Methodology and input availability parameters to calculate OpEx as well as CapEx costs for realistic network scenarios

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The availability requirements for today's networks are very high. However, higher availability often comes with a higher cost. This paper describes several steps required to estimate the costs for realistic network scenarios. CapEx and OpEx are classified. An activity based approach is followed to quantify the cost of the event-driven operational processes like repair and service provisioning. We discuss activity duration and availability parameters as required input data in order to calculate 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.

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1. Introduction

Since the impact of telecommunications in all its forms has grown on society, commerce, government, and education, the costs of the network scenarios providing the required network services also have gained a lot of importance. Increasing requirements concerning efficiency and availability lead to higher costs to provide and operate those networks. Therefore, network planning and design decisions should take into account cost estimations, preferably as accurate as possible. They will allow to make 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 CapEx costs, whereas 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 estimating the capital as well as operational expenses for a realistic network scenario. In the second section of the 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 the third section, an activity based description of the identified operational processes is given. Section 4 indicates how to estimate the costs of activities in the processes. Section 5 discusses availability parameters as an input to the routine operation and repair processes. Section 6 summarizes the overall methodology 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 operational expenditures for a telecom operator

The total expenditures of a company such as a telecom operator can be split generally in two parts: the capital expenditures and the operational expenditures. Some obscurity exists in literature concerning their exact definitions. Below we highlight our view and how it relates to the different literature souces. Capital expenditures (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, IP routers) and software (e.g. network management system). Note that buying equipment always contributes to CapEx, independent from the fact whether the payment is made in one time or spread over time. Also interests to be paid for a loan are included here. Operational expenditures (OpEx) do not contribute to the infrastructure itself, they represent the cost to keep the company operational and include costs for technical and commercial operations, administration, etc. For a network operator, OpEx is mainly constituted of rented and leased infrastructure (land, building, network equipment, fiber,…) and personnel wages. This approach is consistent with [2]. However, other sources, like [3] and [4] believe all infrastructure (no matter whether it is bought or leased) is to be counted as CapEx.

Capital and operational expenditures are interconnected issues. A network technology allowing to perform a lot of maintenance and provisioning tasks automatically, will probably have higher acquisition cost (CapEx), but will be cheaper to operate (OpEx). To estimate the capital expenditure 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 wants to make a contribution to that field.

The major contributors to the operational expenditures for a telecom operator can be classified in the following three sub-categories: *OpEx parts directly related to operate 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.

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

The left-most columns group the expenditures to operate an existing network (network which is up and running). First, there is the cost to keep the network operational in a failure free situation, we call this the *telco specific continuous cost of infrastructure*. It includes the costs for paying (floor) space, power and cooling energy and leasing network equipment (e.g. fiber rental). Also 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. Secondly, the traditional *maintenance cost* can be seen as the cost to maintain the network or to operate the network in case a failure may occur. 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 order equipment if needed), software management (keeping track of software versions, and install updates), security management (keeping track of people trying to violate the system and block resources if needed), change management (keeping track of 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 interrupts, dependent on the used protection scheme. The actions involved in the repair process are diagnosis and analysis, the technicians traveling to the place of the failure, the actual fixing of the failure and performing the needed tests to verify that the failure is actually repaired. The fourth important part of the OpEx cost is given by the process of *provisioning and service management*. This follows the service request by the potential customer and includes the entire process from order entrance 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 the customers and making sure they pay. It includes actions like collecting information on service usage per customer, calculate cost per customer as well as sending bills and checking payments. 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 which is up and running, including day-to-day planning, re-optimization, planning upgrades. Finally, there is the cost for *marketing*. With marketing we mean acquiring new customers for a specific service of the telco. The actions involved are promoting a new service, providing information concerning pricing etc. Possibly, new technologies enable new services.

The second category of operational expenditures we distinguish is the OpEx 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], as 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 o*f new network equipment. All costs related to installing the equipment (after buying it) is counted here. This 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 to *capitalize* 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 '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 continuous 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 the payment administration for employees, the secretary, the human resources department etc. 'Non-telco specific administration' and 'non-telco specific cost of infrastructure' can jointly be seen as 'overhead' costs.

The matrix representation of Fig. 1 representation clarifies our belief that personnel costs (wages) should not be considered as a subpart of OpEx on itself (as suggested in [7]), but rather as a kind of expenses present in several OpEx subparts. Other expenses apparent in several OpEx subparts are (floor) space, energy and rental. 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. Here also the cost to actually buy the necessary tools is included: [8] believes these tools are bought and therefore CapEx. [4] and [9] on the other hand, believe they 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, screw drivers, mobile phones to name only a few. Unlike the big investment of buying assets like buildings, network equipment and inherent instrumentation equipment (which is CapEx), the small investment to buy those 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 actual operational processes that interact with each other. The maintenance (routine operation) process is the central process. An important task of the routine operation process is to monitor the status of the network and its components. Network utilization info 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 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 which 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).

Fig. 2 illustrates the repair process, Fig. 3 the service provisioning process. For a detailed description of all processes we refer to [10].

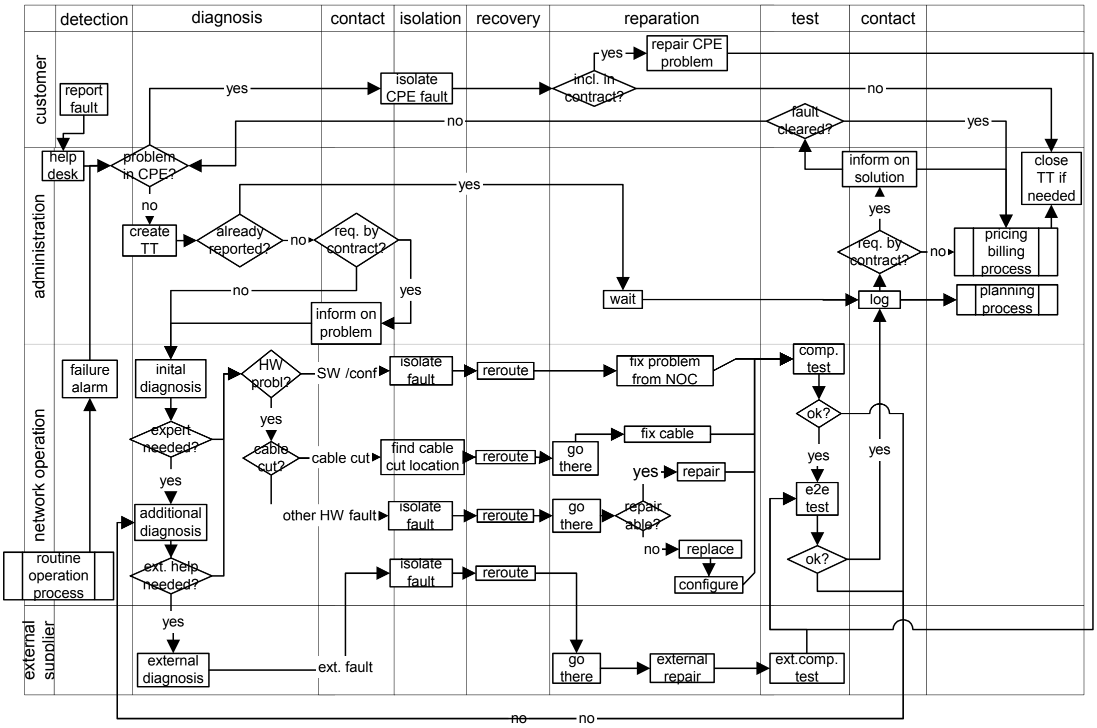

Fig. 2: Activity-based description of repair process

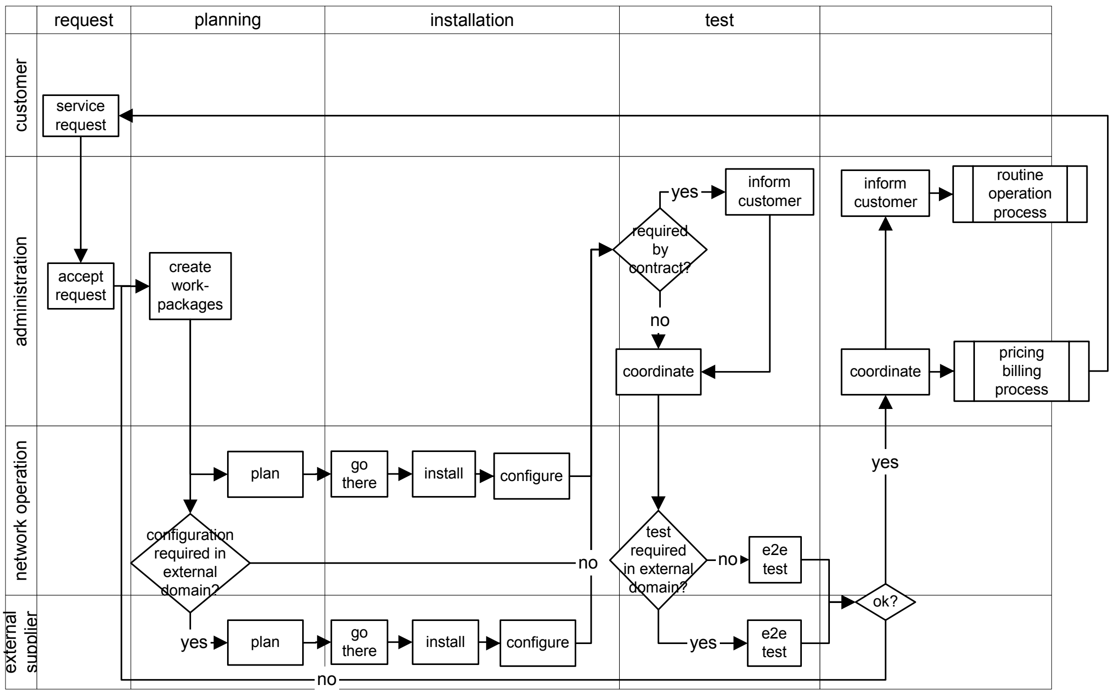

Fig. 3: Activity-based description of service provisioning process

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, that 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 this action and multiply it by the wages of the person taking care of it. This approach is also suggested in [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. Exactly calculating the 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 (e.g. technicians will need more tools than administrative personnel), so that we can identify a weight factor for all considered personnel categories what the personnel cost needs to be multiplied by. The use of the weight factor is similar to what is described in [9]. A possible way to estimate 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 form the personnel wages, also the activity duration is required to calculate 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 [14].

Calculation of OpEx costs using the suggested process-based approach allows to study the impact of the business organization of the considered carrier, i.e. more efficient workflows are reflected in the processes directly, where more efficient organization (e.g. smaller departments) are reflected in the weight factor. This approach is far more flexible and more realistic than the traditional approach where OpEx is 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, SDH and WDM equipment as well as optical fiber. Using 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 like [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.

Tab. 1 lists the collected availability numbers: *Mean Time Between Failures (MTBF)*, its alternative *Failures in Time (FIT)* where MTBF[h] = 10E09/FIT and *Mean Time To Repair (MTTR)*. More information concerning the rationale behind the numbers can be found in [20]. 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 (CC) value of 3E02 km, indicating the average cable length suffering from 1 cable-cut per year [22]) and a MTTR of 12 hours.

	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

Tab. 1: Collected availability numbers

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 can allow to estimate the frequency of occurrence of the repair process. However, knowing this figure, for some components, preventive replacement (in the service window, and therefore during routing operation) could be planned for. Preventive replacements increase the cost of the routine operation processes, while decreasing 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 to calculate the total cost, CapEx as well as 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, such as equipment price and availability information, power consumption and footprint. In case a real network scenario is considered, this can be found in the datasheets provided by the equipment vendor. In case a theoretical study is performed, without reference to a specific vendor, the assumptions need to be based on public sources like the collected availability numbers of section 5 or some educated guesses for equipment costs (based on [5]), footprint and power consumption, as shown in Tab. 2 for some 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 Gbps)	0.5	0 (inserted in OXC)	2.00
LR transponder (2.5 Gbps)	0.5	0 (inserted in OXC)	2.50
unequipped OXC (512 ports)	3	3 racks	100.00

Tab. 2: equipment characteristics for optical network equipment

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 learns 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 theoretic study, it can be estimated as a fraction of the CapEx costs, e.g. 30%.

5. *Calculating OpEx for a network which is up and running.* Using the activity-based approach of section 3, the costs of all identified operational processes can be estimated, based on the input information concerning personnel wages and activity duration. This information suffices to calculate the cost for the continuous processes like routine operation, operational network planning and marketing. For the recurring processes, the number of occurrence over the considered time frame (e.g. one year) is required. For the repair process, this follows from the availability information. For the service provisioning process it is determined by the number of service requests and for the pricing and billing process 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 which 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 in order to evaluate investment decision criteria like 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 an WDM network (only the cost of the optical layer of the network is considered here) carrying 2.5 Gbps leased lines. Although, in a realistic network, leased lines would probably be offered via SDH or 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 a GMPLS-enabled network i.e. a network with Generalized Multiprotocol Label Switching (GMPLS) control plane functions such as routing and signaling for automized 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 setup 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 is 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 Tab. 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 a CapEx part. 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 leading 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 using 1+1 protection. The OpEx costs for equipment installation are estimated to mount to 30% of the CapEx costs, in both cases. The telco-specific continuous cost of infrastructure was calculated from floorspace 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 as well as for a GMPLS-enabled network. We evaluated how GMPLS technologies impact the costs of the operations a 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 of GMPLS-enabled network on them, see [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 and the GMPLS-enabled network. The yearly recurring OpEx has a small impact, so that the picture doesn't change a lot in case of 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.

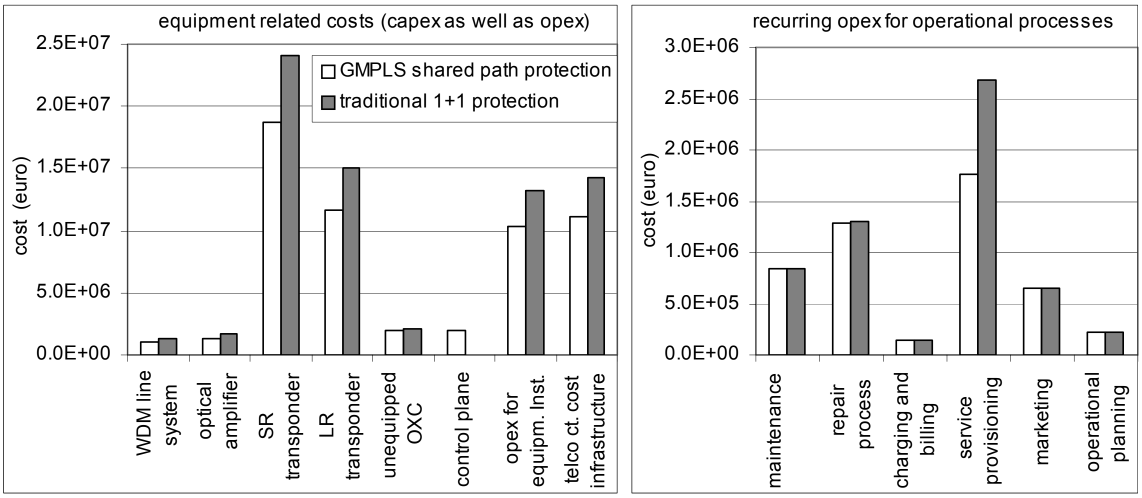

Fig. 4: CapEx and OpEx costs for German reference network scenario.

8. Conclusion

In the rapidly changing telecom market, an 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 to calculate 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 to calculate the operational expenditures for a certain network scenario. We have shown that most network operators' processes are similar and can be modeled quite generically. We discussed the required input data in order to calculate 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 and a GMPLS-enabled network.

9. Acknowledgment

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