Methodology and input availability parameters for calculating OpEx and CapEx costs for realistic network scenarios

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The availability requirements for today's networks are very high. Higher availability often comes with a higher cost. We describe several steps required for estimating the costs of realistic network scenarios. Capital expenditures (CapEx) and operational expenditures (OpEx) are classified. An activity-based approach is used to quantify the cost of the event-driven operational processes such as repair and service provisioning. We discuss activity duration and availability parameters as required input data, which are necessary for calculating the processes' costs for realistic network scenarios. The relevant availability measures for an IP-over-Optical network are described using a triplet representation with optimistic, nominal, and conservative values. The model is applied to a reference German network scenario. © 2006 Optical Society of America

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1. Introduction

Since telecommunications in all its forms has grown in society, commerce, government, and education, the costs of the network scenarios that provide the required network services have gained a lot of importance. Increasing requirements concerning efficiency and availability leads to higher costs of providing and operating those networks. Therefore, network planning and design decisions should take into account cost estimations as accurately as possible. Such estimations will enable a trade-off between the required availability of the network and the associated cost. In most cases, an equipment cost model is used to estimate capital expenditures (CapEx) costs, whereas operational expenditures (OpEx) costs tend to be neglected or only dealt with summarily, e.g., estimated proportionally to CapEx. The goal of this paper is to suggest a comprehensive cost model that is easy to apply and allows us to estimate both capital and operational expenses for a realistic network scenario. In Section 2 of this paper the relation between CapEx and OpEx is discussed, and the operational expenses for a telecom operator are classified according to a matrix structure. In Section 3, an activity-based description of the identified operational processes is given. Section 4 indicates how to estimate the costs of activities in the processes. In Section 5 we discuss availability parameters as an input to the routine operation and repair processes. Section 6 summarizes the overall methodology used to calculate the total CapEx and OpEx costs for a certain network scenario. In Section 7, the suggested model is illustrated by applying it to a German reference network scenario. Finally, Section 8 summarizes the paper.

2. Classification of OpEx for a Telecom Operator

The total expenditures of a company such as a telecom operator can be split generally into two parts: CapEx and OpEx. Some obscurity exists in the literature concerning their exact definitions. Below we highlight our view and how it relates to the different literature sources. CapEx contribute to the fixed infrastructure of the company, and they are depreciated over time [1]. For a network operator, they include the purchase of land and buildings (e.g., to house the personnel), network infrastructure (e.g., optical fiber and IP routers), and software (e.g., network management system). Note that buying equipment always contributes to CapEx, regardless of whether the payment is made all at once or spread over time. Also, interest to be paid for a loan is included here. OpEx do not contribute to the infrastructure; they represent the cost of keeping the company operational and include costs of technical and commercial operations, administration, etc. For a network operator, OpEx are mainly constituted of rented and leased infrastructure (land, building, network equipment, fiber, ...) and personnel wages. This approach is consistent with that in Ref. [2]. However, other sources such as Refs. [3, 4] consider all infrastructure (regardless of whether it is bought or leased) as CapEx.

CapEx and OpEx are interconnected issues. A network technology that enables automated maintenance and provisioning tasks will probably have higher acquisition costs (CapEx) but will be cheaper to operate (OpEx). To help with estimating the CapEx costs for a network operator, equipment cost models are available in literature, e.g., the model specified within the IST-Lion project [5]. For operational expenses, however, very little work has been done and quantitative results are very rare. This paper aims to make a contribution to that field.

The major contributors to the OpEx for a telecom operator can be classified into the following three subcategories: *OpEx parts directly related to operating an existing network* (which has already been set up), *OpEx for equipment installation,* and *some more general OpEx* (aspects not specific to a network operator). All of them have been classified in a matrix representation as shown in Fig. 1.

The left-most columns group seven expenditures for operating an existing, up and running network. First, there is the cost of keeping the network operational in a failure-free situation. We call this the *telco-specific continuous cost of infrastructure*. It includes the costs for floor space, power and cooling energy, and leasing network equipment (e.g., fiber rental). Right-of-ways, i.e., the privilege to put fiber on the property of someone else (e.g., along railways) is part of this cost. Second, the traditional *maintenance cost* can be seen as the costs of preventative measures such as monitoring and maintaining the network against possible failures. The main actions performed here aim at monitoring the network and its services. Therefore, the actions involved include direct as well as indirect (requested by an alarm) polling of a component, logging status information, etc. Also stock management (keeping track of the available resources and ordering equipment if needed), software management (tracking software versions and install updates), security management (tracking people who try to violate the system, and blocking resources if needed), change management (tracking changes in the network, e.g., whether a certain component goes down), and preventive replacement are included. Furthermore, cleaning of equipment can be taken into account as well. Third, *repair* means actually repairing the failure in the network, if this cannot happen in routine operation. Repair may lead to actual service interruptions, depending on what protection scheme is used. The repair process includes diagnosis and analysis, travel by technicians to the place of the failure, fixing the failure, and testing to verify the repair. The fourth important part of the OpEx cost is given by the process of *provisioning and service management*. This begins with a service request from a potential customer and includes the entire process from order entry by the administration to performing the needed tests, service provisioning, service move or change, and service cessation. The cost to operate the network includes the cost of *pricing and billing* as a fifth part. This means sending bills to customers and ensuring payment. In addition, it includes actions such as collecting information on service usage per customer and calculating cost per customer. Calculating penalties to be paid by the operator for not fulfilling the service level agreement (SLA) is another task here. As the sixth OpEx cost part, we distinguish the ongoing network planning activity, which we call *operational network planning*. It includes all planning performed in an existing network that is up and running, including day-to-day planning, reoptimization, and planning upgrades. Finally, there is the cost for *marketing*, meaning the acquiring of new customers for a specific service of the telco. Marketing involves promoting a new service, providing information concerning pricing, etc. Possibly, new technologies enable new services. The above seven components summarize the first of the three main categories of OpEx.

The second category of OpEx that we distinguish is associated with equipment installation and is denoted by the second group of columns. This represents all the costs to be made before connecting the first customer in case of a green field scenario, or the migration costs before the network becomes operational again in case of a major network extension. In some cost models this OpEx category is taken together with CapEx as "first installed costs" [6], since a simple modeling approach could estimate the OpEx for equipment installation as some fraction of the CapEx cost. It includes the costs for *up-front planning*, which denotes all planning done before the decision "let's go for this approach" is taken: planning studies to evaluate the building of a new network, changing the network topology, introducing a new technology or a new service platform, etc. The second part of the OpEx category on equipment installation is constituted by the operational aspects of *first-time installation* of new network equipment. All costs related to installing the equipment (after buying it) are counted here. The cost of first-time installation includes the actual connecting and installation of the new component into the network, as well as the necessary testing of the component and its installation. This first-time installation is usually carried out by the equipment vendor. In this case, the costs for the operator are included in the contract with the vendor. Note that the legislation (tax laws) in some countries allows for *capitalizing* some of the cost parts described above; if they concern internal operations that can be valorized as fixed assets they are called *produced fixed assets*. This may affect the costs in the category of OpEx associated with equipment installation, as well as fiber lease, right-of-ways, and leasing of equipment in general.

The two right-most columns in the matrix indicate OpEx subparts that are present in every company; they are not specific for a telecom operator. *Non-telco-specific cost of infrastructure* denotes the cost of leasing infrastructure, not related to the network itself. This includes buildings to house the personnel, energy for desktop PCs, heating, cleaning of buildings, etc. *Non-telco-specific administration* includes the administration every company has, such as employee payroll administration, office support staff, the human resources department, etc. Non-telco-specific administration and non-telco-specific cost of

GOAL = what you do		telco specific OpEx for network which is up and running							OpEx eq. inst.		general OpEx	
MEANS = what you pay		telco spec. cont. cost of infrastructure	maintenance	repair	service provisioning	pricing and billing	operational network planning	marketing	first time installation	up-front planning	non telco specific cost of infrastructure	non telco specific administration
personnel		■									■	
training	lost work. time	■									■	
	teacher	■									■	
	books, courses	■									■	
tools and transport	tools	■						■			■	■
	transportation	■				■	■			■	■	■
	travel time	■				■	■			■	■	■
space			■	■	■	■	■	■	■	■		■
energy			■	■	■	■	■	■	■	■		■
rental, leasing			■	■	■	■	■	■	■	■		■

Fig. 1. Matrix description of operational expenses for telecom operator.

infrastructure can jointly be seen as “overhead” costs.

The matrix representation of Fig. 1 clarifies our belief that personnel costs (wages) should not be considered as a subpart of OpEx on itself (as suggested in Ref. [7]), but rather as a kind of expense present in several OpEx subparts. Other expenses apparent in several OpEx subparts are floor space, energy, and rent. They are therefore also indicated as matrix rows, whereas the OpEx categories are indicated as matrix columns. Note that, apart from the wages themselves and the expenses related to training, there are other costs related to personnel, namely, the expenses for tools and transport. Reference [8] conveys that tools are bought and therefore are CapEx. References [4, 9], on the other hand, state that tools should be considered OpEx because they can be seen as a part of the personnel cost for the considered technician; the technician cannot operate without those tools. We adopt the latter assumption. Examples of such tools are measurement equipment, screwdrivers, and mobile phones, to name only a few. Unlike the big investments in assets such as buildings, network equipment, and inherent instrumentation equipment (which are CapEx), the small investment in work tools is counted as OpEx. In the matrix of Fig. 1 the inapplicable entries are shaded.

3. Activity-Based Description of Operational Processes

The general framework for OpEx costs is defined by the continuous cost of infrastructure (left-most column in the matrix of Fig. 1), i.e., the costs that need to be paid in any case to keep the network operational (also in the failure-free case). The other columns in the OpEx for an existing network indicate the operational processes that interact with each other. The maintenance (routine operation) process is central. An important task of the routine operation process is to monitor the status of the network and its components. Network utilization information will serve as an input to the pricing and billing process. There is also a constant interaction between the planning process and the routine operation process. The first determines which parameters are to be monitored by the latter and takes the monitoring results as an input to analyze the network behavior and suggest improvements for the future. In case of a failure alarm, the repair process is triggered. The service provisioning process is another central process that sets up the service requested by a customer. There is an interaction with the pricing and billing process to calculate the price of the provisioned service and another one with the repair process that indicates the downtime caused by a failure, and, therefore, the associated penalties to be paid to the customer. The marketing process can be seen as a background process trying to attract new customers; it therefore influences the service provisioning process. The planning process interacts with all other processes as a steering process.

In order to calculate or estimate the costs of the different OpEx subparts, again a distinction has to be made between the continuous cost of infrastructure and the costs for the operational processes. The former can easily be calculated by summing the operational costs for all used network components when all required network characteristics such as power consumption and footprint are known. On the other hand, the costs for the operational processes can be analyzed using an activity-based approach. Therefore, diagrams have been developed describing all processes under study, indicating the different steps in the considered process (on the horizontal axis in the diagram) as well as the departments involved (on the vertical axis in the diagram).

Figures 2 and 3 illustrate the repair process and the service provisioning process, respectively. For a detailed description of all processes we refer to Ref. [10].

4. Activity Duration and Relation with Process Cost

Starting from the process diagrams and attaching costs to the rectangles (denoting actions) and probabilities to the branches out of the diamonds (denoting answers to the diamonds' questions), we can easily determine the formula for cost of an entire process, which can then be calculated by summing up the cost of all sequential actions and the weighted costs of the conditional actions. Finally, we sum the cost of all continuous processes (routine operation, planning, marketing, continuous cost of infrastructure) and the product of the event-driven processes (repair, service provisioning, pricing and billing) with their number of occurrences over the considered time frame to find the total OpEx cost for the considered network scenario. The number of occurrences of the repair process is determined by the availability characteristics of the considered equipment: for the service provisioning processes it is determined by the number of service requests, and for the pricing and billing processes by the number of customer contracts.

A straightforward way to attach costs to the actions in the operational processes is to estimate the time needed to perform an action and multiply it by the wages of the person who is taking care of it. This approach is also suggested in Ref. [11]. We should take into account that several types of employees are involved in the operation of a network and several classes of wages should be used for them. Personnel wages could be estimated from company internal information or from public sources like information from trade unions, e.g., for the Belgian case [12]. However, it appears that the additional personnel costs for training and for tools and transport (second and third row in the matrix of Fig. 1) are not covered by the model in this way. Calculating the exact amount of training and the tools needed for each of the considered actions is probably impossible. On the other hand, some general trends can easily be detected. For example, technicians will need more tools than administrative personnel. Such trends enable us to identify, for all considered personnel categories, a weight factor by which the personnel cost needs to be multiplied by. The use of the weight factor is similar to what is described in Ref. [9]. A possible way to estimate

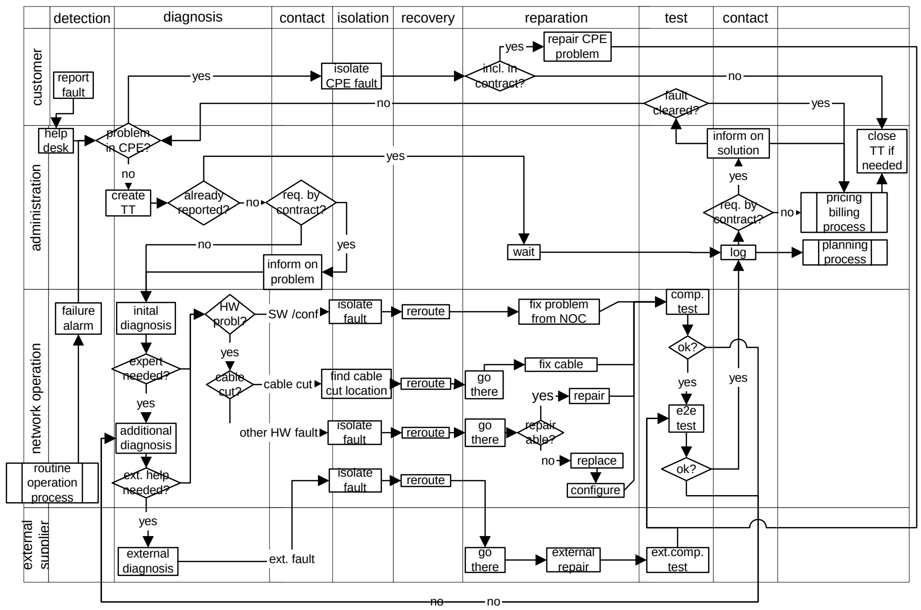

Fig. 2. Activity-based description of repair process.

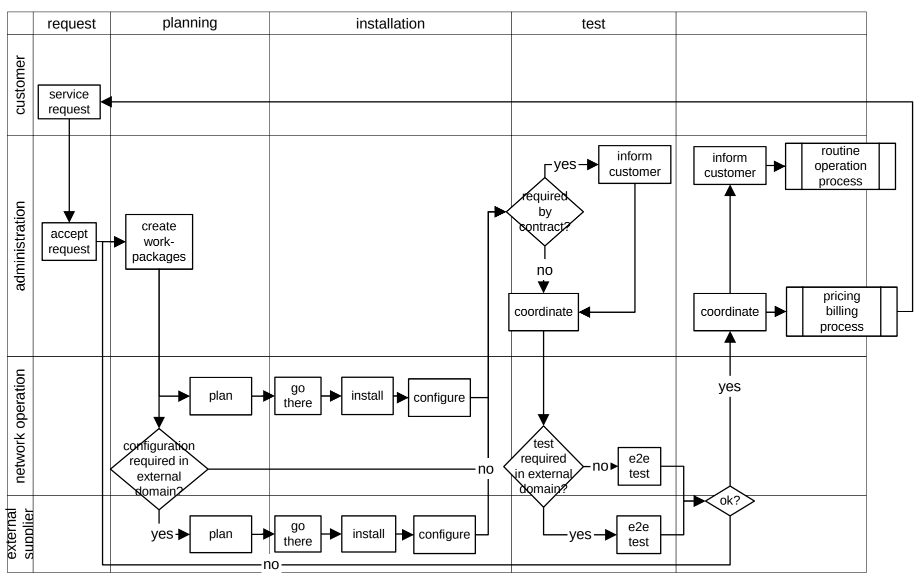

Fig. 3. Activity-based description of service provisioning process.

the weight factor is by dividing the total expenses of a certain company department by the actual cost of the personnel, as suggested in ABC-costing [13]. Apart from personnel wages, the duration of activity is also required for calculating the cost of the actions. This activity duration could be estimated from company internal information. However, some company-independent estimations obtained from a survey with different network operators can be found in Ref. [14].

Calculation of OpEx costs using the suggested process-based approach allows us to study the impact of the business organization of the considered carrier, i.e., more-efficient workflows are reflected in the processes directly, whereas more-efficient organization (e.g., smaller departments) is reflected in the weight factor. This approach is far more flexible and more realistic than the traditional approach in which OpEx are estimated to be proportional to the CapEx cost.

5. Availability Measures in Relation with Routine Operation and Repair Costs

The repair process is event driven. In order to determine its number of occurrences, availability information concerning the considered network equipment is required. Within the IST project, NOBEL, we took the initiative to define a general availability model and collect general vendor-independent availability numbers for IP, synchronous digital hierarchy (SDH), and WDM equipment as well as optical fiber. In a questionnaire, consortium partners were asked to express their opinion on equipment reliability for the components in our model. Only in some cases, the initial estimation could be based on literature sources [15–20]. After bringing all received data together, a reliability interval was obtained for all components and harmonized between all partners to obtain a consensus. Finally, we ended up with a triplet representation for each of the availability measures: *[optimistic value, nominal value, conservative value]*. The *conservative value* indicates a pessimistic view on the availability of the system, the *nominal value* represents the average of the values from different information sources, and the *optimistic value* represents a best-case scenario, as it indicates the lower bound on the collected numbers.

Table 1 lists the collected availability numbers: *Mean Time Between Failures (MTBF)*, its alternative *Failures in Time (FIT)* where $\text{MTBF}\,[\text{h}] = 10E09/\text{FIT}$, and *Mean Time To Repair (MTTR)*. More information concerning the rationale behind the numbers can be found in Ref. [21]. Link failure probability values for optical fiber should take into consideration both the type of the physical link and the geographical distribution of network segments. For buried cable, we assume a nominal MTBF of 2.63E06 hours for 1 km (corresponding to a cable-cuts value of 3E02 km, indicating the average cable length suffering from 1 cable cut per year [22]) and a MTTR of 12 hours.

Note that there is a relation between availability numbers and the repair as well as the routine operation (maintenance) process. The MTBF value indicates the average time between two failures of a component. This allows us to estimate the frequency of occurrence of the repair process. However, with knowledge of this figure for some components, preventive replacement could be planned (in the service window) during routing operation. Preventive replacements increase the cost of the routine operation processes while they decrease the repair process cost.

6. Calculation of Overall Cost for a Network Scenario

After describing several building blocks in the previous sections, in this section we want to summarize the overall methodology for calculating the total cost, both CapEx and OpEx, for a certain network scenario. We distinguish several steps:

1. *Collecting equipment information*. Knowing the technology for the network scenario under study, some information about the considered equipment needs to be collected,

Table 1. Collected availability numbers

	Equipment Part	MTBF (hours)	FIT	MTTR (hours)
IP Layer Equipment	IP Router: Route Processor	[optimistic] 1E06	[optimistic] 1E03	[optimistic] 1.8
		[nominal] 2E05	[nominal] 5E03	[nominal] 4
		[conservative] 4E03	[conservative] 2.5E05	[conservative] 10
	IP Router: Interface Card	[optimistic] 3.5E05	[optimistic] 2.86E03	[optimistic] 2
		[nominal] 8.5E04	[nominal] 1.18E04	[nominal] 4
		[conservative] 1E04	[conservative] 1E05	[conservative] 3.5
	IP Router: SW	[optimistic] 1E05	[optimistic] 1E04	[optimistic] 4E-04
		[nominal] 3E04	[nominal] 3.33E04	[nominal] 2E-02
		[conservative] 5E03	[conservative] 2E05	[conservative] 2.5E-01
SDH Equipment	SDH DXC or ADM	[optimistic] 1E06	[optimistic] 1E03	[optimistic] 2
		[nominal] 5E05	[nominal] 2E03	[nominal] 4
		[conservative] 1E05	[conservative] 1E04	[conservative] 9
WDM Equipment	bidir OA	[optimistic] 5E05	[optimistic] 2E03	[optimistic] 2
		[nominal] 2.5E05	[nominal] 4E03	[nominal] 6
		[conservative] 1E05	[conservative] 1E04	[conservative] 9
	bidir mux/demux	[optimistic] 1E06	[optimistic] 1E03	[optimistic] 2
		[nominal] 1.67E05	[nominal] 6E03	[nominal] 6
		[conservative] 1E05	[conservative] 1E04	[conservative] 9
	Transponder 2.5 Gbps	[optimistic] 5E05	[optimistic] 2E03	[optimistic] 2
		[nominal] 4E05	[nominal] 2.5E03	[nominal] 6
		[conservative] 2.94E05	[conservative] 3.4E03	[conservative] 9
	Transponder 10 Gbps	[optimistic] 9.6E05	[optimistic] 1.04E03	[optimistic] 2
		[nominal] 3.5E05	[nominal] 2.86E03	[nominal] 6
		[conservative] 2.94E05	[conservative] 3.4E03	[conservative] 9
OXC Equip.	WDM OXC (OEO) or OADM	[nominal] 1E05	[nominal] 1E04	[nominal] 6
	ODXC Redundant: 1+1 Protected	[nominal] 2E06	[nominal] 5E02	[nominal] 4

such as equipment price and availability information, power consumption, and footprint. For cases in which a real network scenario is considered, this can be found in the datasheets provided by the equipment vendor. In the case of a theoretical study, performed without reference to a specific vendor, the assumptions need to be based on public sources such as the collected availability numbers of Section 5 or some educated guesses for equipment costs (based on Ref. [5]), footprint, and power consumption for optical network equipment, as shown in Table 2 .

Table 2. Equipment characteristics for optical network equipment

Equipment Type	Power (kW)	Footprint (ETSI)	Price (k€)
WDM line system (40 lambda)	1	3 racks	12.00
Fiber	0	0	not considered
Optical amplifier	0.5	0.25 rack	7.90
SR transponder (2.5 Gbit/s)	0.5	0 (inserted in OXC)	2.00
LR transponder (2.5 Gbit/s)	0.5	0 (inserted in OXC)	2.50
Unequipped OXC (512 ports)	3	3 racks	100.00

2. *Dimensioning the network*. From the estimated number of customers and their expected demand pattern, the capacity requirements for the network can be determined. Dimensioning the network for this amount of capacity helps us determine the required number of components of each equipment type.

3. *Calculating total CapEx cost*. Multiplying the number of components of each equipment type by the corresponding component price, and summing this over all components in the network, results in the total CapEx cost.

4. *Calculating OpEx for equipment installation*. The OpEx costs associated with equipment installation are to be determined together with the CapEx costs as "first installed costs." For a real network scenario this information comes from the contract with the equipment vendor. For a theoretical study, it can be estimated as a fraction of the CapEx costs, e.g., 30%.

5. *Calculating OpEx for a network that is up and running*. When the activity-based approach of Section 3 is used, the costs of all identified operational processes can be estimated on the basis of the input information concerning personnel wages and activity duration. This information is sufficient for calculating the cost for the continuous processes such as routine operation, operational network planning, and marketing. For the recurring processes, the number of occurrences over the considered time frame (e.g., one year) is required. For the repair process, the number of occurrences follows from the availability information. For the service provisioning process the number of occurrences is determined by the number of service requests. The number of occurrences of the pricing and billing process is determined by the number of customer contracts.

6. *Calculating the cost distribution over time*. Given the results for CapEx and OpEx costs, the distribution of the costs over the considered planning interval can be determined. CapEx and OpEx for equipment installation are one-time costs in the beginning of the planning interval. OpEx for the network that is up and running is to be counted for every time period (e.g., every year). The knowledge of the cost distribution over time is important for evaluating investment decision criteria such as net present value (NPV) [23].

7. Case Study

In this section we present a quantitative study on the total expenditures for a transport network operator in a German reference network scenario. We consider a WDM network (only the cost of the optical layer of the network is considered here) carrying 2.5 Gbit/s leased lines. Although, in a realistic network, leased lines would probably be offered via SDH or optical transport network (OTN) over WDM, we focus on this architecture for the sake of simplicity. The topology is the reference German network [24] with 17 nodes and 26 links and the associated traffic demand matrix for 2004. This traffic leads to 1214 services for one year, 80% of which we assume to be standard services. We also assume that there is no service cessation or move. We compare a traditional network to one enabled by Generalized Multiprotocol Label Switching (GMPLS), i.e., a network with GMPLS control plane functions such as routing and signaling for automated connection control. Note that in this paper we do not distinguish the details of the approaches described by ITU, OIF, and IETF, but generally assume a control plane supporting automation of network operations. We use the term GMPLS to refer to any kind of control plane according to one or several of these standards. For the traditional network we consider $1+1$ protection (two connections are set up simultaneously, one of them being used as backup), and we assume that the network provides end-to-end services. We assume that in a GMPLS-enabled network, shared mesh protection will be used instead of $1+1$ protection. For shared protection, two connections are also planned, but only one is actually provisioned, the second one being provisioned only when the first one has failed. The advantage is that the resources of the latter can be shared among several backup connections, leading to more-efficient resource utilization. Note that shared protection could also be used in a non-GMPLS network, but we consider it more applicable in the GMPLS case because the backup path can be provisioned and switched much faster. The GMPLS-enabled network additionally offers dynamic services.

After dimensioning the network we have calculated the CapEx cost using the equipment prices of Table 2. In case of the GMPLS-enabled network, we assumed an additional cost for the control plane and estimated it to be as expensive as the unequipped OXC. This is a software cost, but still part of CapEx. The resulting CapEx costs are shown in Fig. 4. The main difference between the two networks can be explained by the different protection scheme in use, $1+1$ protection, which leads to higher capacity requirements and therefore higher CapEx costs. Overall, the CapEx cost of the GMPLS-enabled network with shared path protection is 78% of that of the traditional network that uses $1+1$ protection. The OpEx costs for equipment installation are estimated to amount to 30% of the CapEx costs in both cases. The telco-specific continuous cost of infrastructure was calculated from floor space and energy consumption of the dimensioned network equipment. Concerning the cost of the operational processes, we started from the OpEx model of Section 3 and defined the operational processes for the traditional network as well as for a GMPLS-enabled network. We evaluated how GMPLS technologies impact the costs of the operations as well as the probabilities of the processes' branches. It is clear that the main difference in OpEx costs can be found in service offer (more expensive in case of GMPLS because the customer should be able to trigger the provisioning "on the fly," so that everything has to be in place before hand) and actual service provisioning (cheaper in case of GMPLS because of automated operations). For a detailed analysis of those OpEx parts and the impact that a GMPLS-enabled network has on them, see Ref. [25]. The other OpEx parts are not significantly changed by the use of GMPLS, as shown in Fig. 4.

We consider a planning interval of 10 years. The total network cost for the GMPLS-enabled network is 79% of the total network cost for the traditional network. The ratio OpEx/CapEx is about 75% for both the traditional network and the GMPLS-enabled network. The yearly recurring OpEx have a small impact, so the picture does not change much

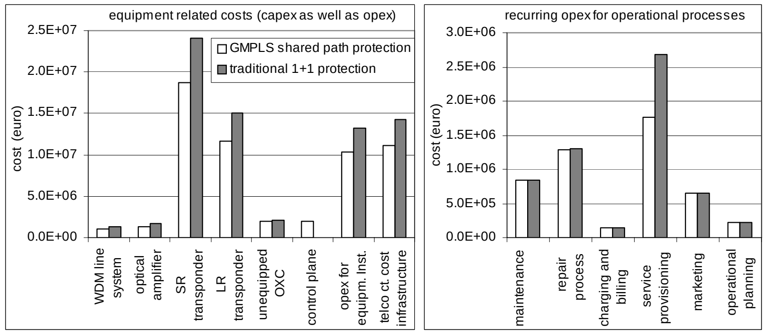

Fig. 4. CapEx and OpEx costs for German reference network scenario.

when the planning interval is slightly shorter or longer. Within the yearly recurring OpEx costs, the telco-specific continuous cost of infrastructure is more important (about 57% of the recurring OpEx cost) than the costs for the operational processes. The one-time OpEx for equipment installation has an important impact. If the actual cost of equipment installation would be close to 50% of the CapEx cost (instead of the 30% we assumed), the actual OpEx/CapEx would be close to 100%. Note that we didn't include the general OpEx parts (non-telco-specific continuous cost of infrastructure and non-telco-specific administration), as they probably have a small impact.

8. Conclusion

In the rapidly changing telecom market, accurate planning of different network deployment plans is important. Often a trade-off needs to be made between network availability and cost. In this paper, we have described a general methodology for calculating the costs for a telecom operator. CapEx and OpEx were classified. We have represented the identified OpEx subparts in a matrix structure and starting from this, we have discussed the most important operational processes. We have indicated how attaching costs to the individual actions in those processes allows us to calculate OpEx for a certain network scenario. We have shown that most network operators' processes are similar and can be modeled quite generically. We discussed the input data required for calculating the processes' costs for realistic network scenarios. They include activity duration and availability parameters. In a case study, applying our model to a German reference network scenario, we compared the expenses for a traditional network and a GMPLS-enabled network.

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