Infrastructure

$$C_{infrastructure_{x|y}} = C_{trench} + C_{materials} \quad (3.4.2\text{-}6)$$

$$C_{trench} = C_{trench\ conduit} + C_{trench\ buried\ cable} \quad (3.4.2\text{-}7)$$

$$C_{trench\,conduit} = TVST_x\_TVSt_y \cdot AKK_{VK} \cdot P\_GK\_m(ZG_{VK};OF_{VK}) \cdot KBF_{Kanal}$$
$$C_{trench\ conduit} = TVST_x\_TVSt_y \cdot \left(1 - AKK_{VK}\right) \cdot P\_GE\_m(OF_{VK}) \cdot KBF_{GF\_Erdkabel} \quad (3.4.2\text{-}8)$$

$$C_{materials} = C_{conduits} + C_{tape/\ protective\ hoods} + C_{manholes} \quad (3.4.2\text{-}9)$$

$$C_{ducts} = TVSt_x\_TVSt_y \cdot AKK_{VK} \cdot P\_Rohr\_m \cdot ZG_{VK} \cdot KBF_{Kanal}$$
$$C_{manholes} = \frac{TVSt_x\_TVSt_y \cdot AKK_{VK}}{Abs\_Schacht} \cdot P\_Schacht\left(ZG_{VK}\right) \cdot KBF_{Kanal}$$
$$C_{tape/\ protective\ hoods} = TVSt_x\_TVSt_y \cdot (1 - AKK_{VK}) \cdot (P\_Band\_m + P\_Hauben\_m) \cdot KBF_{GF\_Erdkabel}$$

(3.4.2-10)

3.4.2.3.2 Costs of Cables

It is assumed that monomode fibre cables with 12 fibres are used for 140 Mbit/s and 565 Mbit/s optical fibre systems. Costs per metre include the laying and splicing of cables. The cable costs are then derived as follows:

$$C_{cable} = TVSt_x\_TVSt_y \cdot AKK_{VK} \cdot P\_GF\_m \cdot KBF_{GF\_Röhrenkabel} + TVSt_x\_TVSt_y \cdot (1 - AKK_{VK}) \cdot P\_GF\_m \cdot KBF_{GF\_Erdkabel} \quad (3.4.2\text{-}11)$$

The next step breaks down these interoffice network costs into the costs of providing transmission capacity for leased lines, the costs of long-distance connections and, finally, the costs of local connections. The allocation standard used is the number of DSV2s on a transmission path provided for the various types of connection.

3.5 Conversion of Network Costs to Costs per Unit of Demand

The model calculations made so far form the basis for determining the long run incremental costs of the separate network elements and of access services at local network level. In line with the procedures we have described, the costs are shown as the annual costs of the entire infrastructure of the local network studied. Where expected traffic demand plays a role in determining the investment volume, these costs are also seen as costs incurred for providing capacity to cover busy hour demand. Hence establishing the costs of an average call minute or of an average call set-up presupposes determination of annual demand.

3.5.1 Costing the Subscriber Line

The average long run incremental costs of a subscriber line related to one year are derived by adding the costs incurred for the various sections of the access network and then dividing the result by the number of subscribers in the local network. Only the share of total costs attributable to the subscriber lines in accordance with their share in the wire pairs used need be taken into account. Various sections of the access network such as the costs of access in the feeder section, can also be costed in this way.

3.5.2 Costing Conveyance Services

Specific conveyance services as part of special network access are costed in several steps. First of all, the service which is the object of costing is defined. Then the network elements providing the service are identified. Possibly, usage factors indicating how many units of usage must be considered on average for a network element required for a service may need to be identified at this stage. Finally, the costs of the annual average unit of service demand are ascertained for the various network elements. Units of service demand as used in this modelling approach may be a call minute or call set-up.

The disaggregated modelling presented here indicates the costs of the following network elements:

- Connections between remote concentrators and local exchanges
- Connections between local exchanges of a local network
- Connections between local exchanges and a point of interconnection to the long-distance network
- Local exchanges further subdivided into:
  - centrally or remotely located digital line units
  - subscriber-facing line trunk groups
  - network-facing line trunk groups
  - switching network elements
  - control units (coordination processor).

The investment volume determined for each of these elements or, in the case of the component parts of the local exchange, sub-elements, is based on call minutes or call attempts in an average busy hour (multiplied by a peak load factor). Traffic demand in an average busy hour can be extrapolated to provide annual demand if the ratio of the two parameters to each other is known. Approximatively, traffic demand in an average busy hour can be multiplied by a factor corresponding to the reciprocal value of the share of busy hour demand in per day demand. This value is then multiplied by the number of busy hour days occurring per year.

This determines the costs of an average unit of output for the individual elements. If we now seek to determine the costs of services using several elements, the unit costs of the elements will be multiplied by the element usage factors of the service before being adding up. This is illustrated in the following, taking a call minute in the local network as an example.

One call minute involves a channel in the concentrating units being occupied at both ends. In addition, channels are also occupied at both ends in the subscriber-facing line trunk groups. As regards the network (sub-)elements switching network, coordination processor, interoffice network and connections to remote concentrators, usage factors must be identified that correspond to the average load caused by one call minute. The usage factor for connections to remote concentrators is derived, at both ends, from the ratio of outgoing local traffic on the connections between remote concentrator and local exchange, to total outgoing local traffic. We then assume that the usage factor for the connection to the local exchange will be 0.5 at each end if 50% of the outgoing local traffic is generated in these access areas. In this case the result is that an (average) call minute is exactly equivalent to one minute of use of connections to remote concentrators. The switching network and the coordination processor in the local exchange of the calling subscriber are always used. The usage factor for a second local exchange is derived from the ratio between the outgoing internal traffic of the exchanges in the local network and the total outgoing local traffic. Hence it is between 0 and 1. If the factor is again 0.5, an average call minute in the local network would correspond to 1.5 usage minutes in the switching network and, analogously, 1.5 processor activities for average call set-up. Moreover, on average, there is half a usage minute in the interoffice network and one minute of usage of the network-facing line trunk groups in the respective local exchanges. The same procedure applies to other services.

3.5.3 Averaging

In principle, the approach described here establishes costs in relation to individual local networks. Should it be necessary to take averages, this will be done on the basis of a sample test. We have elected to proceed in this way since we must assume, especially with regard to the costs of the subscriber line, that costing based on the structure of an average local network will not yield reliable results. Only if values are ascertained for many individual local networks will it be possible to take averages for the costs of network elements and interconnection services as well as for any usage factors that may be applied at different aggregation levels. Any averaging must weight the costs appropriately. Moreover, sample tests must ensure the representativeness of the parent population.

4. Concluding Remarks

The following recaps on the essential features of the cost model. This is followed by comments on the model's goals and on planned further action.

4.1 Essential Features of the Cost Model

This document describes a method for costing local telecommunications network elements using an analytical cost model. The model measures the installation and operating costs of the network infrastructure, ie of all transmission and switching facilities including subscriber lines. The model is based on a number of economic and technical relationships between input and output parameters, that is to say, between relevant factor inputs - labour and capital - and their output in the form of subscriber lines, calls and call minutes. Owing to their generic nature, these relationships can be applied to a number of different objects, ie local networks with different geographical dimensions and demand patterns.

The model looks at a generic network based on assumptions regarding appropriate forward-looking methods meeting the efficiency requirement for the supply of those services to be costed by the model. The overall production process including different types of access, switching and transmission technology that are used or may be used in local networks is beyond the scope of the model.

The aim of the model is to calculate the costs, or more specifically, the long run incremental costs of narrowband conveyance in the context of network interconnection and other special network access, especially access to (unbundled) subscriber lines. The generic network presented here is structured as a local copper network radiating from given MDF sites. The interoffice network has a two-stage structure, being configured as a star network connecting remote concentrators with local exchanges, and as a meshed network connecting local exchanges.

In costing, a local network is broken down into separate network elements according to their functionality. The current model looks at the subscriber line, transmission to the local exchange, switching, transmission between local exchanges, and transmission to a point within the local network providing interconnection to the long-distance network. For calculation purposes, some of these elements are broken down into sub-elements. The requisite investment volumes are calculated for each of the elements and sub-elements as a function of demand forecasts. The investment level is valued using current replacement costs, and subsequently converted into annualised costs taking account of depreciation, expected return on investments and operating costs. These costs are distributed between annual service demand levels in order to cost network elements in terms of call minutes or annual costs for the provision of subscriber lines.

4.2 Purpose of the Model

Companies subject to rates regulation under the Telecommunications Act and the Telecommunications Rates Regulation Ordinance are obliged to submit cost statements to the Regulatory Authority for Telecommunications and Posts for approval purposes (§2 of the Telecommunications Rates Regulation Ordinance). Under the rates approval procedure the Regulatory Authority examines whether the rates proposed are based on the costs of efficient service provision (§3 of the Telecommunications Rates Regulation Ordinance). The cost model described in this document is intended to enable the Regulatory Authority to compare the cost statements submitted, especially those relating to network access and network interconnection, with the results of calculations based on a generic, non-operator-specific network. The outcome of such a comparison may be used for rate approval decisions and their justification.

Since the aim is to establish transparent and calculable models for the approval of the rates proposed by companies with a dominant market position, the model developed for future rates approval procedures is published prior to its initial application to give interested parties an opportunity to state their views. It is hoped that publication of the proposed model will lead to a factual discussion about the method to be applied in fixing the relevant charges.

4.3 Further Action

After the Regulatory Authority has considered the comments received, the model will be revised or extended where this is considered necessary. The next step will be to define the requisite parameters for the model calculations so that the model can be used for regulatory purposes, notably for rates approval. The Regulatory Authority may request companies engaged in the German telecommunications market to supply data on some or all of the input values listed at Annex B.

At the same time an extended model is being developed for the long-distance network, which is not or only marginally covered by the current model. The aim of this project is to establish benchmarks for the costs of all relevant network access activities within a relatively short timescale.

Annex A
Topics for Discussion relating to the Cost Model for Local Telecommunications Networks

All interested parties are invited to submit their views on the proposed model for costing network access in the local service area. Publication of the proposed model and the consultation process aim to create transparency in the costing methodology and to accommodate comments and proposals received in the application and refinement of the model. Analytical cost models are intended as a tool for determining benchmarks for the costs of efficient service provision, to be used in the examination of cost statements submitted under future rates approval procedures.

Comments on this consultative document should refer to the issues specified below. The appended questions are intended to clarify the views of the respondent on the structure of the model as a whole and on proposed assumptions and conventions in particular.

1. In the proposed model, network infrastructure is costed on the basis of network elements, ie the network is broken down into elements defined by their functionality, such as switching or transmission. Services supplied are described by combining the functionality of several network elements.

   – Is the breakdown of the network into elements adequate or already too detailed?

2. The extent of shared use of certain infrastructural facilities (buildings, but especially trenches and the duct network) by network elements as well as by the telecommunications networks for narrowband services considered here and other networks (cable TV networks, broadband overlay networks, gas, water and electricity supply networks) is a significant cost factor. Initially, the modelling approach described does not take shared use into account.

   – How should the extent of shared use by network elements or networks be identified and made calculable?

   – Would it suffice to adjust input prices such as civil engineering costs or should an explicit cost allocation algorithm be integrated in the model?

3. Forward-looking demand parameters should be defined for the services supplied in a local network (subscriber lines, switching and transmission, and possibly leased lines) which may be used for costing but which may also serve as a basis for determining annual service demand.

   – What sources of information other than demographic statistics and network operator data should be used to identify the demand for subscriber lines?

   – From which empirical or primary sources should traffic levels per subscriber line be derived?

   – To what extent should a distinction be made between different access types or different customer groups?

4. The assumptions about the number and location of main distribution frames (MDF) and nodes of the generic network underpinning costing have a significant impact on the calculation results, especially those for the subscriber line.

   – What criteria should the model define with regard to number and type of nodes and MDF sites?

5. The model is based on assumptions regarding the structure and technology of the generic network, aimed at covering relevant and efficient procedures for the provision of narrowband conveyance and subscriber lines.

– Should the assumptions be extended?

6. A number of conventions have been defined for determining the capital costs of invested productive capital. The approach adopted in this document is characterised by the following key elements: current replacement costs of capital goods, ie their current purchase price, are built into the model, straight-line depreciation is applied, return on capital employed is derived from the weighted sum of the expected rate of return on equities (before corporate income tax) and the average rate of interest on debt, taking price changes in the value of assets into account, and depreciation and expected return on investment are converted into an annuity using the capital recovery factor.

   – How should current replacement costs be determined?

   – How should price reductions such as volume discounts be identified and addressed?

   – What factors should be taken into consideration in determining the relevant depreciation periods for different asset categories?

   – Have the different asset categories been broken down to an adequate level?

   – How should the company-specific risk regarding equity costs, which must be considered in addition to general market risk, be determined?

7. Network operating costs must be added to the capital cost of the assets.

   – How should forward-looking operating costs be determined for the various asset categories?

   – Are operating cost factors corresponding to the relationship between the historic cost of fixed assets and current expenses applicable?

   – How should such values be updated and any inefficiencies eliminated?

8. The long run incremental costs of elements of the switching network are the annual costs of providing peak load capacity, ie busy hour Erlangs and busy hour call attempts. Conversion of these costs into costs per minute or per call is based on the convention that the costs of a network element should be distributed equally over total annual service demand. To this end average busy hour demand is related to overall demand per day and subsequently to annual demand.

   – Is empirical data available on the above-mentioned relationships?

9. The long run incremental costs of network elements are to be determined on the basis of a sample calculation. This means that a representative set of the relevant local network parameters should be selected. Subscriber density and subscriber numbers are considered relevant parameters.

   – Should other local network parameters be included in a sample to obtain a representative set?

10. The modelling described in Chapter 3 of this consultative document covers the main reference measures for local network costs.

   – Should further reference measures for cost factors be included in the model and if so, which ones?

   – Should the assumption of a fully meshed interoffice network which, in large local networks, may lead to an overstatement of the costs of efficient service provision, be modified?

11. Costing does not cover distribution and customer administration costs in the case of special network access since these costs are highly customer-specific and hence not accessible within the framework of a generic model.
    - Should reference measures not included in the model be used to calculate these costs and if so, which ones?
    - How high are these costs in relation to the reference measures?
    - What is the proportion of non-volume-sensitive common costs to total distribution and customer administration costs?
12. Non-volume-sensitive costs, ie costs which cannot be allocated either directly or indirectly to services on the basis of the principle of causation, have not been input into the model but are nevertheless part of the costs of efficient service provision as defined in the Telecommunications Rates Regulation Ordinance (§3(2)).
    - What non-volume-sensitive common costs incurred by network operation can be allocated to the totality of local networks but not to individual networks or network elements?
    - What is the ratio of these costs to the sum total of the costs that can be allocated to individual local networks?
    - What is the proportion of non-volume-sensitive costs, excluding the costs referred to in the previous two questions, to the total costs of a telecommunications company?
13. Under the Telecommunications Rates Regulation Ordinance non-volume-sensitive costs are to be considered under the rates approval procedure in the form of appropriate mark-ups on the long run incremental costs.
    - Would a uniform mark-up or separate mark-ups on the costs determined for the different services be appropriate for the common cost categories mentioned in questions 11 and 12?

Annex B: Input List

The following list contains the input data used in the model. In the course of the consultation the Regulatory Authority for Telecommunications and Posts may request participating companies to supply data on all or select input values.

Input Value	**Abbreviation** (if used)	**Comments**
Location		
Local network boundaries		
MDF sites		
Allocation of local exchanges to MDF sites		
Allocation of remote concentrators to MDF sites		
Allocation of remote concentrators to local exchanges		
Planning Targets		
Percentage of conductor diameters for different loop lengths		Information in tabular form possible
Technical spare capacity factor for wire pairs	TRes_Fkt_DA	General parameter
Economic spare capacity factor for wire pairs in the feeder cable	$Res\_Fkt\_DA_{HK}$	At local network level
Economic spare capacity factor for wire pairs in the distribution cable	$Res\_Fkt\_DA_{VZB}$	Breakdown according to subscriber density
Leased line factor in the access network	FV_Fkt_DA	As a percentage of wire pairs for subscriber lines
Leased line factor in the interoffice network	FV_Fkt	As a percentage of 2 Mbit/s digital connections in the interoffice network
Spare capacity factor in the interoffice network	Res_Fkt	As a percentage of 2 Mbit/s digital connections in the interoffice network
Share of conduit routes in the feeder section	AKK_{HK}	At local network level

Share of conduit routes in the distribution area	AKK_{VZB}	Breakdown according to subscriber density
Share of conduit routes in the interoffice network	AKK_{VK}	At local network level
Number of ducts in the feeder cable	ZG_{HK}	At local network level
Number of ducts in the distribution area	ZG_{VZB}	Breakdown according to subscriber density
Number of ducts in the junction cable	ZG_{VK}	At local network level
Average distance between manholes	Abs_Schacht	General parameter; breakdown according to copper and optical fibre cables
Number of cables per route metre in the feeder section	K_Tm_{HK}	At local network level
Number of cables per route metre in the distribution area	K_Tm_{VZB}	Breakdown according to subscriber density
Surface type along feeder cable routes	OF_{HK}	Breakdown of surface types to be reconstructed (green areas/asphalt/ interlocking pavers); at local network level
Surface type along routes in the distribution area	OF_{VZB}	Breakdown of surface types to be reconstructed (green areas/asphalt/ interlocking pavers); breakdown according to subscriber density
Surface type along junction cable routes	OF_{VK}	Breakdown of surface types to be reconstructed (green areas/asphalt/ interlocking pavers); at local network level
Number of taps (sleeves) per subscriber line	M_Asl	Breakdown according to subscriber density
Number of SDIs per subscriber line	EVz_Asl	Breakdown according to subscriber density
Number of drop segments and trenches per subscriber line	G_Asl	Breakdown according to subscriber density
Wire pairs per subscriber line in the drop segment	DA_Asl	Breakdown according to subscriber density

Length of final drop (drop segment)	LH	Breakdown according to subscriber density
Maximum distance between regenerative repeaters	Abs_ZWR	General parameter. Breakdown according to 140 Mbit/s and 565 Mbit/s systems

Costs		Cost data is taken to mean total investment necessary for installation of the facility ready for service.
Civil engineering costs of conduit systems per metre	P_GrK_m	Breakdown of data according to different duct numbers (eg 3/6/12/18 ducts) and according to surface type (green areas/asphalt/interlocking pavers)
Cost of trench per metre for buried cable installation	P_GrE_m	Breakdown of data according to surface type (green areas/asphalt/ interlocking pavers)
Cost of PVC duct per metre	P_Rohr_m	Breakdown of data according to diameter (50 mm/100 mm)
Cost of marker tape per metre	P_Band_m	
Cost of a manhole	P_Schacht	Breakdown of data according to number of ducts (3/6/12/18 ducts)
Cost of copper cable including installation (sleeves) per metre		Breakdown of data according to underground/buried cable, different pair capacities and wire diameters (0.4 mm/0.6 mm/0.8 mm)
Cost of protective hood per metre	P_Schutzhaube_m	
Cost of a tap (sleeve)	P_Muffe	
Cost of an SDI	P_EVz	
Cost of a Subscriber Line Module analogue (SLMA)	P_SLMA	EWSD module designation
Cost of a Subscriber Line Module digital (SLMD)	P_SLMD	EWSD module designation
Cost of a Digital Line Unit (DLU)	P_DLU	EWSD module designation

Cost of a Line Trunk Group (LTG)	P_LTG	EWSD module designation
Cost of a switching network element 120*2Mbit/s	P_KN	
Base price of the CP in a local exchange	P_CP	
Cost of an additional 1,000 BHCA traffic load	P_BHCA	
Cost of a multiplexer pair	P_MUX	Breakdown of data according to type (2/34, 34/140, 140/565 Mbit/s)
Cost of a regenerative repeater	P_ZWR	Breakdown of data according to 140 Mbit/s and 565 Mbit/s systems
Cost of optical fibre per metre including installation (splicing)	P_GF_m	Breakdown of data according to buried cable/underground cable; assumed no. of fibres: 12
Cost of an optical line termination per fibre pair	P_LE	Breakdown of data according to 140 Mbit/s and 565 Mbit/s systems
Base price of an MDF	P_HVt_Fix	Fixed component of the MDF investment
Cost of MDF per wire pair	P_HVt_DA	Wire-dependent component of MDF investment
Cost of in-house cabling	P_EndStK	Breakdown according to subscriber density
Cost of a telecommunications plug and socket	P_TAE	
Cost of an FDI	P_KVz	
Cost of housing a local exchange	$P\_Unterbringung_{TVST}$	
Cost of housing a remote concentrator	$P\_Unterbringung_{AK}$	
Supplementary equipment for a local exchange	$P\_Ausstattung_{TVSt}$	Includes power supply, air conditioning, operator terminals, etc
Supplementary equipment for a remote concentrator	$P\_Ausstattung_{TVSt}$	Includes power supply, operator terminals, etc

Demand Data		
Residential subscribers per grid square	PK_PQ	Data to be based on demographic statistics and residential telephone penetration
Business subscribers as a function of the number of residential subscribers per grid square	GK_Fkt	General parameter
Average traffic load per residential line in an average busy hour	BHE_PK	General parameter
Average traffic load per business line in an average busy hour	BHE_GK	General parameter
Average holding time in the busy hour	HT	General parameter
Factor for the ratio of successful to total call attempts	α	General parameter
Peak load factor	LSF	General parameter
Share of long-distance traffic in total subscriber traffic	AFV	At local network level
Loss probability on final routes	B	General parameter
Dynamic capacity of a local exchange with basic equipment	Kap_CP	General parameter, manufacturer data

Capital and Operating Costs		All factors are taken to be general parameters.
Average rate of price change for the various asset categories	ΔP_U	Breakdown of data according to buildings, supplementary equipment, transmission equipment, switching equipment, underground copper cable, underground optical fibre cable, buried copper cable, buried optical fibre cable, conduit systems, drop segments, in-house cabling
Average economic-technical lifetime of the various asset categories	ND_U	Breakdown as for the average rate of price change
Equity ratio	eK	
Debt ratio	fK	Interest-bearing debt only
Expected rate of return on equity	D	After corporate income tax
Effective corporate income tax rate	T	
Interest rate on debt	R	Average interest rate
Operating cost factors for asset categories	BKF_U	Breakdown as for the average rate of price change