Development projects for radical innovations are typically long in duration and, therefore, surrounded by a high level of technological, market, organizational and resource uncertainties. Various techniques have been developed in order to manage the uncertainties due to unpredictable future and to support managers in their strategic decision making during the innovation development process. Typically such techniques give support for decision making only in a particular phase or element of the innovation process. Systematic strategic support throughout the innovation process under high level of future uncertainty, from the first evaluation of ideas of new business opportunities through design and development stages to commercialization and launch, is usually highly insufficient or missing.

This paper describes a systematic framework to support strategic decision making in innovation development that attempts to put appropriate amounts of planning resource into the process at different stages. It is constructed to make use of qualitative evaluation techniques, based on risk management methodology, early in the process when faster, less expensive methods are preferred to more accurate quantitative techniques. It is also constructed to make use of a small number of reusable process building blocks, including a simple process for approximating expert consensus without requiring face-to-face meetings of experts. It makes use of modern contingency planning techniques in order reduce wasteful investment in ideas that will eventually be discarded during the innovation process.

The starting point of the paper was a large interview study about innovation management practices in major Finnish organizations. The study identified management of future uncertainty as one of the main challenges of corporate executives, which initiated the present research for the development of practical techniques to support strategic decision making at multiple critical decision points of innovation development under high level of uncertain information. The work is a joint study involving IBM Research and VTT Technical Research Centre of Finland. As a result, separately developed techniques were integrated to produce a more systematic, more comprehensive, but highly efficient innovation management framework.

Keywords: Innovation Development, Uncertainty Management, Risk Management, Decision Support, Contingency Planning, Signpost
Introduction

The importance of innovations and innovation management is recognised in companies, research institutes, and in the whole of society. Most innovations will not achieve commercial success, as a matter of fact, most innovations fail. On the other hand, companies that do not innovate will, sooner or later, face an economic crisis and die.

Innovations can be classified as incremental and radical (disruptive) according to changes resulting from the innovation (see e.g. Morone, 1993, Utterback, 1994, Leifer et al, 2000). Most innovations are incremental being gradual enhancements or feature replacements to existing products, services, processes, business models. Actually, it is often difficult to say when the question is about ‘new innovation’ and when about ‘product enhancement’. Incremental innovations have a sustaining nature and allow an organization to maintain its current approach to target markets. That is, they do not create new lines of business, nor do they completely new markets for an existing product or service.

Radical innovations, by contrast, correspond to disruptive change. The disruptive change can be related to technology, markets, society, or all of them. An innovation can be said to be radical when it has the potential to produce one or more of the following: (a) an entirely new set of performance features, (b) improvements in known performance features of five times or greater, or (c) a significant (30 percent or greater) reduction of cost (Leifer et al, 2000). A radical innovation significantly changes supply and demand conditions in a market. Radical innovations create new lines of business. The introduction of consumer digital photography is a good example of a radical innovation that caused major disruptive technological and social changes. Such major disruptive changes are rare; but smaller scale disruptive changes, affecting primarily the business of a single company, happen frequently.

Development projects for radical innovation are typically long in duration. It often takes several years from the discovery of a new business opportunity through the incubation (i.e. evolving the opportunity into a business proposition) to acceleration or ramping up of the business to stand on its own (O’Connor, 2006). Ten years is not a long time for this process. Partially because of the long duration, development projects for radical innovations are surrounded by multiple uncertainties (Utterback, 1994, Leifer et al, 2000). Leifer et al. (2000) have defined four major dimensions of uncertainty that are relevant for all radical innovation development projects: technological, market, organizational, and resource uncertainties. The management challenge of multiple dimensions of uncertainty is complicated by the fact that the uncertainties interact with each other, in the sense that there are complex correlations. Further complexity is brought by the long time span of the process during which major disruptive changes may happen in technology, markets and competition having major influence (either positive or negative) to the business potential of the innovation.

In this paper we propose a relatively inexpensive, systematic approach to managing future uncertainty related to radical innovation. The starting point of the paper is a large interview study about innovation management practices in major Finnish organizations (Kettunen et al, 2007). The study revealed that management of future uncertainty is one of the main challenges of corporate executives. That initiated the present research for the development of practical methods and tools to support strategic decision making at multiple critical decision points in the innovation process.
Research Methodology

In 2005 VTT performed a large interview study of innovation management practice in which 43 managers were interviewed from 12 major companies and public organizations in Finland. The goals of the study were to understand and describe innovation management practices in the organizations, to chart generic success factors, and to identify potential problem areas and development needs. The interviews also covered strategies and business models. The list of interviewed organizations includes ABB, Consolis, FMI, Metso, M-Real, Nokia, Schering, Tekes, Vaisala, VTI Technologies, VTT, and Wärtsilä. These are well established, globally recognized enterprises possessing process descriptions for their innovation processes. They represent diverse branches of industry and are intended to provide some level of comprehensiveness. The interviews were semi-structured with a special focus on obtaining a wide range of differing opinions. Interviewed managers included people occupying senior corporate, R&D and business unit or marketing management positions. The interviews were supplemented by written material including process descriptions, strategies, and product presentations of the organizations.

A group of scientists from VTT (including one author of this paper) applied a constructivist collective case methodology to material from the interviews. This methodology focuses on different viewpoints and lived experience of organizational members (Schwandt, 1994, Hatch, 1997) and is committed to bringing up multiple voices and viewpoints. The group has extensive experience in technology R&D and management at various companies and research organizations. The analysis was done from four major perspectives of innovation management: fuzzy front end, commercialization and market entry, networking, steering and financing. The main results and conclusions of the study were published by Kettunen et al. (2007), the detailed case analyses, however, remaining confidential.

The potential problem areas and development needs identified by the study triggered the initiation of several lines of research, including the one which this paper reports. The original study identified management of future uncertainty as one of the main challenges to corporate executives. This challenge was reported to be great throughout the innovation process, but greatest at the fuzzy front end, which is much less structured than new product development and commercialization processes at each of the case organizations of the study.

In this paper we suggest an answer to the question, How should future uncertainty be managed during the entire innovation process?

The approach of the work towards finding answers to the research question was, again, based on constructivist methodology. The authors have wide experience in research and development for various fields, in the development of new services, and in consultancy work in the fields of technology foresight and risk management. This experience allows us to assimilate different viewpoints and experience, at first, in order to specify the research problem in a more detail, and then, to develop tools and methods in order to overcome the weak
points, from the viewpoint of uncertainty management, in the new innovation development processes identified in the interview study.

Initially we focussed on specific phases of new innovation and business development. As we developed and tested the tools for each phase, we found that we still lacked a systematic approach to decision making that could be applied throughout the innovation process. This discovery initiated the final stage of our research: the development of a systematic, comprehensive, and efficient innovation management framework focused on providing support for strategic decision making under conditions of high uncertainty about the future. Our framework includes techniques, originally developed for the separate phases, integrated by means of generic risk management methodology (Suokas and Kakko, 1993).

This paper focuses to the research and results of the final stage. The resulting framework is supplemented by working hypotheses which are strongly influenced by the experience of the authors and reflect our interpretation of development needs in innovation management practice.

**Management of Unpredictable Futures**

The future will always be unpredictable, but with the right techniques the opportunities and threats of the future can be managed. The right choice of techniques depends on the scope of study: short term studies can be largely done by extrapolating current trends and exploring the likelihood of meeting current challenges, while long term future studies require different approaches in order to better prepare for unexpected. Time series and other history data can not predict disruptive changes. In the case of radical technological innovation development, long time span is very important (but challenging), because technology R&D will take place over several years (typically 5-10 years) while markets operate with a much shorter time horizon.

The technology roadmap approach (Phaal, 2004) has been widely used in technology foresight studies as well as in business planning and project planning for innovation development (Kettunen *et al.*, 2007). In practice, according to our experience and the results of the interview study, this road mapping methodology is predominately restricted to the extrapolation of current trends. Thus, road mapping is suitable for business and innovation development planning for a three to five year horizon, within which the plans are based on the expected course of technology progress and business environment (Strong *et al.*, 2007a). Accordingly, the technique is very suitable for incremental innovation development projects.

To accommodate a time horizon longer than 3-5 years or to better prepare for the unexpected, scenario planning techniques are widely used to support strategic decision making for business development (Wack, 1985, Godet, 2000). Scenario planning explores multiple potential futures rather than a single “most likely” future. These explorations are framed in narratives (called scenarios) designed to influence key decision makers. By working with scenarios of quite different futures, the analytical focus is shifted from trying to estimating what is most likely to occur towards contingency planning to determine the consequences and most appropriate responses under different circumstances (Duinker and Greig, 2007).

The scenario process as well as the application of scenarios in strategic decision making include also pitfalls: One must ask the right questions, formulate the right hypotheses clearly,
and ascertain the coherence and probability of possible combinations. Without these, one risks leaving out most possible futures (Godet, 2000). Furthermore, it is not straightforward to tie scenarios to the advancing current state of reality, facilitating the development of a flexible, contingency strategy (Schoemaker, 1998, Strong et al., 2007a). At the level of operative new business development, while scenarios may give some support for the ideation of new innovations and business opportunities, they give little support for the corresponding daily decision making. This is particularly true in the fuzzy front end of the innovation development process where the critical decisions affecting the success potential of the innovation are made (Koen et al., 2002, Paasi, 2007). All these call for other, perhaps complementary, methods to link the management of unpredictable future to the daily strategic decision making of innovation or new business development.

Strong et al. (2007a, 2007b) proposed a novel methodology, called the signpost method, for adaptive contingency planning at the strategic initiative level, complementing normal business planning that uses a schedule based on predictions tied to dates in the future. A signpost is a recognizable potential future event that signals a change of such importance to an enterprise that it is actionable. The methodology includes ideation, information mining, scenario envisioning, and the selection of signpost events upon which to base a set of contingent strategic initiatives. The signpost method has been successfully field tested in several cases related to enterprise strategy (Strong et al., 2007a, 2007b), but not for direct support of the entire innovation process.

Managing New Innovation Development

Recall that the VTT interview study revealed the following generalizations about the innovation process:

1) new product development is well structured and controlled, but
2) early concept and design is unstructured and uncontrolled

(Kettunen et al., 2007). The reason for (1) may be the well developed theory of new product development (Ullrich and Eppinger, 2004, and Cooper and Edgett, 2005). For the beginning of the process (the front end), there is no similar well established theory. The development of new innovation usually starts from an idea of a new business opportunity but, what follows, is more or less fuzzy until the idea has been elaborated so much that the actual product development work can start. Therefore, the front end of the innovation process is often known as the fuzzy front end. However, the fact that it is fuzzy does not make it unmanageable.

The front end of the process has been modelled in companies: in some models the process is linear like the product development process (see e.g. Ullrich and Eppinger, 2004, Cooper and Edgett, 2005, Kettunen et al., 2007), other models emphasize the complex and iterative nature of the front end (Orihata and Watanabe, 2000, Koen et al., 2002, Dorval and Lauer, 2004). In a study of front end practices, Koen et al. (2002) identified five clearly distinguishable elements: opportunity identification, opportunity analysis, idea generation and enrichment, idea selection, and concept definition. The process starts with an idea for new
business opportunity but after that it may proceed through the different elements in variable orders until the idea has been developed into a vision or concept that is ready in both technological and business aspects. Each of the elements incorporates important decision points.

Innovation processes include lots of different kinds of decision points. In the context of innovation uncertainty management, we must ask two questions:

1) Are all decision points critical and equally important?
2) What are the critical decision points of innovation development process in which foresight plays an important role?

To (1) we suggest that not all decision points are critical and equally important. Paasi et al. (2007) identified four critical decision points in the front end of radical innovation development: selection of new business opportunity for further elaboration, selection of elaborated business idea for concept definition, selection of external partners for networking, and selection of concepts of new innovations for product development. Each of these decision points includes strategic aspects to which foresight is relevant. Subsequent critical decision points in the innovation development process could be the gates of new product development and commercialization process suggested by Dunham (2002) and by Schmidt (2005).

**Our Framework for Systematic Decision Support**

We developed our framework model for systematic strategic decision support in innovation development from the following specifications, which are based on the constructivist analysis of the interview material by the authors:

1. The model should be flexible in order to adapt company specific innovation processes, which are often stage-gate like processes, and it should be made of reusable process building blocks which would progressively evolve along the use of the model, creating a reusable innovation management asset.

2. It should optimise the amounts of planning resources into the process at different stages. This can be achieved by a three-part approach: (a) fast reduction in the number of ideas and projects in the innovation development process, (b) qualitative evaluation techniques early in the process when faster, less expensive methods are preferred to more accurate quantitative techniques (work demanding more accurate quantitative studies can be valuable at later stages of the process for topics identified in qualitative studies), and (c) a simple process for approximating expert consensus without requiring face-to-face meetings of experts.

3. The foresight aspect should promote enterprise strategic preparation for the unexpected, and should be so practical that it ties important scenarios to the advancing current state of reality in way which guides right-timed actions at the strategic initiative level of new innovation and business development throughout the process.

4. Risk management methodology should be built into the model in order to make uncertainty management systematic and straightforward in identifying potential opportunities and threats where specific management actions or deeper studies and analysis could be necessary.

The resulting framework model is presented in Figure 1. The framework starts with (preferably many) ideas of new business opportunities and ends with one or more lines of business (or analogous innovation results for non-profit organizations).
Figure 1  Framework of strategic decision making in the development of new innovations and new lines of business.

At the beginning there is an ideation stage which includes phases of preparatory background information studies, idea generation and idea clustering. Idea clustering means that compatible and related ideas are collected together to be treated as one object of analysis having a common vision of future. A particular challenge in ideation is to create ideas and visions for which realization will likely occur beyond the typical business planning horizon of three to five years. Being generally unexpected such ideas are more likely to be associated with radical disruptions. Reasoning about such ideas can also lead to unexpected ideas that could likely be realized in the near future and could lead eventually to the deeper future ideas. Such unexpected ideas can be generated by asking subject matter experts for deep future ideas “one hundred years out” and then backcasting into the near future. See Strong et al (2007a, 2007b) and references therein for more details about the ideation stage.

After ideation there is the first filtering of ideas (visions) in order to reduce the number of ideas, visions, and projects in subsequent stages. We accelerate the narrowing of the funnel depicted by increasing the bias toward stopping an idea at an early filtration step. Filtration is followed by recommendations for further actions, which may simply be ‘stop’, ‘hold’ or ‘continue’. A ‘stop’ recommendation could mean either discarding or recycling the idea. A ‘Hold’ recommendation could mean creating one or more signposts and active monitoring these signposts for future conditions under which the idea would be returned to the active
innovation process. A ‘continue’ may include alternatives of product development, commercialization, collaborating, outsourcing, patenting, licensing, selling, publishing. All these are strategic decisions.

Filtration, recommendations, monitoring and elaboration of vision (i.e. the actual innovation development work) form a five-phased iterative process which will be repeated at each stage of innovation process and, depending on the company, may even be repeated inside a single stage such as product development, Fig 2. The filtration and recommendations phases are current business practices at the gates of the stage-gate process. Active monitoring of ideas or projects on hold, however, is a novel enhancement to observed innovation practices reported in (Kettunen et al, 2007).

![Figure 2](image-url)  A five-phased iterative process of innovation development consisting of strategic decision making elements of filtration, recommendations and decision, active monitoring supporting the decision making, and the elaboration of vision, which contains the actual innovation development work.

Idea generation, filtration of ideas, recommendations for further actions, elaboration of ideas, and accelerated early reduction of development projects (so that, for example, from 100 ideas only 10 will be conceptualized and only one will be commercialized) correspond to current best innovation practices. What is novel is the linkage between the strategic initiative level and decision making by means of active monitoring of signposts (easily recognizable potential future events that signal changes of importance to the enterprise and call for a strategic action in the innovation development process). Furthermore, what is novel is the systematic way this is done throughout the innovation process from idea evaluation through conceptualization and new product development stages until the launching decision. The model can even be used to facilitate decisions about when to terminate a line of business. The idea to terminate can be sent through the entire innovation process with appropriate analogs for design and development phases. For example, the anticipated cost savings in terminating the line of business at the right time, can be viewed as the impact or reward.

Uncertainty management has been built in the model by the means of risk management. Risk management is systematic process where organizations methodologically address the
risks attaching to their activities with the goal of achieving sustained benefit within each activity and across the portfolio of all activities (A Risk Management Standard, 2002). In general, risk management aims to protect the property, income and different activities of a company while minimizing costs. The generic main steps of risk management are shown in Figure 3 (adapted from Suokas and Kakko, 1993). Risk management steps are included in our decision support model with specialization for each innovation stage.

Figure 3  The main steps in risk management (adapted from Suokas and Kakko, 1993).

In our ideation stage risk management is incorporated by going beyond the extrapolation of current trends to prepare for the unexpected. In the stages of innovation development, we supply risk management for the five-phased iterative process shown in Figure 2 in three different ways:

1. Strategic decision making is supported by qualitative risk evaluation maps covering check lists of potential issues for conceptualization/design, development or commercialization aspects of new innovation development (see e.g. Luoma and Paasi (2007).
2. Analysis of risks is largely done by experts using an approximate Delphi procedure fulfilling four key features of the Delphi procedure: anonymity, iteration, controlled feedback, and the statistical aggregation of group response (Rowe and Wright, 1999). The procedure is based on the use of simple, reusable, electronic questionnaires covering those aspects of future uncertainty critical from the viewpoint of strategic decision making. The number of aspects as well as the level of details increases as the project is progressing in the innovation development process.
3. Risks related to timing issues are managed by generating appropriate signposts and by active monitoring of the signposts.

The framework model will be described in more detail elsewhere together with examples of qualitative risk evaluation maps and questionnaires used at the filtration, examples of graphs supplementing the recommendations, and examples of signpost generation for the active monitoring.

Our framework model for innovation development has been generated in accordance with a set of working hypotheses, which will be validated or modified based on continuing experience. These hypotheses are synthesized from our interpretation of the interview study results, related findings reported in the literature, and response from separate field tests of tools and techniques used in the framework model.

**Working hypothesis 1:** Qualitative decision support techniques can be less expensive than quantitative techniques. They may be also less accurate, but they are sufficiently accurate to be appropriate in early stages of innovation development process. In particular an approximate Delphi process using self-rating of expertise for weight in a weighted average is an inexpensive but powerful tool for providing qualitative decision support, especially for prioritizing and filtering ideas in the early stages of the innovation process.

There is always the risk that an important idea is discarded early in the innovation process. This might lead one to spend a great deal of effort at the beginning of the process attempting to predict which ideas will be successful; but we believe that this effort would be misplaced and would encounter a diminishing return in which more and more effort is required to save fewer and fewer innovations. We expect such effort would produce a heavy front end with costs that would discourage innovation. Instead, we propose to mitigate the risk of discarding a good idea by conserving and reusing discarded ideas. Our ability to reuse discarded ideas and to monitor for signposts that would indicate a better time to develop an idea can make us freer to generate and discard ideas easily. Such freedom would likely lead to an enhanced flow of increasingly creative ideas during the early stages of innovation.

Systematic application of increasingly comprehensive qualitative risk management techniques, such as lists of potential risk factors and questions derived from the risk factors directed to subject matter experts who respond according to the approximate Delphi, can, according to our experience, provide the appropriate level of decision support at each stage of the innovation process. Relatively expensive quantitative techniques may be valuable at later stages of the innovation process for studying specific questions arising from the qualitative analyses. Quantitative techniques to be considered may include: light weight information mining techniques useful in generating and monitoring signposts and in estimating general levels of R&D investment in given topics, heavier information mining techniques to determine buzz about a topic such as a technology, and massive and expensive polling techniques for determining market readiness.

**Working hypothesis 2:** The intellectual capital represented by innovative ideas in various stages of design and development can and should be conserved, even when it is appropriate to stop or hold (pause) the innovation process.
Signposts have been suggested as a link between scenario based strategic initiatives and the advancing state of the world (Schoemaker 1998, Strong 2007a) We suggest that signposts could link strategic initiatives to decision points in an expanded innovation process that includes a hold state. This could dramatically improve right timing of innovations. Ideas can be placed on hold to be returned to the same stage of the innovation process when conditions are more appropriate. This process can conserve much of the intellectual capital of even relatively developed ideas, if the return can be associated with the realization of a recognizable signpost event. Active monitoring of signposts can insure that ideas are brought to market at the right time rather than at the first time they are ready.

Working hypothesis 3: High uncertainty in risk factors is tolerable in the design stage of innovation but must be reduced before launch (unless negative potential consequences are mitigated).

Radical innovation development projects are surrounded by multiple dimensions of uncertainty, as described already in the Introduction. Such projects may be attractive when high risks are accompanied by high opportunities for rewarding new business. Our framework provides a way to engage risk management from the beginning of innovation development in order to manage and reduce the uncertainties. Working hypothesis 3 can be phrased as an operating principle for innovation development: start the development phase with high uncertainty in many high level factors but launch with low uncertainty in all. Ideally the development phase should be started with low uncertainty; but, according to our experience, this desire is unrealistic for radical innovation development projects. An accompanying principle is that, for factors over which there is little or no direct control, interpret high uncertainty (without mitigation of potential negative consequences) as an indication that “it is not the right time for this project. A “not right time” result suggests either stopping development or putting development on hold and actively monitoring one or more signposts. For factors over which there is significant direct control, uncertainty management actions should be executed. If uncertainty is not reduced by the actions, development work should stop.

Conclusions

We have presented a framework for decision support for the innovation process, especially for radical innovation development projects surrounded by high level of multiple dimensions of uncertainty. In the framework, we have integrated fast risk-reward estimation foresight techniques with high level risk management techniques to produce inexpensive qualitative filters for the design and development phases, and suggested the addition of increasingly expensive quantitative techniques toward the end of the development phase, especially for exploring competition and market issues. Furthermore, we have proposed the novel idea of putting plans on hold and actively monitoring signposts with consequent improvement in right timing of market launch.
We believe that our systematic strategic decision support framework will assist managers in their decision making, by supplying systematic answers to the following questions throughout the radical innovation development process:

- How do we conserve the intellectual capital represented by partially developed ideas and visions.
- How do we avoid launching a new innovation either too early or too late?
- How much time and effort should be invested in early idea filtration and how much time in decision support for ideas that are progressing through development toward commercialization?
- How do we manage uncertainty during development?
- How do we maintain a steady pipeline of innovation?

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