# Predicting the unpredictable: dealing with risk and uncertainty in broadband roll-out

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**Abstract**

**Purpose** – *The objective of this paper is to offer a validated framework for the analysis of (future) risks and uncertainties involved in the decision-making process concerning the upgrade and roll-out of large infrastructural projects, e.g. broadband networks. The framework classifies risks and uncertainties based on the nature of the risks, levels and sources.*

**Design/methodology/approach** – *The approach takes the form of conceptual as well as qualitative and quantitative empirical analyses.*

**Findings** – *Telecommunications operators are faced with various types of risks and uncertainties in their decision-making process concerning the upgrade and roll-out of their broadband networks. In one respect, these risks and uncertainties have to do with the characteristics of large infrastructural projects, while, on the other hand, being caused by (unknown) competitor behaviour, (unknown) end-user demand, rapid technological development and different development paths available to operators. Framing risks and uncertainties into a typology provides greater insight into the categories, characteristics and sources of the risks and uncertainties, as well as being a first step in finding ways to deal with them.*

**Originality/value** – *The paper presents and validates a framework for the analysis of risks and uncertainty. It also offers empirical data on how operators manage risk and uncertainties.*

**Keywords** *Risk management, Uncertainty management, Broadband networks*

**Paper type** *Conceptual paper*

## 1. Introduction

The concepts of ''risk'' and ''uncertainty'' illustrate that decisions are made on the basis of incomplete information (Piyatrapoomi *et al.*, 2004). Risks and uncertainties are inherent in large infrastructural projects, as are high initial costs, a long period before recapturing return on investment, irreversibility and indivisibility of investments, high entry and exit thresholds, and inelastic demand. Other sources of uncertainty are the (unknown, future) behavior of competitors and other stakeholders, the (unknown, future) development of end-user demand, the rapid development of new broadband technologies and the different development paths available to operators (Fijnvandraat and Bouwman, 2006). Although there is extensive literature on uncertainty in the decision-making process (i.e. Fontana and Gerrard, 2004; Pomerol, 2001; Kobus *et al.*, 2001; Yager, 2004a, b), most studies focus mainly on decision making in general. Conceptual frameworks are largely missing and analyses are mainly anecdotic and unsystematic (see for example Richardson, 2009). This paper contributes to the development of such a framework, by presenting and validating a typology on risk and uncertainty. Moreover, there is no insight into how different types of risks and uncertainties affect decision-making on large infrastructural projects, such as water infrastructure (Cashman and Ashley, 2008) or energy networks (Rotmans *et al.*, 2001). In this paper we focus on broadband upgrading, i.e. the upgrading of traditional networks, specifically the local loop network, to higher levels of capacity. We define broadband as a connection of at least 10 Mbps symmetrical bandwidth in the local loop. Due to the fact that

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risks and uncertainty cannot be assessed properly, the roll-out of advanced networks is lagging behind. Therefore the following questions will be addressed in this paper:

1. What is the nature and level of uncertainty and risk concerning broadband roll-out?
2. Which sources of risk and uncertainty play a role in the decision-making process concerning the upgrading of broadband networks?
3. Can the effects of risks and uncertainties of broadband roll-out be assessed?
4. What methods do decision-makers apply to manage risks and uncertainties in practice?

This paper offers a framework to assess and deal with risk and uncertainties of large infrastructure projects such as broadband roll-out, that deal with investments that span a long period in which all kind of sources of risk and uncertainty can affect the feasibility and viability of these projects. Assessment of risks and uncertainties and future research are highly related and relevant for technology future analysis (Technology Future Analysis Methods Working Group, 2004; Koivisto *et al.*, 2009).

To answer the research questions, this paper is organized as follows. First, we discuss existing literature and develop a typology for risk and uncertainty that can be used in an empirical analysis and in an assessment of the role they play in the decision-making process with regard to broadband roll-out, after which we discuss several methods to manage risk and uncertainty in projects that are highly dependent on assessing an unknown future behavior of stakeholders, competitors as well as consumers. Next we present the results of our qualitative and quantitative analysis, based on the typology, in order to understand the (effects of) risk and uncertainty on the decision-making process. Finally, we address the applicability of different methods of dealing with risk and uncertainties.

## 2. Risk and uncertainty

### *2.1 Risk*

Risks involved in infrastructural investments are substantial. They are hard to assess in advance and difficult to manage in financial, technological and organizational terms (Renkema, 2000). In classical decision theory, risk is most commonly conceived as reflecting variation in the distribution of possible outcomes, their likelihoods and subjective values. Risk is measured by the variance of the probability distribution of possible gains and losses associated with a particular alternative. A risky alternative is one for which the variance is large. Risk is one of the attributes which, along with the expected value of the alternative, is used in evaluating alternative gambles (Pratt, 1964). Expected value is assumed to be positively associated with the attractiveness of an alternative, while risk is, in contrast with uncertainty, assumed to be negatively associated (March and Shapira, 1987). In most studies, the concept of ''risk'' is assumed to consist of two elements, i.e. the probability (or likelihood) of occurrence of a negative event, and the consequence of this negative event (Berdica, 2002). The former has to do with risk assessment, the latter with risk management (Piyatrapoomi *et al.*, 2004). However, the evaluation of different influencing factors and the consequences of risk depend on the perception of the actors involved. Hence, measuring risk involves considerable uncertainty, caused by various degrees of subjectivity, which makes it more difficult to obtain an objective composition of the likelihood of a negative event and its consequences (Berdica, 2002). There are several additional complications involving the concepts of risk that are used to analyze the actual processes underlying choice behavior (March and Shapira, 1987). The ways in which human decision-makers define risk may vary significantly from the definitions suggested in literature, as may perceptions of risk between individuals. Managers perceive risk in ways that are less precise but that are also different from risk as it appears in decision theory (March and Shapira, 1987). Dealing with risk is a balancing act that should address both positive and negative aspects, taking into account the likelihood and subsequent consequences of any defined event (Dalgleish and Cooper, 2005). Most risk classifications apply to medical and environmental research and for that reason do not yield any useful ontology for decision-making in large infrastructure projects such as broadband upgrading, which require long-term investments, and high sunk costs in a competitive environment in which a limited number of incumbent infrastructure providers are dominant and new entrants have to compete for an unknown user demand. Therefore we decided to use an approach for classification of risk based on a comparable classification of uncertainty, e.g. classifying uncertainty (and risk) according to nature, level and source, as used in the energy sector (Meijer *et al.*, 2006).

### *2.2 Uncertainty*

The term ''uncertainty'' emphasises that decisions are made on the basis of incomplete knowledge about projects that do not yet physically exist (Walker *et al.*, 2003). Based on Walker *et al.* (2003), we define uncertainty as ''any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system''. This broad definition covers uncertainty that can be reduced by knowledge as well as uncertainty that cannot and which is, for this reason, indeterminable (Meijer *et al.*, 2006). Combining the research of Walker *et al.* (2003) and Meijer *et al.* (2006) we analyze uncertainty based on three dimensions: nature, level, and source (see Table I).

*2.2.1 Nature*. The nature of uncertainty describes its origin. The question is whether uncertainty is caused by imperfection of our knowledge (knowledge or epistemic

**Table I** Typology of perceived risks and uncertainties

| *Source* | *Dimension* | *Scale* |
|---|---|---|
| Technological:<br>uncertainty about the technology itself;<br>uncertainty about the relationship between the technology and technological infrastructure;<br>uncertainty about the availability of alternative technological solutions | Nature | Epistemic vs variability |
| | Level | 1, 2, 3, 4[a] |
| Resource:<br>uncertainty about the amount and availability of financial resources;<br>uncertainty about the amount and availability of human resources | Nature | Epistemic vs variability |
| | Level | 1, 2, 3, 4[a] |
| Competitive:<br>Uncertainty about the actions of (potential or actual) competitors;<br>Uncertainty about the effects of competitors' actions | Nature | Epistemic vs variability |
| | Level | 1, 2, 3, 4[a] |
| Supplier:<br>uncertainty about the timing, quality and price of the delivery | Nature | Epistemic vs variability |
| | Level | 1, 2, 3, 4[a] |
| Consumer:<br>uncertainty about consumer preferences;<br>uncertainty about consumer characteristics;<br>uncertainty about the development of consumer demand | Nature | Epistemic vs variability |
| | Level | 1, 2, 3, 4[a] |
| Political:<br>unclear or inconsistent regulation;<br>lack of regulation;<br>future changes in regulation;<br>overall government behavior | Nature | Epistemic vs variability |
| | Level | 1, 2, 3, 4[a] |

**Note:** [a]1: a clear enough future, 2: alternative futures, 3: a range of futures, 4: true ambiguity
**Sources:** Meijer *et al.* (2006); Walker *et al.* (2003); Courtney *et al.* (1997)

uncertainty) or by the inherent variability of the uncertain variables (variability uncertainty). Epistemic uncertainty is defined as ''uncertainty due to the imperfection of our knowledge, which may be reduced by more research and empirical efforts''. Variability uncertainty is defined as ''uncertainty due to inherent variability of the system (changes of the environment), which is especially applicable in human and natural systems and concern social, economic, and technological developments'' (Walker *et al.*, 2003). Knowledge (or epistemic) uncertainty can be overcome by gaining more knowledge, for example via technology assessment, forecasting or market research. An example of epistemic uncertainty is the uncertain economic value of new technologies. Variability uncertainty, however, cannot be overcome this way. Uncertainty with regard to the actions of competitors is an example of variability uncertainty.

*2.2.2 Level*. The level of uncertainty indicates how uncertain a situation is on a spectrum ranging from complete deterministic understanding to total ignorance (Walker *et al.*, 2003). Meijer *et al.* (2006) use the continuum low-high in their uncertainty matrix, while Courtney *et al.* (1997) distinguish four levels of uncertainty. Level 1 (a clear- enough future) is the situation in which decision-makers can develop a single forecast of the future. At level 2 (alternate futures) there are several alternate outcomes (scenarios) for the future. At level 3 (a range of futures) the future is not one of a range of discrete scenarios but lies along a continuum of potential futures. Level 4 (true ambiguity), finally, involves an interaction of multiple dimensions of uncertainty which creates a future that is virtually impossible to predict. At least half of all strategy problems fall into levels 2 or 3 (Courtney *et al.*, 1997). We include the four levels as suggested by Courtney *et al.* (1997) in our risk and uncertainty typology.

*2.2.3 Source*. The source of uncertainty is the domain of the organizational environment about which the decision-maker is uncertain (Milliken, 1987). To cope with uncertainty, decision-makers need to choose appropriate strategies, which makes it important to distinguish between different sources of uncertainty (Wernerfelt and Karnani, 1987). The source of uncertainty is context-dependent (Meijer *et al.*, 2006). Based on the PEST model (Johnson and Scholes, 2002, p. 102), Porter's (1980) five forces of competitive position model and Barney's resource based view (Barney, 1991), Meijer *et al.* (2006) draw the following distinction with regard to sources of uncertainty: technological, resource-related, competitive (new entrants and rivalry), supplier-related, consumer-related (buying power) and political/regulatory uncertainty. In our topology, we adhere to the distinction made by Meijer *et al.* (2006).

*2.2.4 Technological uncertainty*. Meijer *et al.* (2006) distinguish three types of technological uncertainty. The first type is uncertainty about the characteristics of the new technology. There are several characteristics of new technologies that determine the decision in favor of a specific technology (Fijnvandraat and Bouwman, 2006). When a new technology emerges, information is limited and the characteristics of the technology will keep changing while further improvements are being made. Within the broadband market, this can be seen clearly in the developments of DSL technology that have resulted in a rapid succession of various Digital Subscriber Line technologies, i.e. ADSL, ADSL2, ADSL2 + , SDSL, VDSL. These ongoing changes make decisions more complicated, the robustness of a technology hard to assess, as well as the likelihood that one technology will be overtaken by another.

The second type of technological uncertainty is uncertainty about adaptations to the infrastructure that are needed. Some technologies only demand rather small adaptations to the existing infrastructure, while other technological changes require large infrastructural adaptations, an example of which is the transition from ADSL2 + to VDSL, which requires a partial replacement of the access network. For fibre to the home (FttH), an entirely new access network has to be rolled out (Fijnvandraat and Bouwman, 2006). Due to the necessary large investments and long life spans involved, infrastructural adaptations are, in contrast to more applications and service related technologies, difficult to implement.

The third technological uncertainty concerns the possibility of choosing alternative (future) technological options. As demonstrated in Fijnvandraat and Bouwman (2006) as well as by

Yoon *et al.* (2005), operators can choose between many (combinations of) competing technological options to upgrade their existing networks. This uncertainty is increased by the ongoing process of technological changes and the possibility for operators to wait for the arrival of a new generation of technologies. Other uncertainty-increasing factors are the speed with which new technologies arrive, the degree of improvement of these technologies as compared to the currently available ones, and uncertainty about the possibility that future technologies can cause existing technologies to become obsolete, as well as dependency on the legacy of already implemented technologies.

*2.2.5 Resource uncertainty.* Resource uncertainty includes four aspects of uncertainty about:

1. The amount and availability of raw material.
2. Human resources (knowledge and skills needed).
3. Financial resources (how much capital to invest) needed for innovations.
4. How to organize the process.

The uncertainty is caused by the difficulty involved in making accurate forecasts for the resources that are required. More resources will be needed for radical, i.e. a disruptive breach with the existing situation and with path dependency, than for incremental infrastructure upgrades.

*2.2.6 Competitive uncertainty.* Competitive uncertainty has to do with to uncertainty about the behavior of (potential or actual) competitors and the effects of their behavior upon the competitive position of the own firm. Wernerfelt and Karnani (1987) mention five factors that are highly relevant to competitive strategy under uncertainty: first mover advantages, economies of scale, the number of competitors, the relative competitive position and past investments of the firm.

*2.2.7 Supplier uncertainty.* Supplier uncertainty is related to the timing, quality and price of the delivery (Meijer *et al.*, 2006). Supply networks (including various types of intercompany relationships) have become very complex (Bouwman *et al.*, 2008) and are vulnerable to a variety of risks (Hallikas *et al.*, 2005). Sources for this complexity are, among other things, globalization, increasing product/service complexity, outsourcing (Harland *et al.*, 2003), the use of inter-organizational information systems and dependency on critical infrastructures. Companies increasingly depend on external resources. Supplier uncertainty becomes more important when dependence on suppliers is high, in which case suppliers have greater bargaining power and are able to create uncertainty with regard to the quality and price of their products (Meijer *et al.*, 2006).

*2.2.8 Consumer uncertainty.* Consumer uncertainty can be ascribed to three sources. The first is consumer preferences with respect to the characteristics of the new technology: will they adopt a new technology or not? Operators perceive uncertainty about the market opportunities due to the uncertainty related to (customer perceptions) of product characteristics, such as quality, prices and distribution channels). The second source of consumer uncertainty is related to end-user characteristics. The compatibility of new technologies or services characteristics with customer characteristics affects the chances of adoption. The third source of consumer is the uncertainty on long-term development of the demand. This uncertainty refers to the size and stability of demand, and is partly caused by general macro-economic developments.

*2.2.9 Political/regulatory uncertainty.* Political/regulatory uncertainty has to do with uncertainty regarding governmental behavior, regimes and policies. Meijer *et al.* (2006) mention six underlying causes of regulatory uncertainty: existing policies, unclear or inconsistent regulation, lack of regulation, future changes in regulation which occur rapidly or are hard to predict, and uncertain government behavior in general. The last one is caused by, for example, contradictory political statements or confusion about a mix up of the public and private role of governments.

### 2.3 Dealing with risk and uncertainty

Most uncertainties cannot be eliminated: they must be accepted, understood and managed (Walker and Marchau, 2003). There are several ways for dealing with risk and uncertainty. The first (and traditionally the most commonly used) way is to ignore it, implicitly assuming that the future world will be structurally more or less the same as the existing one (Walker and Marchau, 2003). Decision-makers can also try to reduce or minimize risk and uncertainty. There are various methods available to deal with risk and uncertainties (see Technology Future Analysis Methods Working Group, 2004). Examples include amongst others scenario analysis (Bouwman and Van der Duin, 2003), technology and demand forecasting/ assessment and intelligence: obtaining more information related to sources of uncertainty.

*2.3.1 Scenario investigation*. The future is uncertain and there are risks involved. Constructing possible scenarios and looking for options that perform reasonably well with minimal risk is one way of dealing with uncertainty and risks (Piyatrapoomi *et al.*, 2004; Walker *et al.*, 2003). Scenario assessment is a basic tool that is used to assess risk and uncertainty regarding future situations. Scenarios help identify, evaluate and act upon contingencies, uncertainties, trends and opportunities that are often unanticipated. Moreover, scenarios encourage managers to think about how they can take advantage of opportunities and avoid potential threats (Miller *et al.*, 2003). The creation of business cases, in which input variables can be altered and which can be tested in scenarios focusing viability and feasibility, allow telecom operators greater flexibility (Bouwman *et al.*, 2008).

*2.3.2 Demand and technology forecasting/assessment*. Planning a telecommunication network is based on the estimation of future needs. For this reason, forecasting is essential. It is, however, a complex procedure that involves a large number of factors affecting network development (Acimovic-Raspopovic *et al.*, 2003). Telecom operators use forecasting to determine the impact of developments involving competition, equipment costs, broadband technology and demand on their own position. Companies also use forecasts to gain insight into technological developments in the market that may be useful to their own company. Dynamic forecasting models contain options for creating insight into consequences of changing competitive behavior or demand and financial margins. These models need to be able to adapt input variables to changes, given the dynamics of the telecommunication market. Operators invest a great deal of time and capacity in marketing research, i.e. demand and customer satisfaction and in monitoring competitors' behavior. Although forecasting is used to reduce uncertainty, a certain amount of uncertainty is intrinsic to forecasting, and forecasting errors themselves are a source of uncertainty as well (Piyatrapoomi *et al.*, 2004).

*2.3.3 Intelligence*. Epistemic or knowledge-related uncertainty can be reduced by obtaining more information, e.g. business intelligence (Meijer *et al.*, 2006). This can be done by means of different methods. A first way is gaining information from suppliers on new upcoming equipment and technologies. This information, whether or not combined with knowledge from other sources like own specialists or market studies, can be applied to perform detailed technological analyses to compare technological options with regard to several relevant criteria (see Fijnvandraat and Bouwman, 2006). Cost-benefit analysis or a more advanced type of financial analysis, like real options, can be applied as a next step to gain more insight into the financial aspects and to reduce uncertainty related to unforeseen costs or ROI periods. Another applied way in business environments is benchmarking with competitors to learn from their experiences, successes and mistakes.

## 3. Method

We used both a qualitative and a quantitative approach to collect data and analyze the results. We obtained detailed insight into the evolvement of decision-making processes by means of in-depth interviews, in addition we used a questionnaire to gain more generic insights to validate the qualitative insights.

### *3.1 Qualitative data analysis*

*3.1.1 Interviews*. For the interviews, we used an interview protocol focused on the decision-making process regarding the upgrading and development of networks. Around 20 questions were asked. Interviews took on average 2.5 hours and were all taped, transcribed and the reports have been reviewed and approved by the interviewees.

*3.1.2 Sample*. In-depth interviews have been held with 12 decision-makers within cable and telecom companies in The Netherlands. Three decision-makers have been interviewed per company. The interviewees are part of the middle or higher management of these companies and are all directly involved in the decision-making process regarding the roll-out or upgrade of the telecom network of the concerning companies. With these companies, we covered the larges part of the Dutch telecom market, including operators with a copper Twisted Pair, cable and ''virtual'' local loop.

### *3.2 Quantitative data analysis*

*3.2.1 Questionnaire*. We developed a questionnaire that was administered via the internet, using an online survey tool called Surveyworld. The questionnaire contains 20 questions, some of them containing multiple items. The questions and items were related to the presented typology. The questionnaire was pre-tested on a small national sample, and after the results were analyzed a second improved online survey was conducted with a broader and bigger international sample. The structure of the main questionnaire was almost identical to that of our pre-test. Some adjustments were made, based on the pre-test and n insights gathered during the in-depth interviews.

*3.2.2 Sample*. The sample consists of persons involved in advice, research or decision-making with regard to broadband. In addition to the researchers' personal networks, the membership list of the International Telecom Society (ITS) was approached to fill in the survey. Of the 105 people who agreed to complete the questionnaire, 87 actually did, originating from 14 countries. With 60 percent, the majority of the respondents are Dutch (48 respondents). A total of 31 percent or 27 respondents come from other European countries. The other respondents originate from other continents: US (six), Australia (one), and Asia (two). Respondents have extensive experience in telecommunication decision making: 40 percent of the survey respondents have ten to 20 years' experience in the telecommunication market, and 26 percent has over 20 years experience. Moreover, the experience of our respondents, as indicated by the years that they are involved in decision-making in the telecommunications sector either as a decision maker (46 percent), an advisor, and/or researcher (54 percent), implies that the sample consist of a very professional and experienced sample of professionals. Although our sample seems relatively small and is based on self-selection, we should point out that the number of people working in broadband decision-making at a strategic level is fairly small, in most cases fewer than five people per Telecom Company, and databases on this population are not available. For those reasons, we assume that 87 respondents can be considered acceptable. Nevertheless we will refrain from strict statistical testing of significant differences seen the small size and self-selection of the sample.

## 4. Results

### *4.1 Empirical tenability of the typology framework*

First, the classification of risks and uncertainty into several sources will be discussed based on the in-depth interviews. Then, the classification of risk and uncertainties into nature, comprising ''epistemic'' and ''variability'' uncertainty, is investigated based on the online questionnaires. This provides us with insight into which uncertainties could be reduced based on increased knowledge. Finally, our online-respondents were asked to indicate the level of unpredictability of several risks and uncertainties.

*4.1.1 Sources of risk and uncertainty*. Technological risk and uncertainty: uncertainty about the technology can relate to the technology itself, to the relationship between the technology and the technological infrastructure due to system changes or to the availability of alternative existing and future technological solutions. The first category of uncertainty, concerning the technology itself, relates, according to our interviewees, to the stability of the networks. This uncertainty has two main causes: explosive customer growth and new technologies, as illustrated by two interviewees:

> . . . The biggest problem lies in the fact that, due to explosive network growth, IT systems must support five times more customers than five years ago. IT systems are, however not scalable enough to handle this, which causes that they're reaching their boundaries.
>
> In case of new technologies the stability of these technologies forms a big uncertainty. It concerns stability towards end-users but also during replacing parts of the network and sharing means within the network like new line cards, new chassis, new routers, etc.

The second type of technology uncertainty relates to whether and to what extent adaptations need to be made to the technological infrastructure. The following interviewee illustrates the uncertainty of determining the practical impact on the infrastructure as a result of technological adaptations . . .

> Immature technologies come together with uncertainties in the field of standardization, uptake, and availability. We also have (in this case) a detrimental risk because you start a migration path overnight which closes the way back. Another risk is what it will mean for your organization. You put down boxes everywhere in your network but is the technology really future proof although we now think it is?

The third type of technological uncertainty lies in choices between technologies. Operators are constantly examining characteristics of new technologies, like price, technological possibilities and performance in highly or lowly populated areas and must decide whether or not existing technologies should be replaced. Operators see the necessity to upgrade their networks. Although it is not known when this necessity will exactly occur and when a company should invest, they must be prepared for the upgrading and must have all options ready in order to be able to follow their competitors quickly enough, in case the necessity to follow occurs, as is demonstrated by the following statement:

> Uncertainty is also shaped by the variants you choose for: VDSL 1 vs VDSL 2, ADSL 1 vs ADSL 2. What is the direction most parties are following? Which vendor and which underlying choice is eventually going to give you the best price?

Other risks involved in the implementation of new technologies include the availability of a new technology, standards, the risk of irreversibility of the chosen technology path, the risk of the chosen technology becoming outdated, and path dependency.

Resource risk and uncertainty: operators indicate they face all these types of resource uncertainty: amount and availability of raw material, human resources and financial resources. One operator clearly illustrates the uncertainty regarding human resources:

> During network upgrade you really have to deal with priorities concerning the allocation of people: should you renew something or allocate people to fix problems in the existing network? This process is difficult to manage. Operation has to do with people and you are dependent on operational issues that do or do not elapse well. This is very complex.

Another interviewee told us that the uncertainty in network upgrades lies in the future availability of equipment (material) when a certain technology is chosen:

> . . .It's the uncertainty of technological developments. In case you make a certain technological choice, is your supplier following that development?

Several operators mention financial risk and uncertainty as very important uncertainties related to network upgrades. As one of them puts it:

> Technological developments are succeeding one another faster and faster. The result is that the first investment has not been paid back yet when the next one presents itself. Your business case is based on a payback time from five years but after two years a new technology is already there, reducing your payback time to only three years. Technologies are succeeding one another so fast that you're forced to work with shorter time lines all the time.

Competitive risk and uncertainty: competition is an important driver of network upgrading and roll-out for telecom operators. In case a competitor starts upgrading its network, other companies must follow or risk falling behind. Telecom operators must always be ready to have an adequate answer to what the competition does. However, the actions of competitors are hard to predict, as evidenced by this interviewee:

> Competition plays an important role, for example between DSL and cable. In the past, you saw cable operators being the first parties offering broadband internet by gradually skimming off the market. Then the DSL providers came up and they took over the market. At the moment, cable operators are regaining market share with TV and VOIP. These market developments are difficult to influence and predict.

Operators see a major risk in not following and anticipating on the actions of their competitors, because the effects of these actions lead to high levels of uncertainty about their own future market position:

> In case cable companies are massively starting to upgrade their networks and start offering high bandwidth against low prices and our network is not up-to-date to offer these capacities, we're the ones being left with the bill.

Supplier risk and uncertainty: as discussed earlier, suppliers play an important role in the decision-making process concerning network roll-out and upgrading. Choosing a technology and roll-out is something that is done in close cooperation with suppliers, because technological developments are changing fast and are becoming so complex that operators need suppliers for their specialized knowledge. This close involvement and specialized knowledge provides suppliers with a significant amount of power, which increases supplier dependency, as illustrated in the following fragment:

> Supplier dependency has been increasing strongly within the last years, because equipment becomes more and more complex and technological developments evolve very fast. Suppliers install their equipment by themselves during a roll-out, we're often not even involved in this process anymore.

Consumer risk and uncertainty: Meijer *et al.* (2006) mention three types of consumer uncertainty: uncertainty about consumer preferences, consumer characteristics, and end-user demand. Uncertainty about consumer preferences is clearly expressed by the following interviewee:

> A very important uncertainty is the uptake: will it be successful or not?

Also, the changing behavior, especially the fact that the end-users become more and more demanding, results in higher risks for operators:

> Another risk we see is that the services we offer are becoming more and more important for the business management of our clients. You have to deal more and more with claims and proofs of default the moment you're not operating according to the performance agreements. In case services of a telecom provider are not functioning, this often implies the revenues of a client are on hold . . .

Uncertainty about demand is a very important factor with regard to the technology that is selected. Forecasting demand is extremely difficult, because future demand is almost unpredictable and extremely difficult to measure. While operators have to base their roll-out on a certain level of network occupation, they also make it clear that this is their biggest source of uncertainty:

> Influencing the market is very difficult and complex because consumer behavior is almost unfathomably. You're never able to forecast whether it will evolve slowly, fast or not at all. What kind of new services will really be successful on a large scale?

It is not only the unpredictable behavior of end-users that causes high levels of uncertainty. The different visions operators have on the future of this uncertain market is an extra dimension of risk and uncertainty, as noted by the following interviewee:

> The market forms the most important uncertainty. How open are you going to make your networks? In case you share the same opinion on future demand, it's easier to share networks and

technologies with other parties, which strongly impacts your strategy. The more you share a vision with other parties, the opener you are able to aim, together with the ''telecom market'', for the same solutions. The more diverse the picture, the more secluded everybody is working and the higher the risks, because everybody has chosen a different path. This is very costly and brings along uncertainties.

Uncertainty about the characteristics of end-users was not mentioned specifically during our interviews. Vermaas (2007), however, clearly proves how difficult it is to understand end-users, which causes this type of uncertainty for operators: ''adoption triggers and thresholds are not absolute but subjective and the broadband adopter/user does not exist'' (p. 208).

Political risk and uncertainty: all operators indicate that regulation leads to uncertainty. One interviewee clearly indicates that existing policies can be a cause of uncertainty, in light of the long process involved in obtaining government approval for things like issues like price developments and technological migrations:

> An important factor is that OPTA[1] – procedures and the whole circus of objection and appeal afterwards last very long. We're still waiting for a verdict of a dispute we started in 2000. The process has improved now, but in this world a year is already too long; you already have to move on by then . . .

Uncertainty about future regulatory changes is mentioned several times during the interviews. The following interviewee indicates that, in addition to the question whether a certain regulation will be implemented, an even more important question for operators is when:

> We experience much uncertainty regarding when regulation is going to take place. All these issues have to do with money, investments. And where investments are involved, it is very important to choose the right moment. Timing is of key importance.

Another interviewee mentions uncertainty about which way the new market definitions will influence the business and market position of telecom operators. The question where regulation of emerging markets will turn is also an important issue for existing telecom operators. This interviewee remarks:

> . . . The phase of the highest uncertainty is the current phase, in which you're not sure which direction regulation will go.

These results are validated by an exploratory factor analysis on the risk and uncertainty variables included in the survey research (see Table II). Of the six sources for uncertainty we

**Table II** Risk and uncertainty related to sources, based on factor analysis (varimax rotation)

| | *Consumer and market R&U* | *Political R&U* | *Technological R&U* | *Resource R&U finance* | *Resource R&U operations* |
|---|---|---|---|---|---|
| Consumer preferences/characteristics | 0.82 | | | | |
| Market developments | 0.77 | | | | |
| Development of demand | 0.72 | | | | |
| End-user rates | 0.67 | | | | |
| Changes in regulation | | 0.91 | | | |
| Unclear/inconsistent regulation | | 0.90 | | | |
| Unforeseen costs | | 0.66 | | | |
| The rate of new technological developments | | | 0.84 | | |
| Innovation and development of new broadband technologies | | | 0.76 | | |
| Availability of alternative technological solutions | | | 0.74 | | |
| Price of necessary supplies | | | | 0.81 | |
| Equipment price development | | | | 0.78 | |
| Impact of new broadband networks on operational systems | | | | | 0.85 |
| Right timing of availability/delivery of necessary supplies | | | | | 0.75 |
| Cronbach's $\alpha$ | 0.78 | 0.84 | 0.71 | 0.63 | 0.64 |

see four source explicitly reflected, as illustrated by the high factor loadings of the uncertainty sources (>0.60) on the core factors. One of these factors, i.e. resource uncertainty, appears to have two dimensions: R&U with regard to finance and to operations. Item homogeneity as indicated by Cronbach's $\alpha$ is sufficient for three out of the five scales (>0.70).

*4.1.2 Nature of risk and uncertainty.* It is striking that there is a high level of disagreement between the respondents on the categorization of risk and uncertainty according to their nature (epistemic versus variability). Most respondents agree about the fact that changes in regulation are an uncertainty due to changes in the environment, which means that the resulting uncertainty cannot be reduced by more knowledge. Table III summarizes the five most important uncertainties as mentioned by the respondents in the international survey, as well as their assessment as to whether the uncertainties are epistemic in nature or caused by changes in the environment.

The most convincing scores on categories of risk and uncertainty that can be solved through an increase in knowledge (epistemic) are related to technological and operational network-related aspects, including supplies and the availability of financial resources. Increasing information on these subjects will reduce the uncertainty with which they are associated. Uncertainties regarding regulation, end-user demand and market developments are the least likely to be solved by increasing knowledge and, as such, belong in the category 'variability' uncertainties.

*4.1.3 Level of predictability of risk and uncertainty.* The final classification of risks and uncertainty is based on their level of predictability. Our quantitative results show that the level of unpredictability is the highest for end-user related aspects like consumer preferences and characteristics (20 percent of the respondents considers this completely unpredictable, see Table IV), end-user service development (16 percent completely unpredictable), development of demand (11 percent completely unpredictable). It can be concluded that the behavior of regulators as well as end-users is also clearly seen as an uncertainty that cannot be reduced through an increase in knowledge, although regulators are more predictable than end-users. Ten percent of the respondents, however, maintain that, as far as regulation is concerned, the future is completely unpredictable, which can have a restraining influence on network upgrades. Operational and resource-related topics are considered to be the least unpredictable.

Through our interview and quantitative research, we have shown that the five sources of uncertainty suggested in the framework by Meijer *et al.* (2006) are clearly visible in the telecom market. Decision-makers are faced with technological, resource-related, competitive, supplier-related, consumer-related and political/regulatory uncertainties. Our quantitative analysis confirms these results and shows us that epistemic types of risk and uncertainty are related to technological and operational network-related aspects, including supplies and the availability of financial resources. The behavior of regulators and end-users clearly causes uncertainties that cannot be reduced by increasing knowledge. The level of unpredictability is the highest for end-user related aspects, like consumer preferences and

**Table III** Most important types of risk and uncertainty to their nature and percentage of respondents agreeing

| *Epistemic uncertainty* | *% resp.* | *Variability uncertainty* | *% resp.* |
|---|---|---|---|
| Proper functioning of intelligence within the network | 69 | Changes in regulation | 77 |
| Manageability of QoS of service delivery and network | 69 | Development of broadband end-user services | 75 |
| Quality of necessary supplies | 67 | Market developments | 75 |
| Impact of new broadband networks on operational systems | 62 | Unclear/inconsistent regulation | 71 |
| Availability of financial resources | 59 | Development of demand | 68 |

**Table IV** Degree of unpredictability: the ten most unpredictable risks and uncertainties

| | *(1) Near future is predictable* | *(2) Limited number of possible future scenarios* | *(3) Broad range of possible future scenarios* | *(4) Future is unpredictable* | *Mean* | *SD* |
|---|---|---|---|---|---|---|
| Consumer preferences | 2 | 37 | 41 | 20 | 2.78 | 0.78 |
| Development of broadband end-user services | 6 | 38 | 40 | 16 | 2.67 | 0.82 |
| Development of demand | 5 | 36 | 48 | 11 | 2.67 | 0.74 |
| Market development | | 47 | 46 | 7 | 2.60 | 0.62 |
| Revenues | 5 | 49 | 37 | 9 | 2.51 | 0.73 |
| Unforeseen costs | 5 | 51 | 36 | 9 | 2.49 | 0.73 |
| Change in regulation | 7 | 49 | 33 | 10 | 2.47 | 0.78 |
| Actions of potential or actual competitors | 2 | 56 | 35 | 7 | 2.46 | 0.66 |
| Unclear/inconsistent regulation | 8 | 54 | 28 | 10 | 2.40 | 0.78 |
| Using non-standardized technologies | 14 | 46 | 28 | 13 | 2.39 | 0.88 |



characteristics, end-user service development and development of demand. Regulators are somewhat more predictable than end-users.

### *4.2 Effects of risk and uncertainty*

Operators indicate that the way risks and uncertainties affect technological choices very much depends on the urgency of the problem they are facing. In case it concerns a roadmap of a service that may be successful in about two years, operators will investigate more specifically whether they have selected the right path. In case of high levels of urgency and more rigorous steps, operators are in most cases forced by their environment to select the path that is the best of that particular point in time:

> . . . In case of high urgency, one has to rush aside certain uncertainties. Practice sometimes forces one to make choices.

An important effect of risks and uncertainties indicated by the operators is that they keep several possible development paths open, as explained by the following interviewee:

> In case preliminary steps already must lead to a final decision, the risks are very great, because these cases involve path dependency and irreversibility. For that reason, there is some sort of decision tree in which several paths are kept open. Without these preliminary paths, the way towards FttH would already have been closed off, but now it's kept open, although the final decision has not yet been made.

Marcus (1981) indicates that political uncertainty can affect the rate, timing and substance of an innovation. This is clearly supported by two interviewees:

> (. . .) because too many paths are being kept open, these factors (i.e. regulation, OPTA, and politics) have a delaying impact on decision-making for a certain option. All these alternative solutions demand energy and resources, which is not practicably and decreases focus. This way, these factors are also delaying the roll-out of technologies and services.
>
> . . . In case one would face a major investment decision, like the roll-out of fiber, a climate of uncertainty at the level of political regulation will make one hesitate whether one is making the right decision.

It can be concluded that risks and uncertainties have two important effects. The first involves building in flexibility by keeping more development paths open. This way, different development steps can be chosen, depending on the circumstances. Moreover, adjustments can be made in case the environment changes. Building in flexibility and keeping open more options for the future is a clear example of practically applied real options thinking.

The second effect, brought about by regulatory uncertainty, is a delay in or reconsideration of investments. Although it is difficult for regulators to keep pace with the fast-changing telecom market, they should be aware of the impact uncertainties about the outcomes of regulatory processes have on the decision-making processes of telecom operators. A climate of political and regulatory uncertainty inhibits operators with regard to possible large infrastructural investments.

### *4.3 Dealing with risk and uncertainty*

The question that logically follows after measuring the effects of risk and uncertainty is how to handle and minimize their negative effects. In section 2, we presented several possible ways of dealing with risk and uncertainty, including scenario investigation and forecasting, and several forms of obtaining information (i.e. cost-benefit analysis, technological analysis, benchmarking with competitors, and obtaining information from suppliers). These methods can be used to make the future more predictable for the types of risk and uncertainty that cannot be attributed completely to characteristics of the environment and that are thus in to a greater or lesser extent within the span of control of decision-makers (epistemic uncertainties).

*4.3.1 Quantitative results*. Based on quantitative analysis, scenario analysis is considered the most suitable method. Cost-benefit analysis, forecasting and technological analysis also are considered very suitable. Obtaining information from other parties like suppliers and competitors is seen as considered less suitable. The results are presented in Table V.

*4.3.2 Qualitative results*. Scenario analysis is used to analyze various potential future options and to identity the best solution for the company. Several decision-makers mentioned gaining information from experts as a possible solution, as illustrated by the following statements:

> We have several vendors who can provide us with information on new technologies. As far as possible, information is obtained from several players to prevent supplier dependency. In addition, a special group of architects explores all kinds of technological developments that occur everywhere. They function as radar, measure expectations and look at which expectations actually become a reality.

Technological analysis is often performed by a special department of technological experts within or outside of a company, with the aim of investigating new technologies and the way they can be applied.

Demand and revenue forecasting is indicated as being an important method for building business cases and making decisions whether or not to upgrade or roll-out a network. Forecasts are made for several factors, including bandwidth development, price developments, market positions of competitors and the position of the own company. Interviewees indicate that the most important variable with regard to forecasting is end-user demand:

> Demand forecast is of the utmost importance. Expected demand is the most important factor in determining whether or not to roll-out, and if so, where and with what capacity.

**Table V** Preferences for methods to reduce risk and uncertainty

| | *(1) Not suitable at all* | *(2) Not very suitable* | *(3) Somewhat suitable* | *(4) Mostly suitable* | *(5) Very suitable* | *Mean* | *SD* |
|---|---|---|---|---|---|---|---|
| Scenario analysis | 1 | 1 | 22 | 45 | 31 | 4.03 | 0.83 |
| Cost-benefit analysis | | 8 | 29 | 43 | 21 | 3.76 | 0.88 |
| Demand and revenue forecasting | | 6 | 32 | 44 | 18 | 3.75 | 0.82 |
| Technological assessment and forecasting | 1 | 9 | 39 | 40 | 10 | 3.49 | 0.85 |
| Benchmarking with competitors | | 15 | 37 | 33 | 15 | 3.48 | 0.93 |
| Obtaining information from suppliers | | 9 | 54 | 31 | 6 | 3.33 | 0.73 |

In addition to the methods described above, decision-makers mention pilots as a regularly applied method for gaining insight into potential problems before rolling out a technology on a large scale. In case a certain technology causes many problems, the decision to roll-out this technology can be reconsidered or delayed until the problems are solved, as becomes clear in the following statements:

> To prevent teething problems during the implementation of new technologies, all new equipment and IT systems are tested within the own network. Technologies not always perform the same in practice as they do in a lab. It is only in case the technology functions optimally within a pilot that it will be rolled out within the rest of the network.
>
> One wants to understand what rolling out a certain technology implies. By just taking a decision one runs the risk getting confronted with all kinds of unpleasant surprises like a roll-out costing twice the price you expected. For that reason a pilot will be performed to exclude uncertainties because the investments are enormous.

There are some differences between our quantitative and qualitative results. Our qualitative results show that obtaining information (i.e. technological analysis), forecasting and pilots are the most frequently applied methods for reducing risk and uncertainty. Obtaining information and forecasting take place early in the decision-making process, during the investigation of alternatives. Pilots are performed later on in the process, to prepare for possible unforeseen side-effects of implementing a new technology. The importance of forecasting was also demonstrated by our quantitative results. Our survey results show that scenario analysis and cost-benefit analysis are often applied. Cost-benefit analysis was, however, not mentioned in the interviews we conducted, and although scenario analysis was mentioned, it was not considered very important. The fact that cost-benefit analysis was not mentioned by our interviewees can be ascribed to the fact that it is seen more as a financial assessment method than as a method for reducing risk and uncertainty.

## 5. Conclusions

Telecom operators, like other infrastructure providers, are faced with various types of risks and uncertainties in their decision-making process concerning the upgrade and roll-out of their broadband networks. In one respect, these risks and uncertainties have to do with the characteristics of large infrastructural projects, while on the other hand being caused by (unknown) competitor behavior, (unknown) end-user demand, rapid technological development and different development paths available to operators. Framing risks and uncertainties into a typology provides greater insight into the categories, characteristics and sources of the risks and uncertainties, as well as being a first step in finding ways to deal with them. Based on a qualitative and quantitative data analysis, we have proven that a combination of the uncertainty typologies suggested by Meijer *et al.* (2006) Walker *et al.* (2003) and Courtney *et al.* (1997) can be applied to the risks and uncertainties regarding the decision-making process involving the upgrade and roll-out of broadband networks. Although the typology used by Meijer *et al.* (2006) is designed to deal with transitions within the energy sector, the sources of uncertainty defined in this typology are also visible in broadband-related transitions which underlines the parallels between decision-making in these infrastructure sectors where network transitions are concerned. Including the typology in futures analysis will contribute to a more focused decision process by making nature, level and sources of uncertainty transparent. Tools for dealing with uncertainty based on this typology will help to manage risk and uncertainty in decision making projects regarding large infrastructural projects. As has been stated current tools are far from perfect and rarely used in practice. By making sources of uncertainty and risk explicit, as well as their epistemic or variability nature, managers can choose the proper strategy to deal with them.

Our research validates Meijer *et al.*'s (2006) typology for the telecom domain. It has shown that these six sources of uncertainty are clearly experienced by broadband decision-makers. Epistemic risks and uncertainties (which can be solved by gaining more knowledge) are related to technical and operational network-related aspects, including supplies and the availability of financial resources. The most important variability risks and uncertainties (which cannot be solved by gaining more knowledge) are related to the behavior of regulators and end-users, and general market developments. The level of unpredictability is the highest for end-user related aspects like consumer preferences and characteristics, end-user service development and development of demand. Although behavior of regulators as well as of end-users are both clearly considered being uncertainties that cannot be reduced by gaining more knowledge on their behavior, regulators are more predictable than end-users in their comings and goings. In the fact that the development of broadband end-user services is so unpredictable lies a big part of the explanation of the famous ''chicken-egg'' problem of the broadband market (a lack of high-speed broadband roll-out results in a lack of broadband services development and the other way around). Because infrastructure providers do not know whether there will be sufficient bandwidth demanding services to make their networks profitable, they do not roll-out high speed networks on large scale.

Risks and uncertainties have two important effects. First of all, operators tend to build in flexibility by keeping more development paths open, allowing them to change their approach in case changes in the environment would make that desirable. The second effect, brought about by regulatory uncertainty, is a delay in or reconsideration of investments. Regulators should be aware of this, in light of the fact that, since 2001, national as well as European governments are attempting to accelerate the roll-out of broadband networks (see European Commission, 2002, 2004, 2008; Expert Group Broadband, 2002; Impulscommissie Breedband, 2004, and other publications).

To reduce risk and uncertainty, there are various future analysis methods that are applied by operators. Although there are some differences between the results of the qualitative and quantitative research, both show that scenario analysis and forecasting are very important method when it comes to reducing risk and uncertainty. The relevance of intelligence, focused on reducing epistemic uncertainty, although widely used, cannot be stressed enough. The framework as presented and validated for the telecommunication domain, can support decision makers in the telecommunication domain to analyze uncertainties, their nature, level and source, and to deal with these in a more systematic way in their decision making process. The typology can also be used in other infrastructure domains, or used in dealing with investments in services that are enabled by these infrastructures. Moreover the typology as validated can be made part of scenario analysis, leading to a clearer focus on the topics to be understood in forecasts or direct future business intelligence.

## Note

1. OPTA is the Dutch National Regulatory Authority (NRA).

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