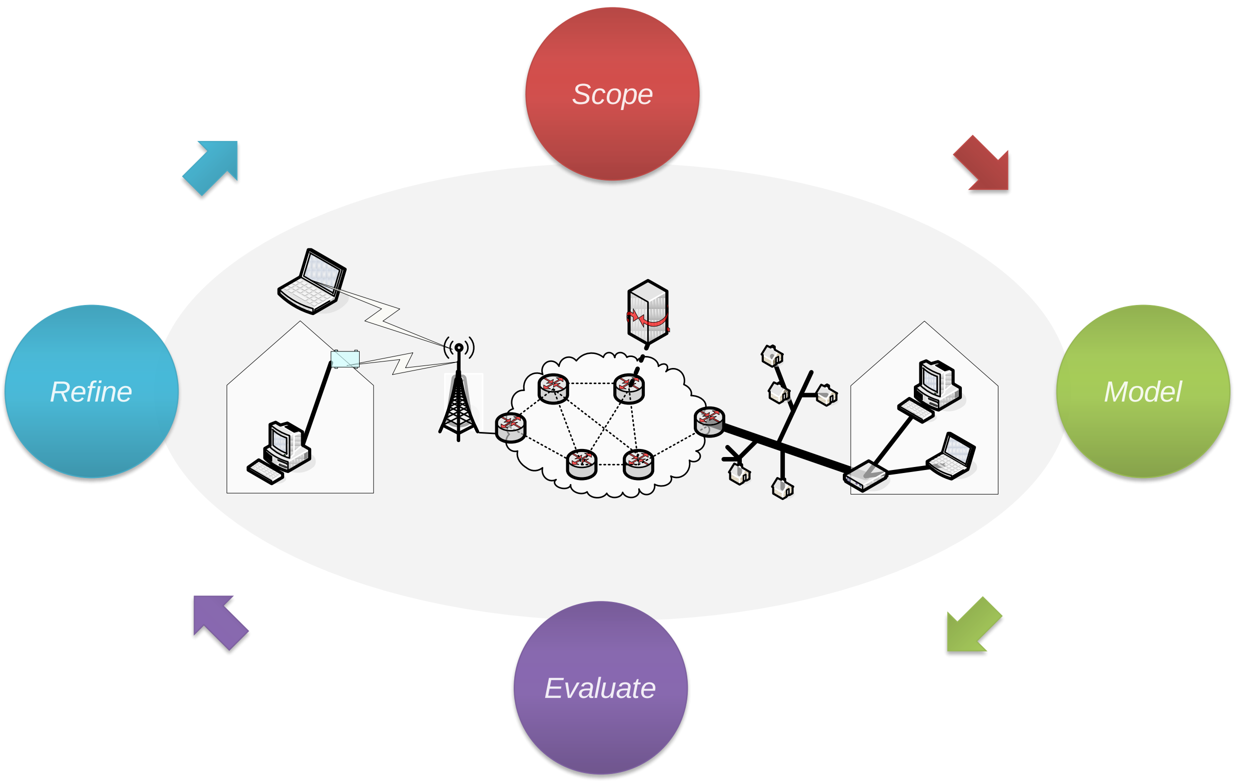
WHITE PAPER: PRACTICAL STEPS IN TECHNO-ECONOMIC EVALUATION OF NETWORK DEPLOYMENT PLANNING



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ABSTRACT

This white paper aims at giving an overview of the techno-economic planning process for network deployment, migration and/or service offerings. We will study the entire flow, starting with a description of the existing situation, subdividing the specific problems, modelling network, processes, costs and revenues and ending with an evaluation of the relevant output parameters such as profitability. All steps are discussed indicating existing models and how they can be applied. Readers will learn to look into the network deployment problem from a techno-economic viewpoint. They will get to know how to focus on the main driving aspects first, while minimizing the chance to get lost in details. As opposed to some practices where one or more parts of the picture are neglected, we will emphasize the importance of the whole picture, choosing the required level of detail for the different parts. Furthermore a detailed analysis will show how to use real options and game theory in telecommunication cases.

TABLE OF CONTENT

1. STRATEGIC NETWORK PLANNING PROCESS

The telecom market is very competitive, technical superiority is not a guarantee for market success. Rather than a pure technical view, a true techno-economic approach towards network deployment planning is appropriate.

The broad field of network planning includes a lot of sub-problems: what are the bandwidth and user requirements, where to install the network nodes, between which nodes to install a direct link (topology design), how much capacity to install on each line (dimensioning problem), what technology to choose, how to route the traffic through the network from its source to its destination (routing problem), in which network layer to provide protection, etc. When considering the whole picture, also social, economic, regulatory and political sub-problems are playing an important role in network rollout and service offerings. All these issues have a direct impact on the viability of the business case and could make or break the project.

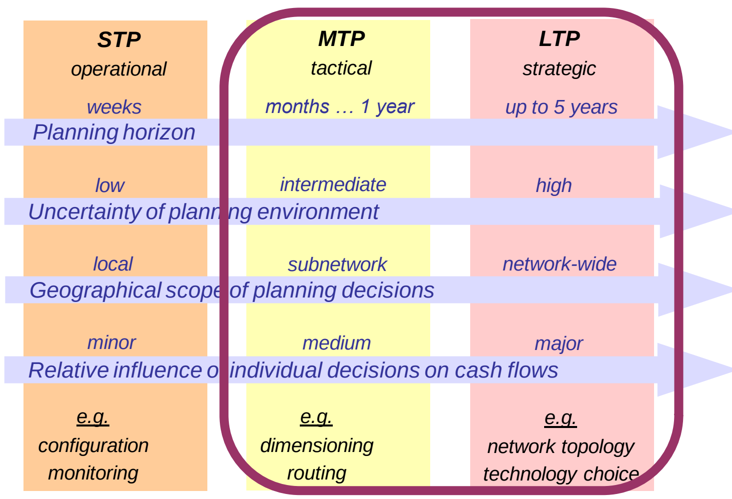

Figure 1: Planning horizon in telecom

A first classification in these sub-problems is dictated by the timescale they consider (Figure 1). Short-term planning or operational planning concerns a planning horizon of some days or weeks, the uncertainty in the planning environment is low and the geographical scope of the decisions is local, the relative influence of individual decisions on cash flows is only minor. Configuration and monitoring problems typically fall within the short-term horizon. Mid-term planning or tactical planning deals with a planning horizon of less than one year, experiencing an intermediate uncertainty of the planning environment, the geographical scope of the planning decisions is typically limited to the sub-network and the relative influence of individual decisions on the cash flows is medium. Dimensioning and routing issues are typical examples of mid-term planning problems. Long-term or strategic network planning considers a planning horizon of up to about 5 years, there is a high uncertainty of the planning environment, the planning decisions have a network-wide geographical scope and there is a major influence of decisions on the cash flows. Examples of strategic planning problems include network topology and technology choice. Of course, the boundaries between the different planning types are not strict. This paper focuses on problems situated in mid- and long-term planning.

The strategic network planning process considered here aims at developing a network deployment plan, indicating what investments should be made at which points in time (Figure 2). Apart from boundary conditions from the existing network, technical and physical constraints, there are two main inputs, which typically follow a dynamic and uncertain evolution. First, the customer demand is always driven by new applications and the overall bandwidth demand keeps growing. Actual forecasts of future demand are very difficult to make and subject to uncertain evolutions. Second, the equipment cost is typically decreasing over time. Cost erosion of around 20% per year is no exception. However, also here the future evolution is unclear because of competition and technological innovations.

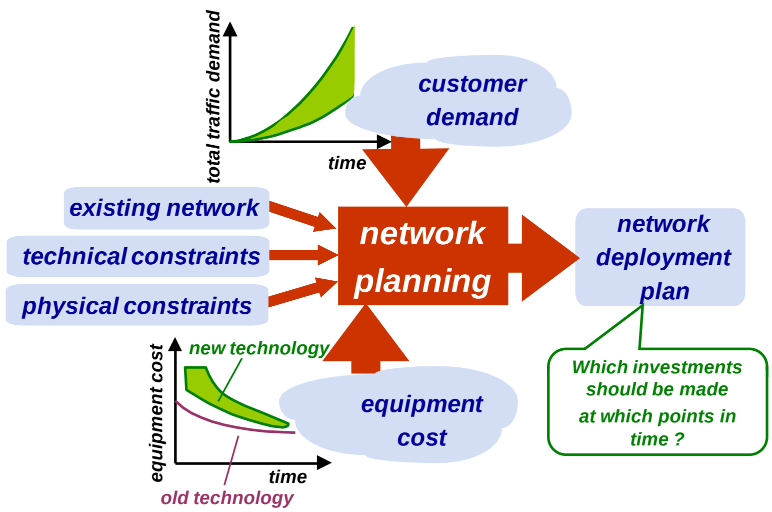

Figure 2: Network planning

2. General methodology overview

Four typical steps can be observed in techno-economic analysis for telecom deployment planning: scope, model, evaluate and refine (Figure 3). This approach is loosely based on the Plan-Do-Check-Act (PDCA) cycle first described by Dr. W. Shewhart and extended by (and more often associated with) Dr. W. Edwards Deming [24]. The cyclic nature of this approach is very important. It allows a gradual refinement of the business case under research.

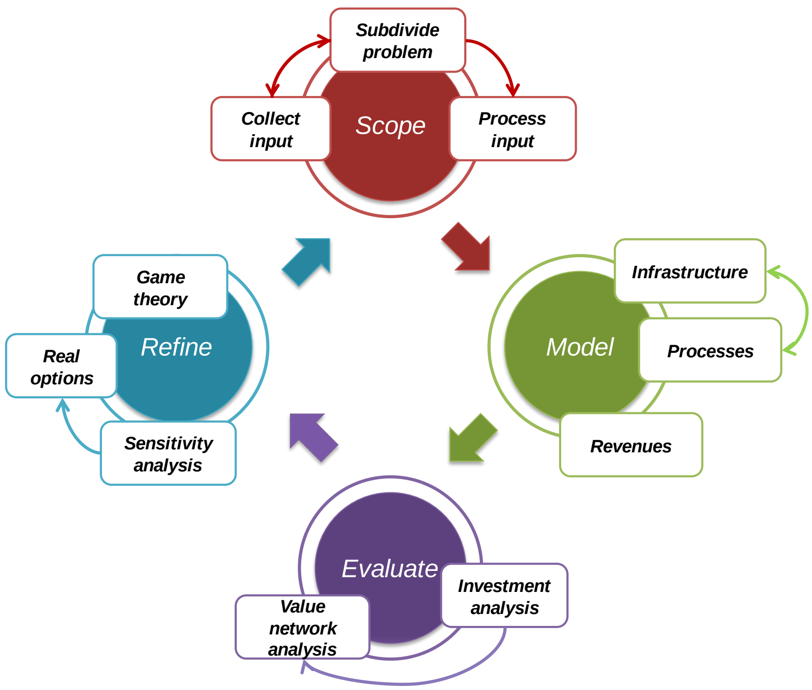

Figure 3: Detailed techno-economic methodology

The initial scope step is constituted of collecting the required input (technology, market, target area), subdividing the problem (which parts of the problem to be studied: areas, users/services, actors, technologies, costs/revenues) and an initial processing of the input (user adoption, business models and technical design).

The second step considers modelling the costs and revenues to be taken into account in the analysis. Here, both a top-down and a bottom-up approach are possible. Within the chosen model, the appropriate level of detail is to be chosen: fractional cost/revenue modelling, modelling as a function of a driver and finally performing an actual dimensioning study (dimensioning the network and/or the processing behind it).

The following step is the actual techno-economic evaluation, taking into account all cash-in and cash-out flows calculated using the models considered in step 2 and based on the input information from step 1. Investment analysis can be performed based on a combination of classic investment decision techniques like payback time, return on investment (ROI), net present value (NPV) and internal rate of return (IRR). Several alternative business models or value networks can be compared, analysing the viability of the case for each actor (multi-actor analysis).

Finally, in the fourth step, the techno-economic evaluation can be refined. Sensitivity analysis gives more information about the impact of different input parameters. Application of real options valuation allows including the value of flexibility to respond to uncertain changes throughout the course of the project. Ideas from game theory allow getting an insight in the impact of competition.

Plenty of application domains for techno-economic analysis of network planning have been given attention in our research during the past years ([1]-[23]). They include: planning of next-generation access networks, i.e. the road towards FTTH, planning and stimulating the deployment of community networks, wireless network rollouts, introduction of Internet on trains, IPTV tariff calculation, planning access and in-house networks for the support of an eHealth system, optimization of server locations, etc.

In the next sections, the different steps will be further elaborated, illustrated with examples from several cases studied by our research group.

3. Scope

In a first step, the aim of the business case and how it will be obtained is studied. We determine where all data will come from and how the problem is split into different sub-problems. Also the data-set is split into logical partitions such as physical regions, years, etc. Finally, in a preliminary processing step some of the huge data-sets are correlated to existing models. This concerns all models which are not directly in the main scope of the investigation, but rather serve as input for building the global business case. Examples of this are customer adoption and price-evolution of equipment.

In this phase also the planning horizon and level of detail will be fixed. There will be a trade off between the planning horizon and the level of confidence of the model. A longer planning horizon will be much more susceptible to (accumulated) errors and as such lead to less reliable results.

3.1. Collect input information

Acquiring data and building knowledge of the problem scope is a difficult and tedious task. Different sources can be accessed or are at the disposal for gathering input information:

- Various target area and market information sources are publicly available such as national statistical institutions [25] and national regulatory instances, press releases and year reports from operators, etc. This information concerns the number of users and services currently offered, and will be used in a further stage for adoption modelling. The actors involved in the network and service offering will be analysed.
- Technology information is mainly found in papers from various authors (papers from research centres and vendors), generally addressing the technical issues as well as the economics concerning the new technology and research aspects. Discussions with equipment vendors and telecom operators within different European, national and bilateral projects enlighten our view on the current and future market and technology situation.

3.2. Subdivide the problem

While the initial research question is fairly comprehensive, the problem quickly increases in both size and complexity when gathering input information. Clearly the more information available, the more realistic the problem is represented and the more reliable the optimal solution will reflect the actual optimum. At this point, just after gathering input information, it is best to structure and aggregate all input information [26].

3.2.1. Areas, users and services

It is often impossible to roll-out the network throughout the whole target area at once (e.g. like a full country or city) due to practical limitations (time and resource constraints, mainly due to lack of manpower) and legal permissions. The rollout speed and sequence must carefully be estimated. For the introduction of new services this issue will be less a problem, depending on the additional investments required in the network (e.g. IPTV). A list of potential users (residential vs. industrial, frequent vs.

occasional) and services (single vs. bundled services, fixed vs. nomadic vs. mobile) to be looked at must be outlined. A cherry picking strategy could help finding the most interesting areas with the highest return on investment. This clustering is based on information concerning distance, market potential (type of buildings, demographics, residential and commercial density, etc) and optimal utilization of equipment (e.g. available locations for wireless base stations, reuse of current infrastructure, etc).

3.2.2. Technology, costs and revenues

A choice must be made on which technologies to consider for the analysis. This will mainly depend on the actor involved in the rollout (reuse of available infrastructure), rollout area, regulation, maturity of the technology, etc. The type of rollout (buried, aerial/façade, or blowing fibre into existing ducts) will highly affect the viability of the business case (Figure 4).

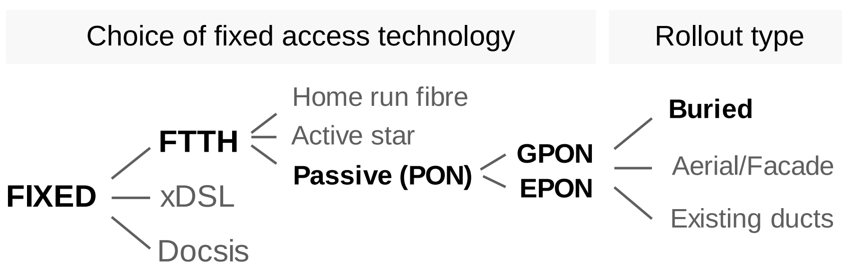

Figure 4: Subdividing technologies

A more detailed approach can be worked out when the choice for technology is determined, using the approach as suggested in Figure 5. A selection and prioritization step must be implemented to focus on the most important parts (indicated by the font size in the picture). This way we can focus on modelling the largest cost and revenue factors in most detail and avoid unnecessary modelling for unimportant cost factors [17].

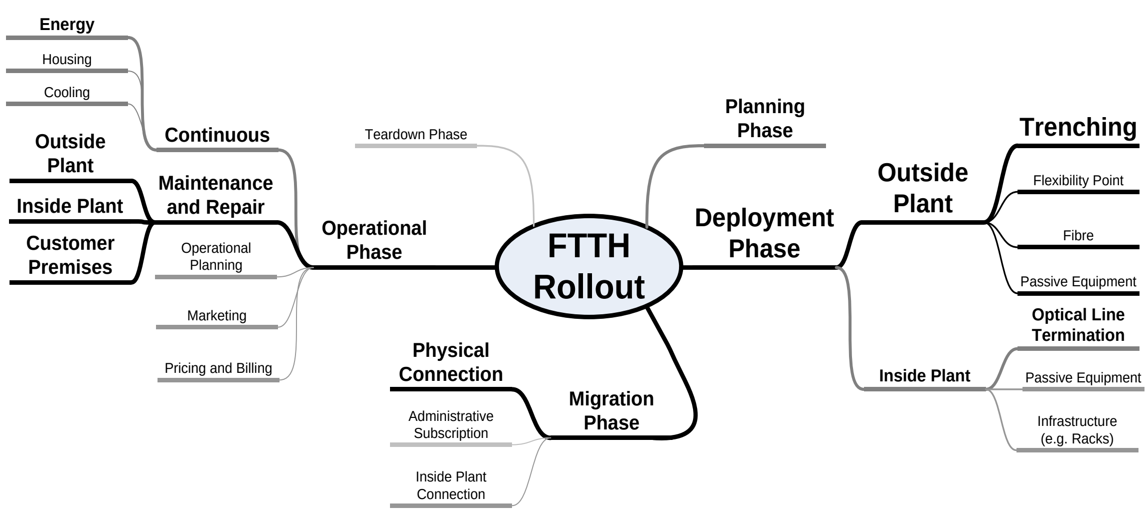

Figure 5: Breakdown of the cost (estimated) of a FTTH rollout with focus (size and weight) based on the impact of the part on the final cost

3.3. Process input information

This is the final step in the preparation of the input information for the business case. In this phase we process the input information into logical input models for the further calculations.

3.3.1. Diffusion models and adoption curves

The information processed in the sub-division step concerning the area type and size, number of potential customers and services offered will be used for creating forecasting models for technology and service usage. In the next paragraphs we will first discuss the most used diffusion models and adoption curves. In the second step we outline how to estimate the model parameter values and explain with an example.

Everett Rogers can be considered as one of the pioneers of diffusion models with his diffusion of innovations theory [27][28]. He proposed that adopters of any new innovation or idea could be categorized in five groups: innovators (2.5%), early adopters (13.5%), early majority (34%), late majority (34%) and laggards (16%). The cumulative percentage of adopters over time (or market share) forms an S-shaped curve, which is the general pattern of any adoption curve (Figure 6)[27][29].

The Bass diffusion model [30] is influenced by the diffusion of innovation from Rogers. The model considers only two separated adopter groups: innovators, who are initial adopters not influenced by others, and imitators, who learn from prior adopters (Figure 7). The cumulative number of adopters again forms a kind of S-shaped curve. Compared to the Rogers's model, adopter group 2 to 5 are now grouped as imitators, and in contrast to the previous mentioned model, the size of the different groups is no longer defined by fixed percentages.

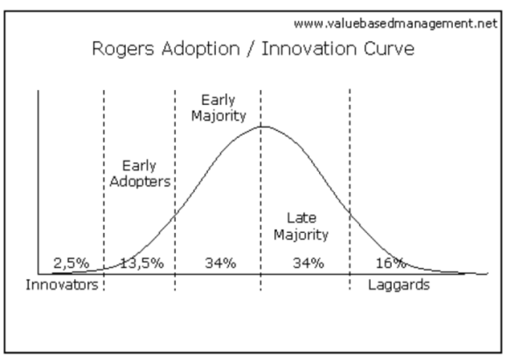

Figure 6: Rogers' new adopters curve

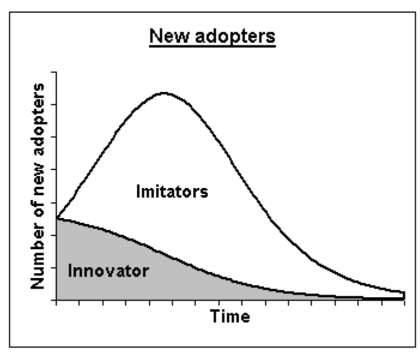

Figure 7: Bass' new adopters curve

The mathematical model of the cumulative market share described by the Bass diffusion model is shown in (3.1). Typical values of *p* and *q* are given in [31]. The average value of *p* has been found to be 0.03, and is often less than 0.01. The average value of *q* has been found to be 0.38, with a typical range between 0.3 and 0.5.

$$S(t) = m \cdot \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}} \qquad (3.1)$$

Where:

m	=	maximum market potential
p	=	coefficient of innovation, i.e. external influence or advertising effect
q	=	coefficient of imitation, i.e. internal influence or word-of-mouth effect

An extension to the Bass curve was formulated by Norton and Bass [32], and it incorporates the adoption of different consecutive generations of the same or comparable technology. The formulation for three generations is provided by (3.2). This model has proven its value for the modelling of successive product generations.

$$\begin{aligned} S_1(t) &= F_1(t)\, m_1 \left[1 - F_2(t-\tau_2)\right] \\ S_2(t) &= F_2(t-\tau_2)\left[m_2 + F_1(t)\, m_1\right]\left[1 - F_3(t-\tau_3)\right] \\ S_3(t) &= F_3(t-\tau_3)\left[m_3 + F_2(t-\tau_2)\left[m_2 + F_1(t)\, m_1\right]\right] \end{aligned} \qquad (3.2)$$

Where:

$F_i(t)$	=	$\frac{1 - e^{-(p_i+q_i)t}}{1 + \frac{q_i}{p_i} e^{-(p_i+q_i)t}}$,
		the fraction of the potential of generation *i* which have adopted by time *t*
m_i	=	market potential uniquely served by generation *i* (and successor generations)
p_i	=	coefficient of innovation of generation *i*
q_i	=	coefficient of imitation of generation *i*
τ_i	=	time at which generation *i* is introduced in the mindset (e.g. nationwide)

The Fisher-Pry curve makes use of a Sigmoid curve, which is a special case of the Logistic curve (i.e. the general mathematical description of an S-curve). It was introduced by Fisher and Pry in [33], and the cumulative market share is given by (3.3). The Fisher-Pry model is especially applicable to technology-driven adoptions where new technology displaces old technology because it is technically and economically superior [29]. In this way, it can be considered as a substitution model.

$$S(t) = m \cdot \frac{1}{1 + e^{-b(t-a)}} \qquad (3.3)$$

Where:

m	=	maximum market potential
a	=	inflection point, i.e. year between a progressive and degressive increase, which occurs at an adoption of 50%
b	=	rate of adoption, i.e. indication of the slope of the maximum increase

The Gompertz curve is originally formulated by Benjamin Gompertz in 1825 [34], and it is a much used curve for forecasting, see e.g. [35][36][37]. The mathematical model for the cumulative market share is given by (3.4). The Gompertz model also forms an S-shaped curve, but it is asymmetric, with the adoption slowing down as it progresses. More precisely, the Gompertz curve assumes that the period of increasing growth of adoption is shorter than the period in which this growth is decreasing and in which it is adjusting to its saturation level. The Gompertz model is usually better suited for consumer adoptions than the Fisher-Pry curve [29].

$$S(t) = m \cdot e^{-e^{-b(t-a)}} \qquad (3.4)$$

Where:

m	=	maximum market potential
a	=	inflection point, which occurs at an adoption of 37%
b	=	rate of adoption (defining the slope of the curve)

As indicated in the previous section, the different adoption curves contain several parameters which have to be estimated. Next to the choice of an appropriate adoption curve, an accurate estimation of the adoption parameters is even more important, but unfortunately not that easy. A commonly used method is based on historical data of similar products, fitted to the most suited adoption curve.

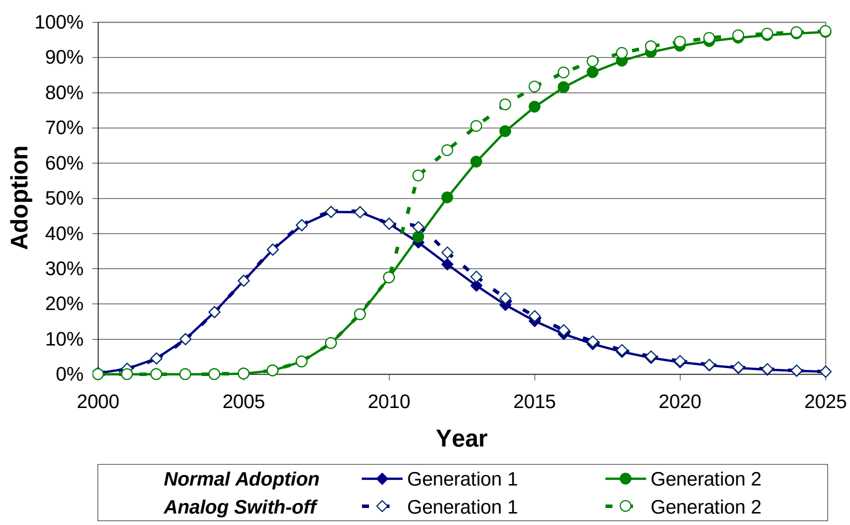

Figure 8: Adoption estimation for new networks considering IPTV

Figure 8 shows an illustrative example of an adoption according to a Gompertz model extended with competition between two generations [14]. Typically, the first generation is broadband not optimally suited for IPTV and the second generation is broadband which is better suited for IPTV. It also includes the impact of analogue switch-off (taking place in 2011). We assumed that all customers choose IPTV and 80% of the new customers choose for the newest generation. This means that we assumed that the total adoption of IPTV jumps up to 98.2% at this point. This could for instance be the case in a country like Belgium with a high penetration of fixed access networks.

3.3.2. Cost price erosion

As time goes by, network equipment costs will typically decrease. Several causes can be identified for that, amongst which cheaper production for bigger quantities. The *learning curve* is often used to represent the extent to which the average cost of producing an item decreases in response to increases in its cumulative total output. The learning curve model can therefore be used to predict future network equipment prices as an explanatory forecasting technique. The model is based on the Wright empiric law: "Each time the cumulated units production doubles, the unit cost decreases with a constant percentage", see formula (3.5). It can also be expressed by a formula where the cost C is a function of the produced output Q (3.6).

$$C_{2n} = KC_n \qquad (3.5)$$

$$C_Q = C_0 \cdot Q^b \qquad (3.6)$$

- C_Q is the cost of the Q^{th} unit of output produced. C_0 is the cost of the first unit produced
- K is the logistic curve rate or cost reducing factor
- $b = log_2 K$ is negative, since increases in cumulative total output reduce cost. If the absolute value of b is large, cost falls faster with increases in cumulative total output than it would if the absolute value of b were small.

Increasing produced quantities may result from a growing market penetration of the equipment. The *logistic growth curve* is used to express the market penetration as a function of time. The logistic model was developed by Verhulst who suggested that the rate of population increase may be limited, i.e. it may depend on population density, as expressed in formula (3.7), where r_o is the maximum possible rate of population growth. In our case of the growing market penetration, the population represents the quantity of the product sold on the market. Population growth rate declines with population numbers Q and reaches 0 when $Q = Q_u$. Parameter Q_u is the upper limit of population growth and it is called carrying capacity. If population numbers exceed Q_u, then population growth rate becomes negative and population numbers decline. The dynamics of the population is described by the differential equation (3.8) which has (3.9) as a solution.

$$r = r_0 \cdot \left(1 - \frac{Q}{Q_u}\right) \qquad (3.7)$$

$$\frac{dQ}{dt} = rQ = r_0 Q \cdot \left(1 - \frac{Q}{Q_u}\right) \qquad (3.8)$$

$$Q(t) = \frac{Q_0 Q_u}{Q_0 + (Q_u - Q_0)\exp(-r_0 t)} \qquad (3.9)$$

The logistic model has three possible outcomes, as illustrated in Figure 9:

- If $Q_0 < Q_u$, the population increases and reaches a plateau. This is the logistic curve, also called S-curve.
- If $Q_0 > Q_u$, the population decreases and reaches a plateau.
- If $Q_0 = Q_u$, the population does not change.

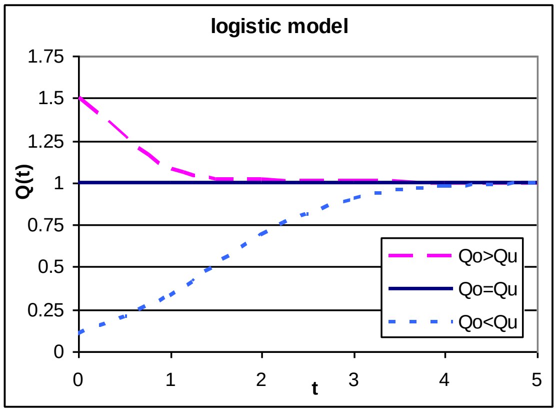

Figure 9: logistic model with r_0=1.5, K=1 and N_0=0.1, 1, 1.5 resp.

The RACE Project TITAN [38] proposes some evolutionary trends for network component production costs versus their technological maturity, based on a combination of the learning curve model and the logistic growth curve model, both discussed before. The trend formula is given by formula (3.9), where *t* indicates the year of the predicted cost, relative to the initial time *0*. Parameters C_0, Δt, Q_0 and *K* are the key input coefficients in the equation. The more reliable these input coefficients are, the more realistic the obtained cost curves can be. Most of the parameters are introduced above, but they are repeated for the sake of completeness.

- C_0 = the observed component cost at a reference time *t=0* (reference year).
- Q_0 = the percentage of penetration volume at the reference time *0*. It is an indicator of the component maturity level reached at *t=0*. A low Q_0 value represents components with a relative short industrial life. In addition, prototype devices usually have extremely low Q_0 values.
- *K* = the learning curve rate or cost reducing factor (the relative decrease in the cost by the double production $C_{2n}=KC_n$). It reflects the production experience increase related with the type of component.
- Δt = the time it takes for the growth curve *Q(t)* to go from *10%* to *90%* of the maximum penetration volume. This indicates the time the product needs to be widely commercialized. A low ΔT-value indicates a technology that will be replaced sooner or a product that will saturate the market quickly. The Δt-parameter, based on its definition, can be written as a function of the previously defined parameters r_0 and Q_u.

$$C(t) = C_0 \left[\frac{1}{Q_0} \left(1 + \exp\left[\ln\left(\frac{1}{Q_0} - 1 \right) - 2t \frac{\ln(9)}{\Delta t} \right] \right)^{-1} \right]^{\log_2 K} \qquad (3.9)$$

An important advantage of this model in the current fast evolving telecom environment is that it can also be used when only a few observations are available or if historical costs are absent. Typical values for n_r, ΔT and *K* are found in [39] for electrical (0.1, 10, 0.9) and optical (0.01, 8, 0.8) network equipment. For both parameter sets, the extended learning curve is shown in Figure 10.

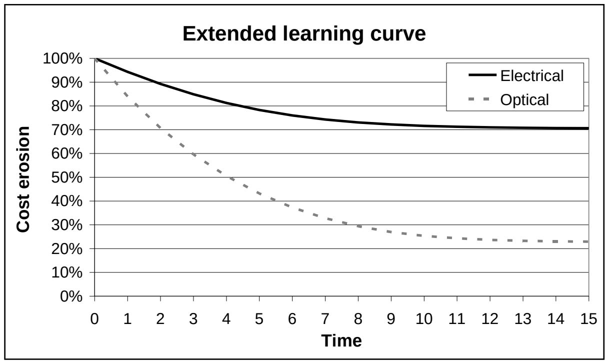

Figure 10: Illustration of the extended learning curve

4. MODEL

There are different approaches towards modelling costs and revenues for a business case. First, the modelling approach and level of detail will be limited by the data-sources available. Detailed information on personnel count, task timing, etc. allows more detailed modelling. Still it will not be opportune to model all components of the cost and revenues with the highest possible level of detail. It will not pay to put too much effort in constructing a detailed model for only a very limited part of the total cost. The optimal strategy, as indicated as well in the scope phase, will focus on the modelling of the largest cost components first, and gradually refine the remaining components in order of size. As it is hard to decide upfront what will be the largest cost component, this approach will always be somewhat speculative.

4.1. APPROACH

In a business case, there is often also a distinction between capital and operating expenses, typically referred to as CapEx and OpEx. This distinction is primarily focussed on depreciation and the potential effect of this on the business case. CapEx, or any capitalizable cost, is defined [40] as *"Funds used by a company to acquire or upgrade physical assets such as property, industrial buildings or equipment. This type of outlay is made by companies to maintain or increase the scope of their operations"*. CapEx are depreciated over time and as such this can be used to optimize taxes by defining the depreciation scheme (where possible). OpEx are defined as [40] *"A category of expenditure that a business incurs as a result of performing its normal business operations"*. Operating expenses are not depreciated over time. Often in investment analysis, depreciation and taxes are left out of consideration. Still once a decision on the investment is made, a fully detailed planning will involve this kind of issues. A recommended distinction between two approaches is based on the input source [5] (Figure 11).

The first approach, the *top-down* method, starts from the existing network infrastructure. In this case, the actual network dimensioning is a result from fluctuations in historic and current demand, e.g. a growing number of customers and increasing traffic volume for several services, but also a declining service demand for other services (e.g. fixed telephone lines). The network is therefore less efficient than a new network (specifically designed for the current traffic demand). The cost of existing equipment is then allocated to the elements needed to deliver the service, through the use of cost drivers [41]. Therefore, an accurate identification of real cost drivers is required. In practice, it might be difficult to select the correct driver, leading to less efficient and less fair allocations. Two important cost bases can be distinguished for the top-down valuation of equipment. *Historical Cost Accounting (HCA)* uses the asset purchase costs as book value, taking depreciation into account. Since this method counts all historical costs, it cannot be used for network optimization. *Current Cost Accounting (CCA)* values assets at the current market price. This cost base represents the replacement cost of an asset, i.e. how much it would cost today to purchase that asset. However, as a result of the continuous evolution of technology, it is not always possible to find the same equipment on the market as what has been installed in the network previously. A possible solution to this problem is given by the *Modern Equivalent Asset (MEA)* cost base, where the costs of equipment is valuated using the cost of a new technology offering the same (or more) functionality as the one that is currently installed.

The second approach, the *bottom-up method,* requires as starting point the demand for the services. The network is dimensioned in such way that it is optimal for the current situation: it can serve all customers with the requested services at the proposed quality of service. Service costs are allocated according to their required network equipment and usage. The bottom-up method can be used for different studies. It can be used for calculating the costs when designing a completely new network-architecture. It can also be used for making the comparison of the costs in an existing network considering an optimized (bottom-up calculated) network-architecture providing the same services. In the bottom-up method, the company's properties and goods will be evaluated following the *forward looking cost (FLC)*. When considering a new network this means that only new and efficient technology will be used. When modelling an existing network, on the other hand, it might mean that less expensive technology is used in the study. This implies that the current network must be reconsidered and remodelled. There are two approaches for doing so, the *scorched earth (green field)* and *scorched node (path dependent)* approach. In the former approach, the network is redesigned with as few constraints as possible: a different number of nodes, a changed topology and other technological solutions can be taken into account. On the other hand, the latter approach makes a more fair compromise between efficiency of new technologies and networks and the existing network structure. The nodes stay at their original positions, whereas all equipment can be changed [42].

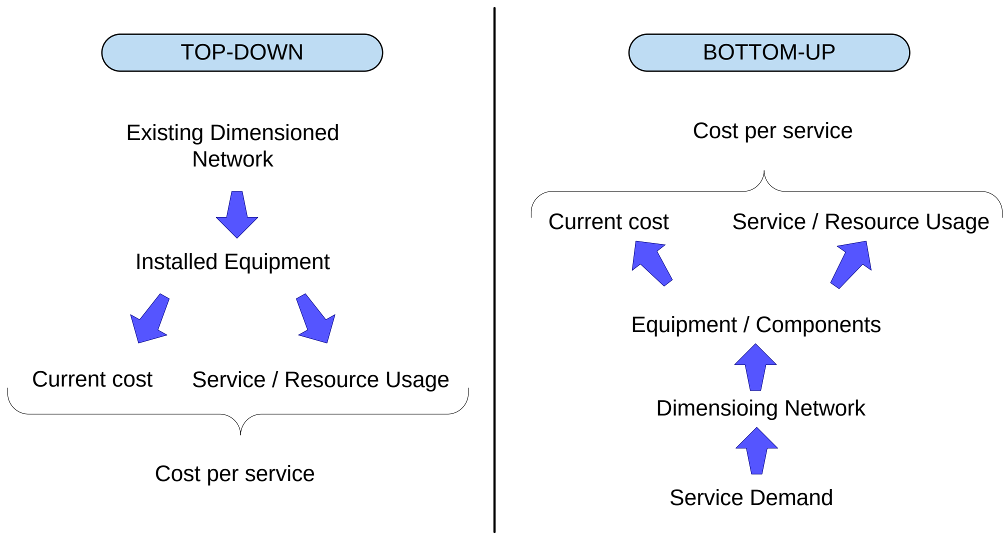

Figure 11: Top-down vs. Bottom-up cost modelling

4.2. Level of detail

In the vision of the refinement within the Deming-cycle we propose a classification based on required level of detail:

1. Fractional models
2. Driver based models
3. Dedicated dimensioning models
    a. Infrastructure dimensioning models
    b. Process dimensioning models

Details on each of those models can be found in the following sections. General modelling encompass both the fractional models and the driver-based models from this classification. Dedicated models allow modelling network and processes in more detail. It is important to note that a large techno-economic model might combine different types of models from this classification into one higher level (dedicated) model.

4.2.1. Fractional modelling

In fractional models, (preferably small) components of the costs are expressed in relation to (larger) components of the costs. Costs of maintenance and replacement of electronic equipment is often modelled in this manner. Its cost is then for instance modelled as being 20% of the initial investment cost (per year) for the actual equipment. Other examples are: costs which are not telecom specific (management, overhead, maintenance of buildings, etc.), administrative work for connecting or disconnecting a customer, pricing and billing (more typically modelled as a percentage of the revenues).

This type of modelling holds no information on the source of the cost and how it might evolve. As such it is not suitable for larger cost components, especially when there might be important differences in this cost between alternative technologies, regions, etc.

4.2.2. Driver based modelling

In driver based models, we use one (or a limited amount of) so-called drivers to model and calculate one part of the cost. A driver based model is actually a function taking one (or a limited amount of) parameters (the drivers) and calculates from this the cost of the component. Of course additional (fixed) parameters can be used in this calculation function. The following example will clarify this. The cost for call-centre and helpdesk is in this model related to the number of customers, which is as such the driver for the cost. In the calculations we considered that one customer would lead to (statistically of course) 1.8 calls per year and handling one such call costs 12€ on average. As such the call-centre and helpdesk cost can be calculated based on the actual number of customers in each year. Of course a more detailed model could be used, where the helpdesk cost will be depending more on the new customers as they encounter more problems. In this case there are two drivers, all customers and new customers, and a slightly different function for the calculation of the cost.

The driver based model can easily resemble other types of models, by changing the driver and the function. In case the driver is set to the cost of another component of the cost, the driver based model replaces the proportional models. Increasing the number of drivers and the complexity of the functions, allows driver based models to resemble dedicated dimensioning models. We distinguish driver based from proportional models by the requirement of a driver which is logically linked to the final cost, and is preferably the most important logical parameter. While driver based (or more in general function based) models can be used to represent all dedicated models, there is a difference in logical structure and solution approach. Operational processes for instance are more intuitively comprehensible and manageable when modelled with flowcharts or other dedicated models.

4.2.3. NETWORK AND PROCESS BASED DIMENSIONING

A. Network dimensioning

In network dimensioning one tries to find out the amount of equipment necessary to provide a given functionality over a telecom network. Even more than simple calculation of a sufficient infrastructure solution, the researcher is often interested in the most efficient (or as efficient as possible) use of infrastructure. The dimensioning of the network leads to a network topology, graphically represented in Figure 12. Different types of architectures will lead to other topologies, with different cost structures. More detailed modelling techniques such as the use of Steiner Tree (e.g. for finding the optimal fiber topology in case of FTTH rollout) could lead to optimized results. In techno-economic modelling a network dimensioning will lead to a so called bill-of-material (BoM) containing a list of all equipment that should be installed to provide the required functionality. This bill-of-material easily allows calculating the actual cost of the infrastructure, as this is just a question of multiplying each part with its (estimated) cost. The granularity of the equipment, meaning the number of customer per type of equipment, must be taken into account. This is shown in Figure 13 where the dark parts mark the used equipment for one customer. Important issues to take into account are economies of scale and scope. The first relates to the effect of more customers taking advantage of the overall size of the investment (less equipment, more optimized usage, etc.) leading to a cost reduction per customer. Economies of scope relate to cost efficiently adding services over the same network (e.g. when an Internet connection is available, offering additional bandwidth to the customer is at low cost).

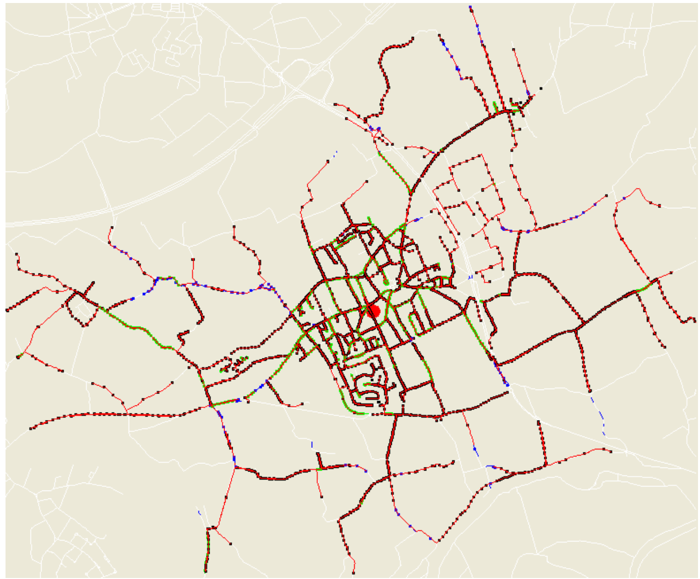

Figure 12: Outside plant optimization

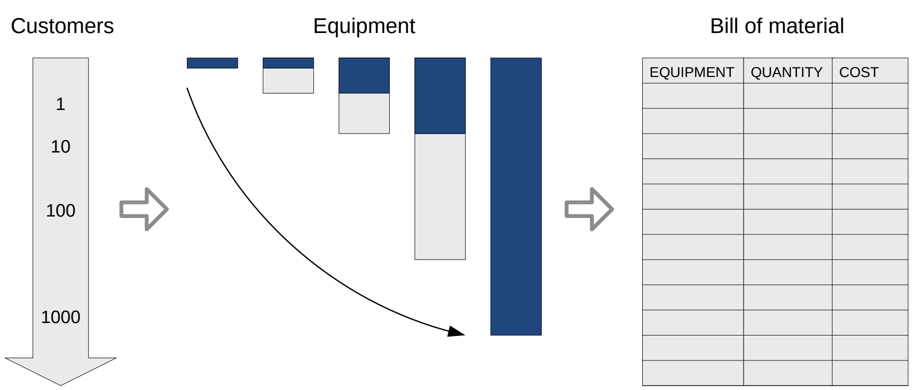

Figure 13: Inside plant bill of material (BoM)

B. Process based modelling

Process based modelling is a dedicated approach, aimed at modelling costs caused by the repetitive execution of a (non-trivial) process. A first research task consists of detecting and documenting the process which is actually executed. There are different types of modelling paradigms and even more languages and graphical representations that can be used in this task. We prefer to use a flowchart based modelling approach (see also Figure 14), as it allows sufficiently detailed documentation and is most intuitively comprehensible for non-initiated readers. A standard representation format is the Business Process Modeling Notation BPMN [43]. A corresponding textual format is the XML Process Definition Language XPDL [44].

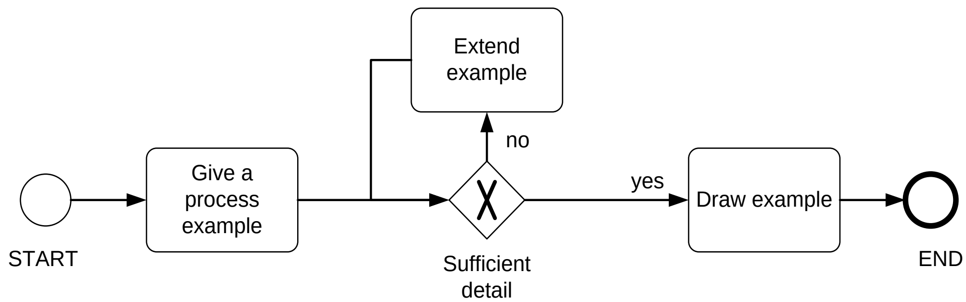

Figure 14: Example of a process using a flowchart based modelling approach

Once the process is adequately documented, the cost of execution this process once can be estimated using for instance activity based costing (ABC) [45]. Each rectangle in the flowchart represents a task assigned to a person or a team. Each diamond in the flowchart represents a conditional split in the execution of subsequent steps. By assigning cost to the execution of a task (or in extension resources such as time and tools consumed when executing that task) and probabilities to the diverging paths of a split, analytical methods can be used for estimating the process execution cost.

More detailed information in the documented processes in combination with advanced calculation and simulation approaches allows doing more than just estimating cost. Depending on the extra information, it might allow to detect bottlenecks and deadlocks, calculate optimized scheduling rules, etc.

The enhanced Telecom Operations Map (eTOM) [46], a business process framework developed by the TeleManagement Forum (TMF) describes several operational processes and sub-processes, grouped in 3 so-called level 0 processes (Figure 15).

- Strategy, Infrastructure and Product, covering planning and lifecycle management;
- Operations, covering the core of operational management;
- Enterprise Management, covering corporate or business support management.

The eTOM framework has been standardized by the ITU in [47]. It gives an overall view on the complete value chain. The map thus also gives a good indication of the interaction between the processes.

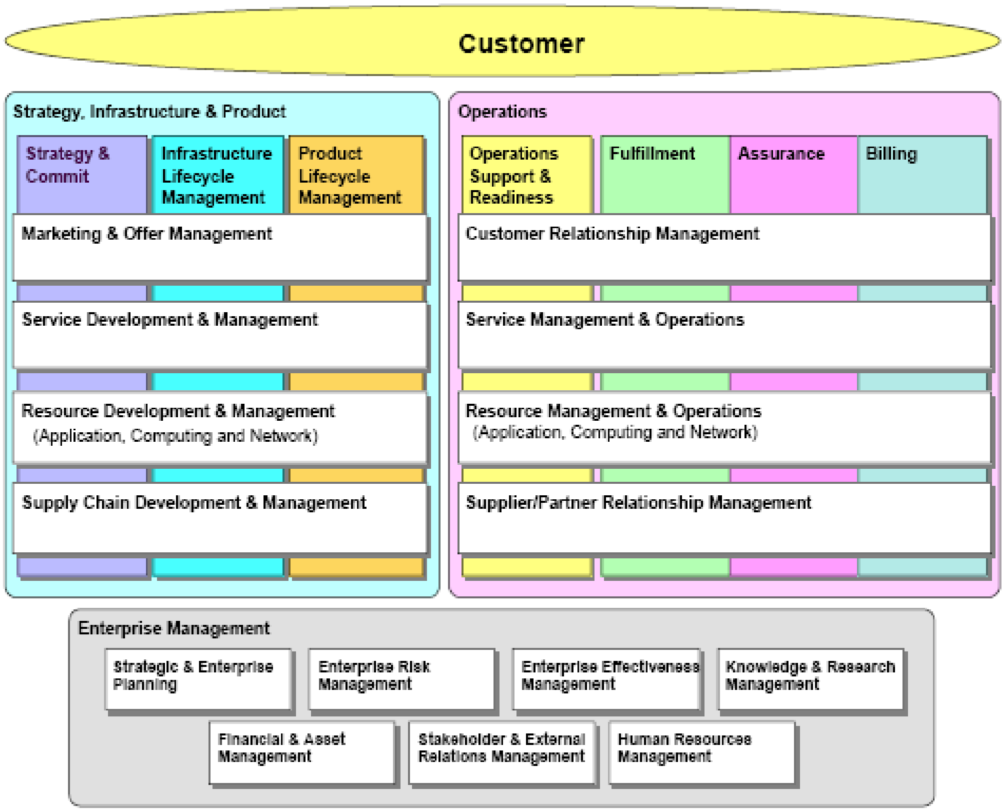

Figure 15: enhanced Telecom Operations Map (eTOM) framework

5. EVALUATE

As input for the evaluation, we assume that a cost and revenue model is developed, using the approach as discussed in the previous section. This cost and revenue model enables us to calculate the cash flows at each point in time. Based on this information, a decision on whether or not to implement this business case should be taken. This decision often also involves the comparison of different possible projects to each other. In the following section we explain the different techniques used in the traditional investment analysis [48].

Beyond the point of evaluating a single project on its profitability also the position of the firm in the business landscape can be investigated. In such broader business modelling, the different roles, actors and money streams are drawn. This type of analysis is called multi-actor analysis and will be further more elaborated in section 5.2. The company can draw a lot of conclusions from this information on opportunities and risks, competitors, co-operations and alliances, etc.

5.1. INVESTMENT ANALYSIS

Cash flow analysis gives a good idea of the profitability of the project and the annual investment costs or profits. Note that there is a difference between cash flows, and costs and revenues [49]. The cash flows indicate the costs and revenues that are actually paid. This can be seen in Table 1 where profit calculation is compared to cash flow calculation.

Table 1: Profit versus cash flow calculation

PROFIT CALCULATION	**CASH FLOW CALCULATION**
TURNOVER	TURNOVER
- Costs of sold goods	- Costs of sold goods
GROSS PROFIT	- Operating expenses
- Total operating expenses	- Capital expenses
EBITDA	- Taxes
- Depreciations and amortizations	- Net working capital
EBIT	NET CASH FLOWS
- Financial result	
EARNINGS BEFORE TAXES	
- Taxes	
EARNINGS AFTER TAXES	

When considering the full cash flow analysis, one can also easily spot the moment at which the revenues become important. A summation of all cash flows gives the profitability of the project over the lifetime.

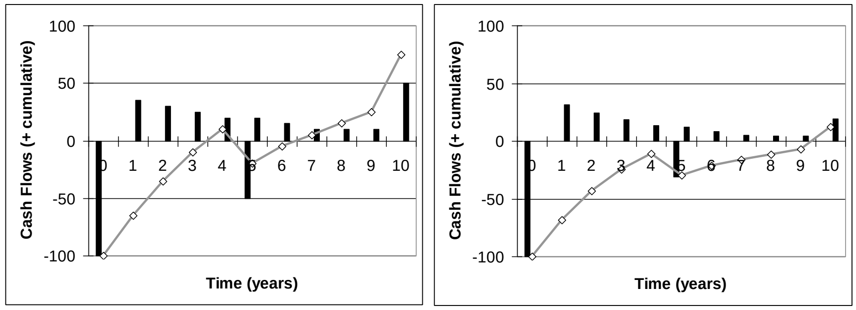

Figure 16: Fictive project cash flows (left) and discounted cash flows (right)

Investing large amounts of money in a project always assumes some gain at the end of the project. Considering company investments, this is minimal gain is defined by the rate that a company is expected to pay to finance its assets. Calculation of Weighted Average Cost of Capital (WACC) for a company with a complex capital structure is a laborious exercise and falls out of scope of this paper. Expected project gains for investment projects relate to the project risk and the size of the project. Typically in telecom this gain is somewhere between 8.1% and 10.6% according to [50] and up to 11.2% for the Belgian incumbent according to [51].

Expected project gain is to be used as a discount factors when considering future money flows, as money spent today is worth less than money spent tomorrow see (5.1) .

$$DCF = \frac{CF_t}{(1+r)^t} \qquad (5.1)$$

Where:

t	=	Time (units, e.g. years) to reference point
CF_t	=	cash flow in time period t
r	=	discount rate

Return on investment (RoI) is calculated from the cash flows by dividing the average future cash flow by the average initial investment (both are averaged over the economic lifetime or planning horizon of the project). In case this is used in the decision process, the project can only be carried out on condition that the return on investment of the project exceeds a certain predefined minimum return on investment. The simple ROI calculation (5.2) is commonly used for short-term (e.g. less than one year) investments and benefits. However, this method is less accurate when investments and cash flows are spread over multiple years and the Discounted ROI method should be used (5.3). Other variations of this method include Return On Assets (ROA), Return On Equity (ROE) or Return On Investment Capital (ROIC).

$$ROI = \sum_{t=0}^{N} \frac{CF_t}{ICF_t} \tag{5.2}$$

$$Discounted\ ROI = \sum_{t=0}^{N} \frac{CF_t / (1+r)^t}{ICF_t / (1+r)^t} \tag{5.3}$$

Where:

ICF_t = Invested cash flows

The cumulative of the cash flows, also shown in Figure 16, gives an idea of the point at which the revenues balance all investment costs. This moment is called the *payback time* (PB) (5.4) and can be used as limiting factor for the project. The project can then only be carried out on condition that the payback time is smaller than or equal to some predefined (acceptable) period. It also gives an idea of the total profit of the project. This leads to a discounted payback time (DPB) (5.5) and a discounted cumulative of the cash flows. This latter is often referred to as the net present value (NPV). Note that the last value in Figure 16 is higher than those before. In some cases, it is assumed that costs and revenues will continue in the years after the considered time-frame (often changing linearly). This cash-flow is then discounted back to that final year and constitutes the so-called terminal value. Considering the NPV is dependent on the length of the time-frame, this can be useful for easier comparison of different projects with different time-frames.

$$Payback\ period = n : \sum_{t=0}^{n-1} CF_t < 0, \sum_{t=0}^{n} CF_t \geq 0 \tag{5.4}$$

$$Discounted\ payback\ period = n : \sum_{t=0}^{n-1} \frac{CF_t}{(1+r)^t} < 0, \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} \geq 0 \tag{5.5}$$

The net present value (5.6) is generally considered the most reliable static comparison and selection criterion. A project can only be selected on condition that it has a positive net present value as the gain is in this case higher than the cost of capital and the project will add value to the firm. Net present value can also be used in comparing two projects, in which the project with the highest net present value will be chosen over the other project. Only in case two projects have the same net present value (within the level of confidence margin of the calculation model) decision could be based on the other techniques.

$$NPV = \sum_{t=0}^{N} \frac{CF_t}{(1+r)^t} \tag{5.6}$$

Where:

t = time of the cash flow

CF_t = cash flow at time t

N = total time period of the project

r = discount rate

Finally also the internal rate of return (IRR) can be calculated. This is defined as the discount rate at which the net present value is equal to 0. The internal rate of return seems very intuitive in its use; any project with an internal rate of return higher than the cost of capital will also have a positive net present value. However the internal rate of return has some important drawbacks, also highlighted in [52]:

- It assumes that interim positive cash flows are reinvested at the same rates of return of the project that generated them. More probably the funds will be reinvested at a rate close to the cost of capital. When greater than the cost of capital the internal rate of return gives an overly optimistic percentage.
- In projects that have irregular cash flows alternating between positive and negative values several times, numerous internal rates of return can be identified. This leads to confusion and possibly also to a wrong investment decision.

Solutions for this problem exist in the form of the extended and the modified internal rate of return (XIRR and MIRR) [53].

$$\sum_{t=0}^{N} \frac{CF_t}{(1+IRR)^t} = 0 \qquad (5.7)$$

5.2. Value Network Analysis

Investment analysis typically considers the profitability of a single project. Value network analysis, on the other hand looks outside this single actor case and considers the broader context, including all actors involved in the project.

5.2.1. Roles and Actors

When describing a value network (e.g. Figure 17), one starts by listing all roles. The roles indicate what needs to be done and are indicated by the rounded boxes in the figure. Actors, on the other hand, indicate who performs the task and are indicated by the grey groupings in the figure. The value network thus indicates which actors take which roles and how they interact. E.g. licensing is a typical role of the regulator in case of a wireless telecom network. The network operators can take multiple roles from network rollout up to service provisioning

The actors identified could easily be classified using for instance the forces driving industry competition as defined by Porter [54]: competition, suppliers, buyers, substitutes and potential entrants.

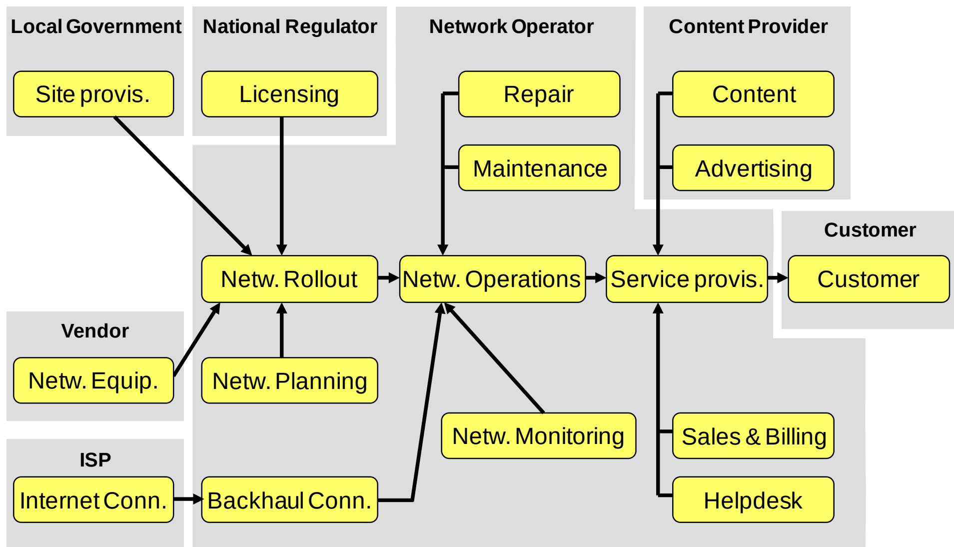

Figure 17: business roles and actors in the value network for offering telecom services

5.2.2. Value networks

A SWOT analysis (strengths, weaknesses, opportunities and threats) can help to indicate the impact of a certain project for different actors, which will help to decide whom to focus on. However, it is also important to focus also on the interactions between the different actors. Which value flows exists? How will the revenues be distributed (e.g. equally to the amount of investment, related to the level of risk and responsibility, etc.)? Which economies of scale and cost will play a role?

Therefore, the money streams between the different actors are to be identified and computed. The relations defined in the value network and business models will determine the risk for each actor, which will be reflected in the cash flows between the different actors. The analysis can also be helpful in decisions on product placement, outsourcing vs. own development, strategic direction of the product (aiming at a niche or at a large customer base) and operational planning. An example in which multi-actor analysis is useful can be found in Figure 18, where the business model is furthermore analysed in terms of size of investment and income, and overall risk.

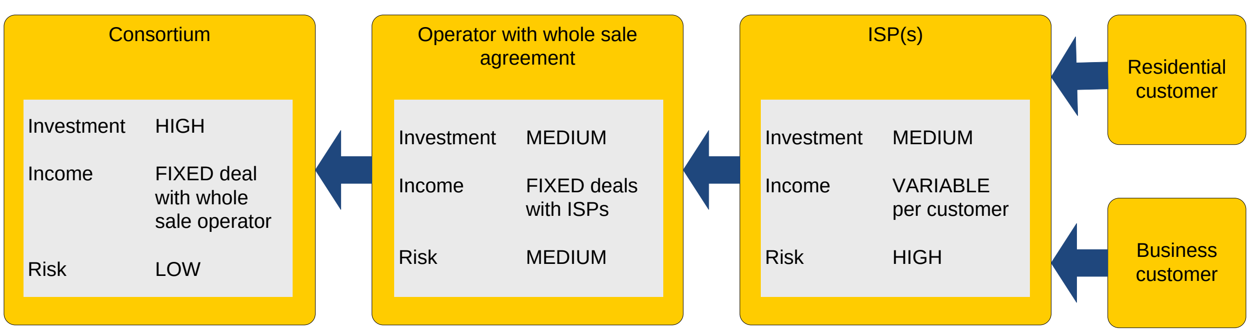

Figure 18: Value network analysis for interaction between actors on different network layers.

6. Refine

The previous section often concludes a business case or a techno-economic research case. The model is developed, all cash flows are calculated and discounted, and finally the project is evaluated and compared to other projects using net present value. The cycle can close at this point and each step can be the subject of refinement. However, also the full techno-economic analysis can be refined or extended in different directions.

The current static implementation of a business case still provides a limited view on the project outcome. There is no information considering uncertainties and risks. What would happen if prices of equipment decrease faster/slower than expected? What if we get less/more customers? What are the boundaries in which we can still be safe and what are the overall chances of a positive business case? We use sensitivity analysis to provide an answer to these questions.

The current implementation also disregards all possible managerial flexibility in the project. While uncertainties might alter the business case outcome, they can also in some cases be countered by deliberate actions. It might for instance be optimal to abandon a project halfway if customer uptake is much smaller than expected, or speedup a project in case customer uptake is better. We use real option valuation to estimate the positive effect of these actions on the business case.

Finally, the current implementation disregards the broader market picture in which competition and cooperation will play an important role. This is very important as the telecom market is very competitive. Game theory provides a context and tools for describing this competition and evaluating the most likely outcomes of a specific case.

6.1. Sensitivity analysis

We use sensitivity analysis when we want more information on the possible variations of outcome for variations in the input. It gives as a broader view on the risks of the project. Especially in case we are very uncertain about some input parameters, sensitivity analysis is required.

In terms of approach, we distinguish between basic sensitivity analysis and global sensitivity analysis. In basic sensitivity analysis, we investigate the impact on the outcome of varying one input parameter at a time (keeping the other parameters fixed). The resulting sensitivity information is the variance of the outcome for the given variation of the input-parameter. Once executed for all input-parameters, a normalized variance can be calculated for each parameter by dividing its own variance by the total variance (sum of the variances of all parameters). This method is optimally suited for a first investigation as it requires very little computational resources. A much-used measure for this impact is the normalized contribution p_j of each parameter to the variance of the outcome, as given by (6.1) for an arbitrary input parameter j. According to [55], this approach is not advisable for detailed analysis, but rather for the reduction of the number of input-parameters to take into account in a global sensitivity analysis.

$$p_j = \frac{\sigma_j^2}{\sum_{j=1}^{m} \sigma_j^2} = \frac{\frac{1}{n}\sum_{i=1}^{n} (x_{ij} - \mu)^2}{\sum_{j=1}^{m}\left(\frac{1}{n}\sum_{i=1}^{n} (x_{ij} - \mu)^2\right)} = \frac{\sum_{i=1}^{n} (x_{ij} - \mu)^2}{\sum_{j=1}^{m}\sum_{i=1}^{n} (x_{ij} - \mu)^2} \qquad (6.1)$$

Where:

σ_j^2	=	variance originating from varying input parameter *j*
m	=	number of varying input parameters
n	=	number of tests (e.g. corresponding to the considered variations of the input parameter)
x_{ij}	=	outcome for test *i* and with varying input parameter *j*
μ	=	average outcome

In a global sensitivity analysis the different key input-parameters are varied according to a predefined probability density function (PDF), for instance by means of a Gaussian, triangular or uniform distribution. Clearly the choice of probability density function and range over which each parameter will be varied (e.g. standard deviation in case of a Gaussian distribution) will be very important. Next, a Monte Carlo method is used for sampling a huge number of possible outcomes for the model at hand (here the business case). In each step of such simulation, a random probable value for each of the key input parameters is generated according to their probability density function. The main result of the global sensitivity analysis is a distribution of all possible outcomes. Using this distribution, we can find the probability of an outcome within predefined margins. In the evaluation of a business case, it is common to search for the probability of a positive net present value. Additionally this global sensitivity analysis can give detailed information on the impact of the key input parameters, on the trend (function of time) or reliability of the results, etc.

6.2. Real option valuation

The real option valuation methodology tries to capture (and include) the value of managerial flexibility present in a business case, much in the same way the flexibility presented in financial options (over stocks) are valued. A financial option gives the right to buy or sell over a limited period the underlying value for a predetermined exercise price. As it is a right (and not obligation) the value of an option will always be positive. Real Options was defined in 1977 [54] and applies option pricing theory to the valuation of investments in real assets. It proved especially useful in investment decisions consisting of different (optional) phases. As it adds flexibility to the business case, it alleviates (partly) the estimation of the risk by means of the discount factor as in the calculation of the net present value.

The introduction of flexibility will very often involve an extra cost at the beginning of the project. To make it possible that several options can be exercised in the next phases, some measures have to be taken from the beginning. Examples are the purchase of licenses to cover all possible scenarios, installation schedules for the trains depending on the amount of relations to be rolled out, etc.

The approach applied to technical projects entails the following three steps:

1. identify the key uncertainties
2. identify the options
3. valuation of the options considering the uncertainties

Sensitivity analysis, discussed in the previous section, is optimally suited for the detection of the key uncertainties and the same probability density functions can be used in the real option valuation. For detecting the different options available in the project, [56] proposes the 7-S framework.

6.2.1. *Type of options*

Various real option types can be classified according to a so-called 7S-framework: invest/growth options (Scale up, Switch up, Scope up), defer/learn options (Study) and disinvest/shrink options (Scale down, Switch down, Scope down) (Table 2).

Table 2: Types of real options: the 7S framework

Category	Type	Description	Examples
Invest Grow	**Scale up**	Sequential investments in a later stage as market grows	Faster rollout if the take rate is higher than expected
	Switch up	Switch products, process or plants given a shift in underlying price or demand	Upgrading UMTS to HSDPA antennas when more demand is requested
	Scope up	Enter another industry when cost-efficiently possible. Link and leverage	Utility companies investing in fibre access networks
Learn	**Study / start**	Delay investments until more information and/or skills are acquired	Looking at best practices in neighbouring countries before rolling out FTTH
Disinvest Shrink	**Scale down**	Shrink or shut down a project if new information changes the expected payoffs	Several municipal WiFi networks in the USA have been shut down due to disappointing customer adoption
	Switch down	Switch to more cost-effective and flexible assets as new information is obtained	Network cards could be replaced with new version leading to more efficient power usage
	Scope down	Limit the scope of operations in a related industry when there is no further potential	Copper networks could be disintegrated when a full FTTH network is in place

For the deployment of a new telecom network, the scale up type real options is used since the network will be extended dependent on future market developments. This option is valuable since the operator need not currently commit to undertaking the future investment, thereby limiting downside risks.

6.2.2. *Option valuation as extension of NPV*

Real Options theory allows attaching a value to the options that become apparent during the life time of an investment project, like expanding, reducing or stopping the project. It can be considered as an extension of the Net Present Value (NPV) rule. NPV discounts the cash flows using a fixed discount rate and evaluates a now-or-never investment decision. For risky projects, it is very difficult to determine an appropriate discount rate. Real Options theory, on the other hand, includes the options that may be present in an investment project with uncertain parameters. It therefore includes flexibility in the decision process and avoids the need to determine an adjusted discount rate for valuating the options. The value of a project can therefore be extended by the value of the options [57], as indicated in formula (6.2).

Expanded (strategic) NPV = passive NPV of expected cash flows + value of options (6.2)

Real Options valuation is especially useful for two-phase investment decisions, with an optional second phase (e.g. only performed if market situation is favourable). This explains the suitability of real options for uncertain investment problems. By the time of the second phase of the investment, the market situation is already more clear, so that a well-advised decision can be taken.

A. The value of an option

Let's start by some additional terminology

- Option price = option premium: price to acquire the option, price to acquire the right
- Exercise price = strike price: price for which option holder can exercise the option (fixed)
- European option: can only be exercised on the exercise date
- American option: can be exercised till the exercise date
- Call option: option holder has right to buy the asset, e.g. Scale up
- Put option: option holder has right to sell the asset, e.g. Scale down

We will consider the end value of an option (value on exercise date). Assume e.g. a call option, the right to buy a stock for a predetermined exercise price X. Assume that the market value of the stock on exercise date is S.

- If $S < X$, the option is useless. Everyone interested in the stock will directly buy it on the market instead of using the option.
- If $S > X$, the option is valuable. It is more interesting to use the option than to just buy the stock on the market. The value of the option is $S - X$

In summary, we can say that the value of a call option on exercise date equals MAX (0, S-X), as illustrated in Figure 19. It is clear that the option always has a positive value.

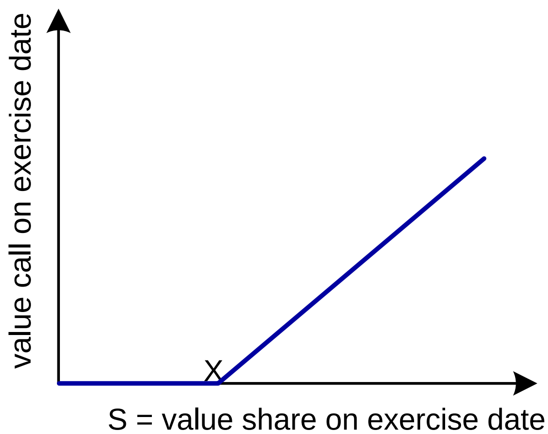

Figure 19: Value of options

B. Options valuation techniques

In economic literature, there exist several option valuation techniques (techniques to indicate the value of an option). The binomial tree method is a straightforward method that assumes 2 possible end values for the stock value. It can be extended for more time periods, if software is used. A popular (European) stock option pricing formula was suggested by Black and Scholes (B&S) [58]. It determines the option value C, based on the exercise price of the option X, the value of the underlying stock S, the variance of the return on the stock σ^2, the risk-free interest rate r and the time until the expiration of the option. Black-Scholes assumes arbitrage-free pricing (financial transactions that make immediate profit without any risk, do not exist) and it assumes that stock price S follows a Brownian motion. Option valuation eliminates the need to adjust the discount ratio for risk, the risk-free interest is used, e.g. in Black&Scholes. [59] states that the uncertainty is accounted for with the estimation of the variance, thus determination of a risk-adjusted discount rate is not necessary.

In this case a Monte Carlo simulation is used on the model taking into account all options and uncertainties. The rollout scheme of a new network will be adapted at discrete points in time (in our simulation we fix the duration of the different phases at one year) to anticipate on the market changes by accelerating or reducing the planned rollout. Several parameters can be chosen as decision variable to determine the rollout in the next phase. We roughly distinguish two groups: diverse economic evaluation parameters are a good choice (e.g. NPV, cash flow, payback period, etc), or we can focus on some uncertain input parameters (e.g. based on the sensitivity results). As the evaluation of the project in the previous sections is mainly based on an NPV analysis, a natural decision variable is the NPV at the end of each year. If the NPV follows the expected trend (e.g. Gauss distribution), the normal rollout speed is followed. Otherwise a faster or slower rollout is performed.

Using the translations of Table 3, real options can be translated into stock options and the above introduced options valuation techniques can also be used for real options. In this way, e.g. B&S formula is often used in the literature to valuate real options. When doing this, however, we should be aware that some assumptions for stock options might not always hold for real options. First of all, stock option valuation is based on arbitrage-free pricing. This is difficult to prove for real options, as those are not traded. Secondly, B&S assumes that stock prices S follow a Brownian motion, considering real options we should prove that the NPV of the cash flows generated by the project follow a Brownian motion. Also binomial tree and option valuation techniques based on simulation can be extended from the financial towards the options world, whereas they allow a more intuitive use than B&S.

[60] provides an extensive introduction to Real Options theory, with a lot of practical examples.

Table 3: Stock options and real options

	Stock option	**Real option**
X	exercise price of the option	investments required to carry out the project
S	value of the underlying stock	NPV of the cash flows generated by the investment project
σ	volatility of the stock	risk grade of the project
r	the risk-free interest rate	risk-free interest rate
t	life time of the option	time period where company has the opportunity to invest in the project

C. Actual real option valuation

We have set up a business case for a phased rollout of a parking sensor network in the city of Ghent. The project runs over a period of six years. The first phase consists of the rollout of the network in the smaller city centre. This allows the testing of the network in a real environment and opens learning options for the management. In year 3, the rollout is extended to the second zone. On this standard static scenario, a sensitivity analysis is conducted. We run a Monte Carlo simulation, varying several input parameters influencing costs and revenues. This results in a NPV distribution as shown in Figure 20.

Choosing for a phased rollout scenario opens several options for the management. Depending on the results in the first years, management can choose to either speed up or slow down the project. We model three different paths, a fast, normal and slow rollout. The evolution of the NPV in these three paths is found in Figure 21.

Due to the phased rollout, management has the flexibility to choose a rollout path, taking into account the knowledge gained in the previous years. If the project turns out better than expected, the management will choose to expand earlier to Zone 2. Running 100.000 simulations with Cristal Ball, again varying the several uncertain input factors, we now allow the management to choose the best scenario, this is MAX(slow, normal, fast). We see an upward shift of the average NPV, due to the two options now included in the analysis. (Figure 20)

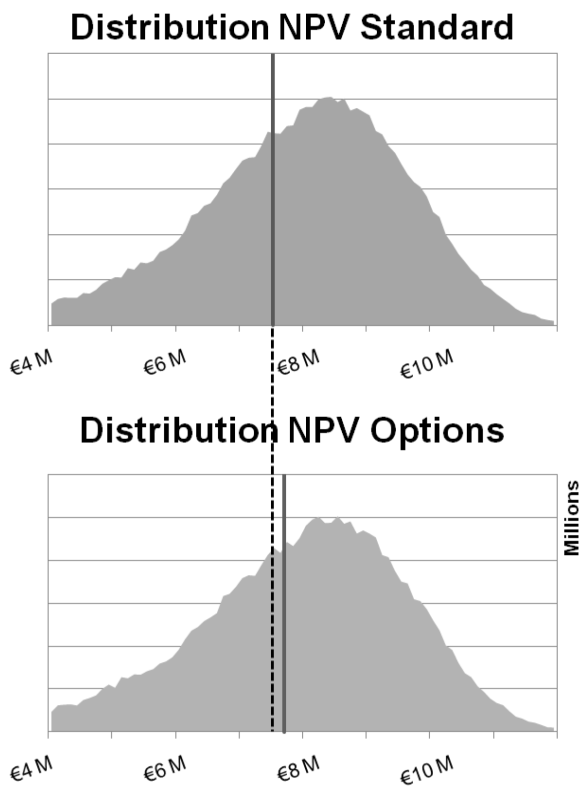

Figure 20: NPV Distributions

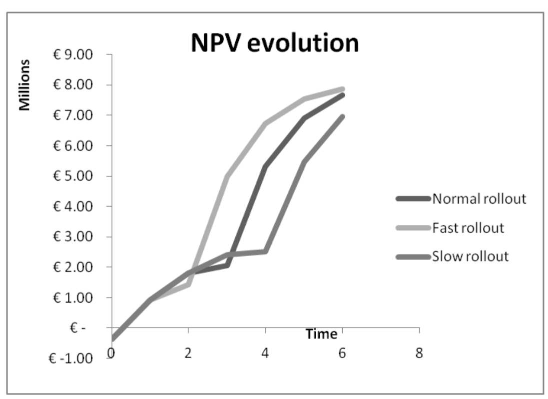

Figure 21: Rollout paths

6.3. GAME THEORY

By means of game theory we try to get a closer look into the effects of interaction between different so-called players. To this aim, we have to build an integrated model, in which the outcome for each player will be depending on his own actions but also on the actions of the other players. The interaction of two players can consist of competition or cooperation. The players will compete for some good or reward. An example in which two wireless players are competing for access to the shared channel, best connectivity or data-transport is given in [61]. Often in business cases, the customer will be the aim of the competition.

As mentioned before, the different players in a game can choose amongst different actions. These are often referred to as strategies. In the scope of techno-economic research, examples of strategies are: rollout new technology, wait for next-generation technology before acting, stop deployment, intensify the rollout in a given area, etc.

Once the players and strategies are defined, and a model is able to calculate the outcome (referred to as payoff), game theoretic concepts can be used for retrieving the most likely (set of) interactions between the players. Equilibrium in a game is the concept used for pinpointing the set of strategies in which no player is inclined to change his strategy. There exist several different equilibrium-definitions of which probably the Nash equilibrium (NE) is the most commonly known and is defined as a situation in which no player can gain by unilaterally changing its strategy. In a pure NE, each player will use a pure strategy, while in mixed NE, the players can play mixes (probabilistic combinations) of strategies [61]. As such, a game with fully rational players (using this equilibrium as criterion) is expected to result in one of the NE being chosen.

As an example Figure 22 shows a game in which two operators will battle for the customers. They can both either stick with their current technology or rollout an FTTH network, the latter is off course more costly. There are as such 4 possible scenarios with payoffs associated in the figure and indicated by *a*-*d*. In scenario *d* both operators can gain by rolling out FTTH. In scenario *b*/*c*, the first/second operator can gain by (unilaterally) rolling out FTTH (move to *b*/*c*). Finally in scenario *a,* no operator will gain by changing his strategy unilaterally.

	FTTH	Existing
FTTH	***50*** 50 *a*	***90*** 40 *b*
Existing	***40*** 90 *c*	***80*** 80 *d*

Figure 22: Fictitious game in strategic form (matrix) for the competition between two operators who can decide to roll out FTTH

Solving a game typically refers to finding one or all equilibrium situations (a strategy for all players). Most game theoretic research uses mathematical models and approaches in order to find an equilibrium in a game [62]. Such mathematical approach poses important limitations on the complexity of the problem and as such only small and abstracted problems are considered in literature. Such mathematical approach is not applicable for large techno-economic models developed to reflect realistic network deployment cases.

Typically static games (the game has one stage in which the players interact) can also be reduced or solved by removing strict dominated strategies. These dominated strategies have a strictly lower payoff than another (dominant) strategy for all possible counter strategies. No fully rational player would play a strict dominated strategy, but would instead play the dominant strategy. As such this strategy can be removed (deleting row or column from the payoff matrix) for the considered player. By iteratively using this approach for the different players, we can in some cases end up with strict dominant strategies. Any solution derived by iterated strict dominance is a NE. Within sequential multi-stage games, backward induction can be used [61]. An example of solving a game using iterated dominance and backward induction is given in Figure 23.

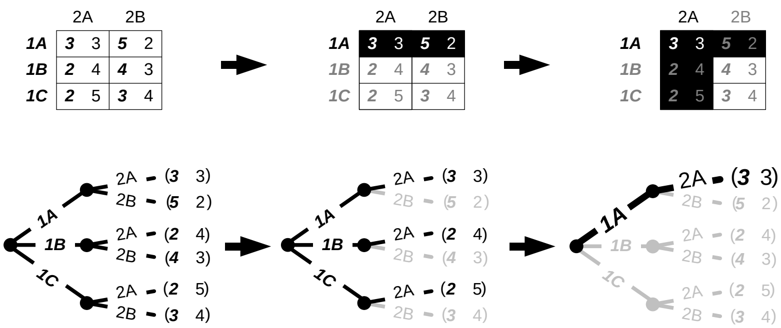

Figure 23: Game solved using iterated (strict) dominance (upper) and the sequential variant of the same game solved using backward induction (bottom)

7. Tool overview

The different steps during the techno-economic evaluation of network deployment planning can be supported by diverse tools. A non-exhaustive tool overview is listed in Table 4, Table 5, Table 6 and Table 7. Note that there does not exist an integrated tool for evaluating the whole cycle.

Table 4: Infrastructure and cost modelling

Toolkit	Application	license
OPNET SP Guru / IT Guru	Network planning and (cost-effective) optimization	Academic ed. Commercial
VPI OnePlan	Network design & planning Economic analysis	Commercial
TONIC	Techno-economic tool Spreadsheet based Including a cost database	Negotiation with IST-FP5 TONIC partners

Table 5: Process modelling

Toolkit	**BPMN**	**XPDL**	**license**
CaseWise	As an extension	As an extension	Commercial, Free for TMForum members
Mega: MegaProcess	Yes	Yes	Commercial
IDS Scheer: ARIS	Yes	Yes	Commercial
MS Visio	Yes	No	Commercial
Tibco business studio	Yes	Yes	Free

Table 6: Process simulation

Toolkit	Graphical modeling	Open Source	License
GPSS	No	No	Free limited ed. Commercial
VenSim (including M-Wave model)	Yes	No	Free limited ed. Commercial
SimJava	No	Yes	Free
Ptolemy II	Yes	Yes	Free

Table 7: Evaluation modelling

Toolkit	Type	Open Source	License
Gambit	Game theory	Yes	Free
Jannealer	Optimization by means of Simulated annealing	Yes	Free
Linear programming tools (e.g. solver, matlab, etc.)	Integer Linear Programming	Typically not	Commercial
Crystal Ball	Sensitivity analysis and RO by simulation	No	Commercial

8. SUMMARY AND CONCLUSIONS

In this white paper, we have given an overview of the techno-economic planning process for network deployment, migration and/or service offerings. We studied the entire flow, starting with a description of the existing situation, subdividing the specific problems, modelling network, processes, costs and revenues and ending with an evaluation of the relevant output parameters such as profitability. All steps were discussed indicating existing models and how they can be applied. We showed how to look into the network deployment problem from a techno-economic viewpoint. A main issue is to focus on the main driving aspects first, and thus minimizing the chance to get lost in details. As opposed to some practices where one or more parts of the picture are neglected, we emphasized the importance of the whole picture, choosing the required level of detail for the different parts. Furthermore a detailed analysis showed how to use real options and game theory in telecommunication cases.

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About TechnoEconomics @ IBCN

IBCN (INTEC Broadband Communication Networks) is a research group of the Department of Information Technology of Ghent University, Belgium. Within our group, network planning and design has always been an important research topic. Over the last years, however, techno-economic analysis and evaluation gained a lot of interest in this area. It is used to extend the business models developed within a lot of interdisciplinary research projects and bring new insights complementing technical comparisons of different possible network development or migration paths. Currently 7 people at IBCN are working in this field. We focus on different network projects and our work resulted in different publications in journals and conference proceedings. More information on TechnoEconomics@IBCN can be found at our website http://ibcn.intec.ugent.be/te/.

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