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Integrating future-oriented technology analysis and risk assessment methodologies

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ABSTRACT

This paper examines the potential of integrating future-oriented technology analysis (FTA) with risk assessment methodologies and tools, with the aim of developing more proactive risk assessments and also systematically including risk assessment in future-oriented technology analysis. The similarities and development challenges of foresight, Technology Analysis (TA) and risk assessment methodologies are discussed in the light of the empirical material gathered from projects performed at VTT. Among the projects are IRRIIS project focusing on risk assessment of critical infrastructures, INNORISK project aiming at managing opportunities, risk and uncertainties in new business creation and a project related to the climate change (CES). The case projects are positioned according to their important design dimensions (informative vs. instrumental outcomes; consensual vs. diverse future perspectives, extensive vs. exclusive stakeholder involvement, and autonomous vs. fixed management). The common and complementary features of FTA and risk assessment are discussed, suggesting new ways to evolve the modular design when integrating FTA and risk assessment methodologies and tools.

1. Introduction

The practices in foresight, technology assessment and industrial risk assessment processes are in many ways parallel. They all explore plausible forthcoming developments, evaluate their desirability, importance and acceptability, and consider the risks involved. The context, emphasis and time horizons of examination vary, however. For instance, risk assessment in the context of industrial process safety aims to predict the risk caused by a failure, deviation, malfunction or error in an industrial system or operation leading to unwanted consequences. The time horizon considered typically is a couple of years maximum, referring to the practice to revise the analysis every three to five years. In an ideal situation the risk analysis is performed continuously to check all appearing changes and situations. Foresight exercises, in turn, usually identify the possible future developments, driving forces, emerging technologies, barriers, threats and opportunities related to a broader socio-techno-economic system. The aim is to produce justified outlooks and proposals of future developments, typically reported as scenarios, visions, roadmaps and action recommendations. The time horizon varies from some five to fifty years, depending on the issues examined and the purpose of the foresight exercise. Technology assessment (TA) has ingredients of both of these approaches, the main emphasis being in balanced evaluation of the short- and long-term impacts of new technologies.

All these future-oriented approaches try to illustrate and manage the future in an explicit and systematic way by identifying, assessing, analysing, combining and interpreting existing data, information and expert opinions. Creating shared understandings among the stakeholders about the possible future developments is also important in each field; in risk assessment the focus has typically been in negative outcomes whereas in foresight exercises the positive developments like innovation possibilities has

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been emphasized. Hence, somehow the link between these two research traditions is in essence present, but in practice the researches, research projects and case studies have separated and are seldom linked. It is thus interesting to explore how these research traditions can contribute to each other. In particular, the aim of this paper is to examine the possibilities of integrating systematic risk assessment with interactive foresight and TA exercises by linking the methodological tools in a reasonable way.

The motivation of writing this paper is twofold: 1) VTT is striving for a more integrated approach in developing its FTA competences and services, and 2) there is a need to share the information with the international FTA community in order to further develop the ideas. The first issue is reflected in the new VTT organisation and its multidisciplinary technology foresight team, consisting of researchers with experience on foresight, technology assessment and risk assessment studies, as well as societal embedding of technological and social innovations. The multiple backgrounds of the team widen the knowledge base, but also increase the challenges of communication and cooperation.

Creating a wider knowledge base and learning across disciplines is, however, considered important in order to develop more proactive and systemic risk assessment that covers even new types of emerging risks (incl. risks related to new technologies and their introduction to the market). On the other hand, the development of foresight and technology assessment methodologies is expected to benefit from the experiences of the industrial risk assessment tradition: the increasingly complex world creates new types of risks that shouldn't be bypassed with the examination of future opportunities, creation of shared visions and assessment of desired impacts. Development of an integrated approach that combines the strengths of FTA and risk assessment traditions is not, however, a straightforward task to be carried out by the VTT foresight team only. Feedback from the international FTA community and cross-border cooperation is needed to direct the development efforts effectively, focusing on the most important issues. Opening up a fruitful dialogue among the FTA researchers and professionals facilitates also mutual learning across the FTA and risk assessment communities.

The paper builds on VTT experience in a variety of prospective risk assessment contexts (information-based infrastructures, new businesses, climate adaptation) and some recent methodological considerations of the VTT foresight team (especially modular foresight/risk assessment process design that allows flexible tailoring of the process for varying needs and objectives). Foresight and risk assessment activities are considered increasingly important throughout the R&D value chain, stressing the need for a flexible, integrative approach. The authors' involvement in technology assessments studies commissioned by the Parliament of Finland, development of proactive risk assessment methodologies for different corporate risk management purposes (identifying the vulnerability of corporate and process actions, managing the risks in occupational, industrial and environmental safety, managing business risks, etc.), and research on societal embedding of innovations and new technologies provide some further insights that contribute to the paper.

The paper examines the prerequisites of and the ways in which risk assessment and FTA methodologies and tools can be systematically integrated on the basis of the VTT experiences. It draws from the disciplines, research traditions and concrete projects the authors are familiar with. The increasing mutual understanding, and the better utilization of the partly overlapping, complementary competence and knowledge bases, are among the objectives of the exercise. For the purpose, the paper is structured as follows:

- o Section 2 discusses the main research traditions contributing to the paper.
- o Section 3 presents the concrete projects in the light of which the issues are illuminated, and positions these projects according to important foresight design dimensions.
- o Section 4 paves the way towards a modular and integrative approach by discussing the common and complementary features of risk assessment and FTA processes.
- o Section 5 points out preliminary conclusions and directions for further research.

2. Methods of FTA and risk assessment

2.1. The methods of future-oriented technology analysis

Future-oriented technology analysis (FTA) can be seen as a common umbrella term for technology foresight, technology forecasting and technology assessment [1]. As noted in Könnölä et al. [2], the gradual paradigm shift in the innovation research and policy from linear to systemic innovation models has challenged the conventional technocratic and technology oriented forecasting practices and called for new participatory and systemic foresight approaches [3]. Also the R&D functions are moving from the basic science and technology push driven innovation processes to the systemic innovations that emerge close to the market [4]. Consequently, the locus of foresight activities has tended to shift from the positivist and rationalist technology-focused approaches towards the recognition of broader concerns that encompass the entire innovation system, including its environmental, social and economic perspectives. The High Level Expert Group appointed by the European Commission crystallized these trends by defining foresight as follows [5]: “A systematic, participatory, future intelligence gathering and medium-to-long-term vision-building process aimed at present-day decisions and mobilising joint action”.

Eerola and Väyrynen [6], (see also [7]), describe foresight exercises with the help of the SECI model as dynamic shared knowledge creation processes that go repeatedly through externalisation, combination, internalisation and socialisation phases in a spiral way [8]. Parallel to the SECI model is the Social Learning Cycle (SLC) [40,41], which structures the information in three dimensional model (I-Space): concrete–abstract, undiffused–diffused and uncodified–codified. The SLC differentiates knowledge making, sense making and decision making as well as diffusion/acting on environment and interaction with other actors in real world.

Both the SECI and SLC model emphasize the shared knowledge making. Network building and participation in the foresight process provide an opportunity to affect the future developments and to create more desirable futures. Foresight is defined as a process involving iterative periods of open reflection, networking, consultation and discussion, leading to the joint refining of future visions [9]. Pre-foresight, recruitment, generation, action and renewal are mentioned as the phases of the foresight process [9]. The process starts with *the pre-foresight phase* where rationales and objectives, project team and methodology design are defined. *The recruitment phase* builds the network of experts, stakeholders and others meaningful to the process. This phase is ongoing during the whole process. *The generation phase* includes three main stages; exploration, analysis and anticipation. In the exploration stage, main issues, trends and drivers as well as key stakeholders' frames are explored. Analysis stage means studying how the context and main issues, trends and drivers influence one another, and synthesising knowledge. Anticipation considers previous analysis and aims at defining possible and/or desired futures. Methods like Delphi, SWOT analysis, benchmarking and expert panels are widely used in the generation phase to generate "new knowledge". In *the action phase*, technology roadmaps, backcasting, narrative scenarios and others are useful methods to disseminate the visions of the future. Finally, the *renewal phase* involves monitoring and evaluation in order to assess whether the foresight process has helped to achieve its objectives.

The nature of foresight methodologies varies from creative to the evidence based and from expertise to interaction based working methods. Fig. 1 illustrates this variety (known as "Popper's diamond") by, for instance, defining the scenario methods the most creative and literature review evidence based, while future workshops are interactive and expert panels more for addressing expert opinions. Popper [9] lists and describes 33 different foresight and assessment methods altogether.

A tentative systemic framework of the potential FTA methods by Saritas [10] is shown in Fig. 2; 'risk analysis' is mentioned in the 'analysis and selection' section of the framework. This will be further discussed in Section 2.2.

Joint Research Centre (JRC) and Institute of Prospective Technological Studies (IPTS) have launched a FOR-LEARN On-Line Foresight Guide developed during the project FOR-LEARN in 6th Framework Programme project of the European Commission. The guide introduces a methodological framework for foresight studies. According to the framework the following functions can be distinguished in a Foresight exercise [42]:

- Diagnosis: Understanding where we are…
- Prognosis: Foresighting what could happen…
- Prescription: Deciding what should be done…

Specific methods to fulfill specific functions are also illustrated in the guide, e.g. the diagnosis phase will apply environmental scanning and trend extrapolation, scenario building and Delphi method may serve the prognosis phase and the prescription phase utilizes the roadmapping, backasting, modelling or simulation methods [42].

Altogether, a substantial shift away from the fixed modelling and management towards more contingent and participatory approaches has taken place in all FTA areas. Possible and potential futures are examined by applying, for instance, scenario, backcasting or roadmapping methods. Among other methods and practices in the field are constructive technology assessment, discursive technology assessment, consensus conferences, brainstorming, expert workshops, Delphi questionnaires and expert

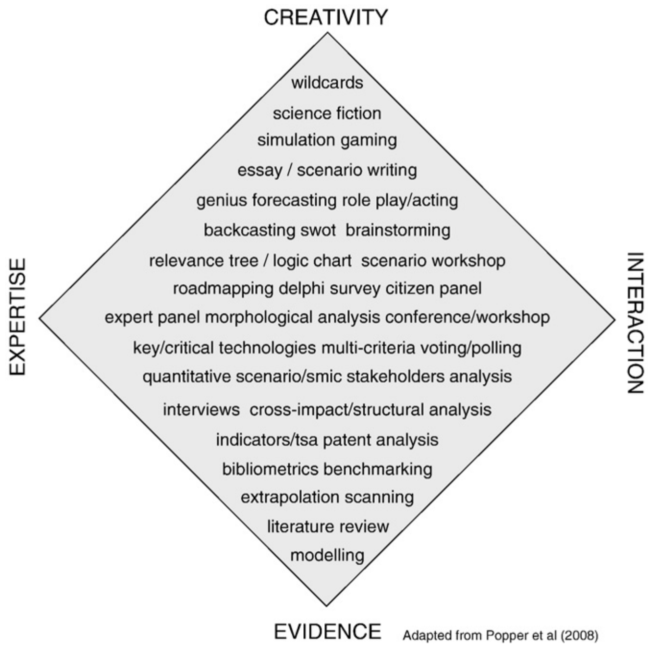

Fig. 1. "Popper's diamond" [9].

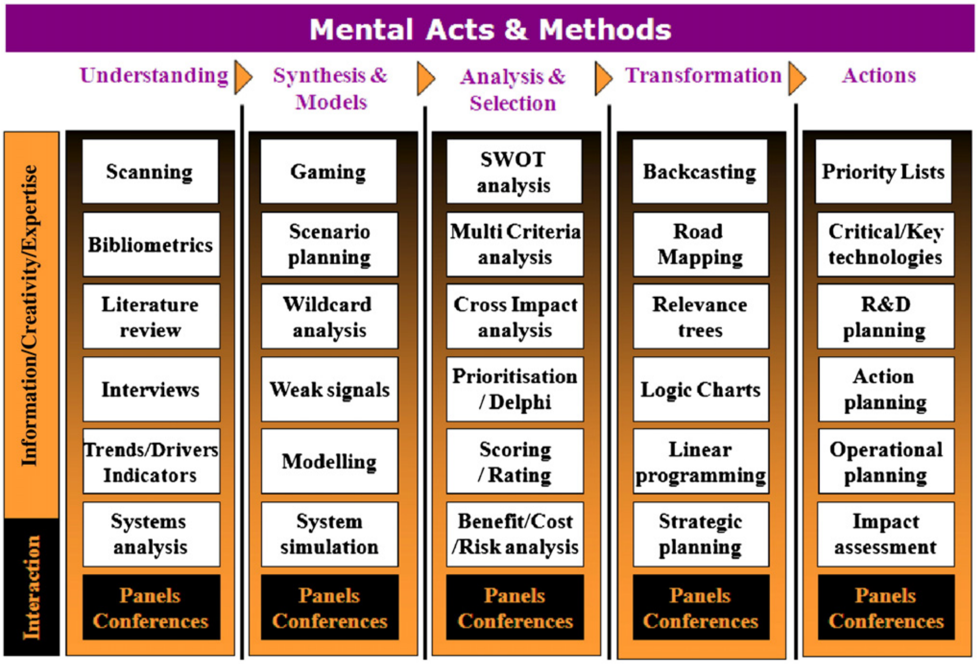

Fig. 2. A systemic framework for methods [10].

interviews. Megatrends and weak signals are also the crucial targets of the examination: they reveal important information and tell important stories about the world around us and how it may change the business or the environment around us.

A paradigm shift and interesting methodological developments are seen for Technology Assessment too: TA originally emerged to balance power between the legislative and executive branches of government,[1] but has increasingly moved towards providing useful knowledge for actively shaping technology. Consequently, concepts such as participatory technology assessment, constructive technology assessment, discursive TA, and consensus conferences have emerged, and both technology-driven and problem-driven approaches are taken [1]. It is also stressed that it is important to see technology as part of a whole technological and societal system [11]. The scope and context of the analysis, as well as the examination of the technology, its impacts and related policy, are all important in this respect. This means, for instance, studying whether the assessed technology does the job better than the previous methods, whether it fits into the company and/or the society, and whether it has impacts or side-effects. It is also crucial to study what the future might be, will the technology be usable and needed also in the future. Consideration of opinions, attitudes, fears, interests and hopes may then be as important as consideration of clear facts. The discussion and dialogue between people is thus considered important when analysing new technologies and the impacts of their market introduction. In this way TA can also play a more significant role in pushing the development in a useful or wanted direction.

2.2. Risk assessment methodologies in industrial safety

As noted in the previous Section 2.1, risk analysis is seen as one of the methods contributing to the FTA exercises. Weak signal and Wild Card analyses for instance are tools used in risk analyses concerning the strategic design of societies or companies, e.g. [43–45]. Risk assessment and risk management concepts can refer e.g. to risk assessment related to health risk, toxicology, ecology, food safety or industrial use [12], but also economical analysis. This section describes the methodological developments of risk assessment in the context of industrial safety, which we have chosen to be the risk assessment focus in this paper — an important area with the well-established and relatively long risk assessment tradition, and strongly linked to corporate decision making.

Development of safety and risk analysis in the industrial context stems from nuclear industry, civil and military aviation, and space technology in the 1960s [13]. These fields are renowned for their complicated systems, where possible accidents may have far-reaching consequences. During the 1970s, a world-wide trend of increasing accidental losses in factories was recognised [14]. Process industrial operations also became more complex and larger volumes of chemicals were used at higher pressures than previously. At the same time, there was a growing public awareness and concern regarding the threat to people and to the environment due to industrial activities. Various major accidents in the process industry in the 1970s (e.g. Flixborough, 1974; Seveso, 1976; see also [15]) provided the impetus for the development of novel loss prevention actions. The use of risk analysis became a common practice to evaluate the safety of processing, storing or transporting dangerous chemicals. A systematic and

[1] For instance, the TA studies carried out by the US Office of Technology (OTA) in 1974–1995 primarily served to inform Congress when technology-related legislative policy options were considered.

analytic way to assess and manage risks in a complex context was rapidly showing its success. The number of industrial accidents and the amount of losses started to decrease.

Currently, different safety management standards guide the implementation of industrial safety at the plant level, e.g. BS 8800 [16] and OHSAS 18001 [17], ISO guides [18,19] and IEC standard [20]. In addition, various risk analysis methods exist for different purposes in the process industry [21,22]. Tixier et al. [23], for instance, reported about 62 risk analysis methodologies. There are methods for mapping the hazards generally, and also methods for a very detailed analysis, such as index methods and strict quantitative modelling. Some methods are tailored to special risks, e.g. environmental risks [24]. Possibly the most frequently used risk analysis method in the world is Hazard and Operability (HAZOP) study which has also been standardised [25]. Potential problem analysis is also widely used. All the methods follow the general structure and demands of the technical risk analysis as defined in the standard IEC 60300-3-9 [20] (see Fig. 3).

The prerequisites for a successful risk assessment are:

- o data on the system being analysed and on all the associated substances,
- o operational model of the system under analysis,
- o systematic hazard identification procedure and risk estimation techniques, and
- o acceptability criteria.

A systematic risk analysis typically starts, after the data gathering, with the identification of hazards and the associated hazardous scenarios according to a specific procedure defined by the selected risk analysis method. If any hazardous scenarios are considered to result in serious consequences, they may be investigated further by applying a consequence analysis. A consequence analysis may consist of dispersion models and dose-exposure analyses.

Risk is defined as the combination of probability (frequency) and consequence of a certain scenario. Relevant probability data is seldom available, and as such, fully quantitative risk estimations are not normally performed in industry. Instead, semi-quantitative procedures are typically applied. Risk categories are defined according to consequence and probability ranges, and are generally represented in a matrix form. According to this estimation, the risks can be classified as catastrophic, major, severe, or minor [20], and prioritised. The risks are then assessed against the acceptability criteria, and the risk control measures are planned and applied based on this prioritisation.

It is recommended that the entire risk assessment procedure is done in brainstorming group sessions in which the participants are selected based on their relevant knowledge and experience of the industrial process. The pertinent literature and other kinds of external expert knowledge are also consulted as deemed necessary.

Traditionally, risks are identified and removed, and risk analysis methods are designed to be a tool of systematic risk identification process. In traditional methods, risks are identified component by component. In recent years the approach towards more comprehensive and holistic risk management has strengthened. Approaches like inherent safety [26] in process design as well as resilience engineering [27] in process operating address the complex nature of industrial process. It has been understood that process safety is not a creation of a component by component study. Instead, the whole process should be understood as a complex socio-technical system in order to make the process safe.

Resilience engineering tries to strengthen the intrinsic safety potential in complex systems in industrial safety. This approach has recently raised interest in the risk management field. Resilience engineering originates from the resilience thinking of ecosystem dynamics [38] implying that ecosystems must cope with continuous changes and constant evolution. As an analogy to

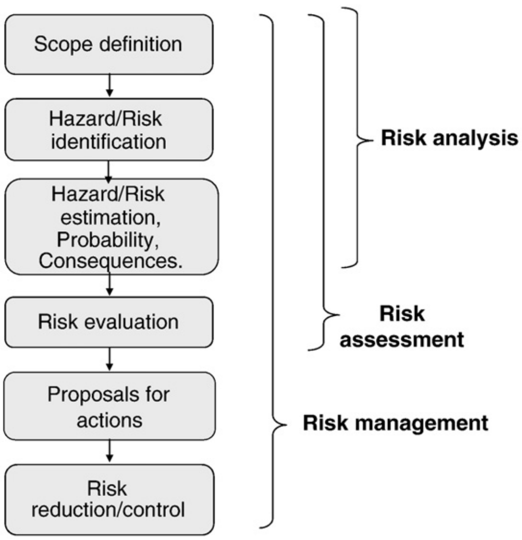

Fig. 3. The process of risk analysis, risk assessment and risk management [20].

the resilient ecosystem dynamics, the resilience engineering stands for an industrial process or organisation understood as an "ecosystem" under continuous change.

Instead of components, resilience engineering emphasises the meaning of practices, events and actions in the process [27]. A safe process is a process, which can handle and overcome errors and other kinds of irregular situations such that consequences are tolerable. In fact, errors and irregularities are very natural in any complex process [27]. The sociological approach to organisational management suggests that vulnerabilities are part of the natural logics of the corporate life [39], just as errors are a part of industrial processes. A sure system tolerates errors or failures and protects itself against the consequences of such events [39].

As in resilience engineering, the dominant "normative" safety/risk management strategy is replaced by a "natural" or "adaptive" strategy in the new paradigm of risk management. Risk management is based not on a striving for "perfection from the start" nor even on systematic surveillance of "deviances" for the purpose of correcting them, but on constant surveillance of the safety margins and levels of risks taken [39]. Hence, the risk management paradigm is changing towards a more holistic approach. The process safety is not considered component-by-component anymore, but rather as a complex socio-technical entity.

However, risk analysis methods have not fully followed the new direction yet; risk analysis methodologies still structure the risk assessment process mechanically. This systematic mechanistic way surely has benefits, which could also be applied in a more holistic approach. One new approach that widens the traditional field of risk assessment might open from the future-oriented, or foresighting, impact assessment (FIA) currently under development at VTT. In this methodology, the concept of risk is widened to consider the risks in the innovation processes may these be either intra-corporate R&D or highly distributed and networked processes. In FIA the risks are considered as emerging already in the innovation process, and cover such areas as investment, communication, trust and general development risks. FIA thus steers the risk assessment to a more anticipatory and proactive direction.

According to this new risk management paradigm, errors and failures are normal in industrial processes and the process management just has to cope with them. In fact, the process usually can manage the errors, because there is an intrinsic safety potential in the process performed by the equipments, personnel and organisation. Although this entire socio-technical complexity is addressed, the new safety approach does not, however, make traditional risk analysis methods useless. Risk analysis methods should still be used for creating safety into the process, namely by creating systematic working methods into the safety information gathering, analysing and understanding, as well as finding ways to mitigate risks and adapt to risks and their consequences. The next section illuminates the synergies between FTA and risk assessment methodologies by analysing the foresight design dimensions of three research projects.

3. Prospective projects illuminating possible synergies and development challenges

To study the integration of FTA and risk assessment some relevant projects were analysed. These projects are chosen based on the authors' knowledge, experiences and/or involvement in the projects. The results of this analysis are presented in the following section.

3.1. Integrated Risk Reduction of Information-based Infrastructure Systems (IRRIIS)

A case study of the use of foresight and scenario methods in a proactive risk assessment of telecommunication and electric power infrastructures was conducted in an EU funded project Integrated Risk Reduction of Information-based Infrastructure Systems (IRRIIS, research period 2006–2009). The aim was to study the possibilities of proactive risk assessment and management of critical infrastructures based on the integration of risk assessment and scenario development methods. The time frame of the study was the year 2015.

The study addresses that the more the scope of risk analysis is moving into a not-so-well-known field the more the risk identification becomes the crucial part of the process [28]. It is also emphasised that new market developments, technologies, threats and vulnerabilities are emerging and that they require proactive anticipation of the future worlds. Organisations have to consider alternative developments of influence factors, gain network thinking and action. They need to focus on strategic thinking and acting towards the future success and exclusively on the current success.

The process begun from very general phenomena of politics, society, economics and technology, applying big amount of creative brainstorming approaches ending to two potential scenarios. The results of the process showed that the created scenarios were too generic to apply the traditional (process safety) risk assessment methods when analysing them. This kind of scenarios cannot sufficiently be analysed by the currently available risk assessment methods, because these methods require more detailed knowledge of the target to be analysed: the process, the technology, people, the environment and so on should be known as fully as possible. The project states that a good modelling tool would help to model the future interdependencies supported by an integration of the scenario work and the systematic risk assessment.

3.2. Managing opportunities, risks and uncertainties related to new businesses (INNORISK)

The INNORISK project aims at creating new tools to manage the innovation process in order to take into consideration potential opportunities and risks. The project is ongoing, but preliminary results sound already promising, and show the fruitful link between the foresight and risk assessment methods.

The INNORISK — Managing opportunities, risks and uncertainties project is a 3-year (2006–2009) joint research project between the Corporate Foresight Group (CoFi) of Åbo Akademi Finland and VTT Technical Research Centre of Finland financed by the Finnish Funding Agency for Technology and Innovation (TEKES). In the INNORISK project the essential focus is on the opportunity recognition and management of future uncertainties and risks in companies that are giving rise to new business [29]. The objective of the INNORISK project is to develop tools and methods for companies in order to support the decision making related to introducing existing technologies into new markets, development of new technologies for existing markets, or creation of new technologies in new markets.

INNORISK project aims at applying *Back-pocket roadmap* [30] (also called Agile Roadmap), *SWOT analysis* [31,32] and *IBM's Signpost methodology* tools together with *Potential Problem/Opportunity (risk) Analysis* (PPA/POA, [33]) and *Risk Map methodology* [34]. All these methods are applied in an innovation process of a new product development. INNORISK project defines the innovation process to include three stages: opportunity recognition (the fuzzy front end), conceptualisation and commercialisation. Foresight and risk assessment are essential parts of each stage. Methods are developed together with the companies in three different case studies: a medium-size company offering control systems for high-tech companies, a medium-size technology company and a large-size technology company.[2]

The back-pocket roadmap starts by defining the state-of-the-art of the markets, the existing technology or know-how, and the existing offering in the markets, as well as the drivers and bottlenecks of the ongoing business in a defined time perspective [29]. The ultimate benefit of this relatively light and fast roadmapping exercise is that the process forces one to think about all the important aspects of the new business creation. SWOT analysis is then used to deepen the knowledge of strengths, opportunities, threats and weaknesses of the new innovation.

In INNORISK project PPA (Potential Problem Analysis) is seen as an example of a brainstorming method that can be used to explode the prevailing mind-set in the opportunity recognition and analysis [29]. PPA/POA applies silent brainstorming and keywords in stimulating the brainstorming process. A special Opportunity Balance Matrix (OBM) is developed in the project based on PPA/POA brainstorming [35]. The preliminary results of the project show that roadmapping and OBM are not alternative methods, but could be used as complementary methods. The link between the opportunity analysis and strategy works of a company becomes evident in the roadmapping process [29].

Risk map/risk taxonomy is used in the INNORISK approach as a link between the fuzzy front end and the commercialisation stages [36]. The risk map can be used like a checklist during the front end phase in order to identify critical factors affecting commercialisation as early as possible. INNORISK researchers also point out that risk management is not only about identifying and assessing risks and selecting risk reducing measures, but also about being able to respond quickly and effectively to realised threats as they arise.

The experiences of the method development in the INNORISK case companies have been positive. Dominating feature in all cases has been that the top management of the companies has been involved actively in the development processes. Active involvement of the decision makers in the analysis allowed them to have a broad and realistic image about opportunities and risks related to the new (potential) business. For instance three alternative futures were created for the opportunities in order to evaluate their business potential after 5–10 years in a medium-size company. One opportunity was selected for more thorough concept development including iterative steps of idea generation and enrichment, concept elaboration and business potential analysis. The criteria used forced to take into account various kinds of uncertainties and make actions in order to manage them. In the medium-size technology company a roadmap of the offering of the company in the future was done as a result of the method development.[3]

3.3. Climate change adaptation and risk assessment (CES)

A joint project concerning the climate change adaptation in Finland and in the Nordic countries is carried out at VTT, namely the Nordic Energy Research Climate and Energy Systems: Risks, Potential and Adaptation (CES, time frame 2007–2010). The project aims at assessing the development of the Nordic electricity system for the next 20–30 years. It will address how the conditions for production of renewable energy in the Nordic area might change due to global warming. It will focus on the potential production and the future safety of the production systems as well as on the related uncertainties. Risk assessment methods to evaluate the uncertainties and consequences of the climate change affecting the Nordic energy production system are developed in the project.

The risk assessment procedure is developed at the first stage of a case study concerning Nordic hydropower production [37]. The case study focuses on the hydropower plants in the Kemijoki region of northern Finland. A generic model of the risk assessment procedure, applicable within the Nordic countries, will initially be framed. The tools to apply the future-oriented risk assessment are developed during this process, and they are at this preliminary stage as follows: the general risk assessment procedure, guidelines for gathering the background information, the seasonal plan, risk identification model and risk/opportunity table, and a method for risk estimation and evaluation. The seasonal plan, for instance, aims at stimulating the risk identification process by listing the normal seasonal routines of the hydropower plant, e.g. spring floods or ice cover freezing over the river in the

[2] E-mail discussions with Pasi Valkokari in INNORISK project March 6th 2009.
[3] E-mail discussions with Pasi Valkokari in INNORISK project March 6th 2009.

autumn. Potential climate change effects are then added to the seasonal plan and changes to the normal seasonal routines can be noticed; the future is in that way linked to present situation.

Risk assessment procedure in CES is designed on the basis of brainstorming sessions between power plant operators and managers as well as climate change experts. Background information contains, for instance, the modelling of the changes in the river flows based on the climate change scenarios. All the identified risks and opportunities are mapped on the fourfold table, and these in turn guide the company on how to deal with the identified challenge: act, prepare or monitor.

Besides natural science kinds of changes climate change poses also social changes in the society. Political decisions are affected by the climate change. In the future, for instance, the need of energy and population migration may be different. Hence, it is also important that social aspects are addressed in the risk assessment procedure. Herein the foresight methodologies considering the possible changes in the society may be helpful.

A major challenge is, however, to be able to manage a multiplicity of the uncertain knowledge sources. Scientific knowledge concerning natural changes constitutes different scenarios of the future, and social knowledge can also be formulated into various scenarios depicting the potential futures. A strategy to handle this multiplicity requires selection. In the context of the Nordic hydropower production and distribution, for instance, the most threatening scenarios are selected for the risk estimation and evaluation process. Such scenarios may, for instance, concern the increased precipitation and flooding, which have political, ecological, social, technological and economical effects in society.

3.4. Positioning the projects according to some important dimensions

Könnölä et al. (forthcoming) propose a taxonomy of foresight activities at a contract research organisation like VTT (see the taxonomy framework in Fig. 4). The axes of the taxonomy are described in the Box 1. According to Könnölä et al. [2] most of the VTT's foresight activities position themselves to the consensual–diverse–informative axis (see Fig. 4). The case projects of this paper seem to position themselves into two diverse parts of the axes: consensual–instrumental section (IRRIIS, CES) and informative–diverse section (INNORISK). When examined from the methodological and participatory point of view, we can see that the IRRIIS and CES exercises were relatively fixed and exclusive expert processes, whereas more autonomous method management and broader participation were used in the INNORISK context.

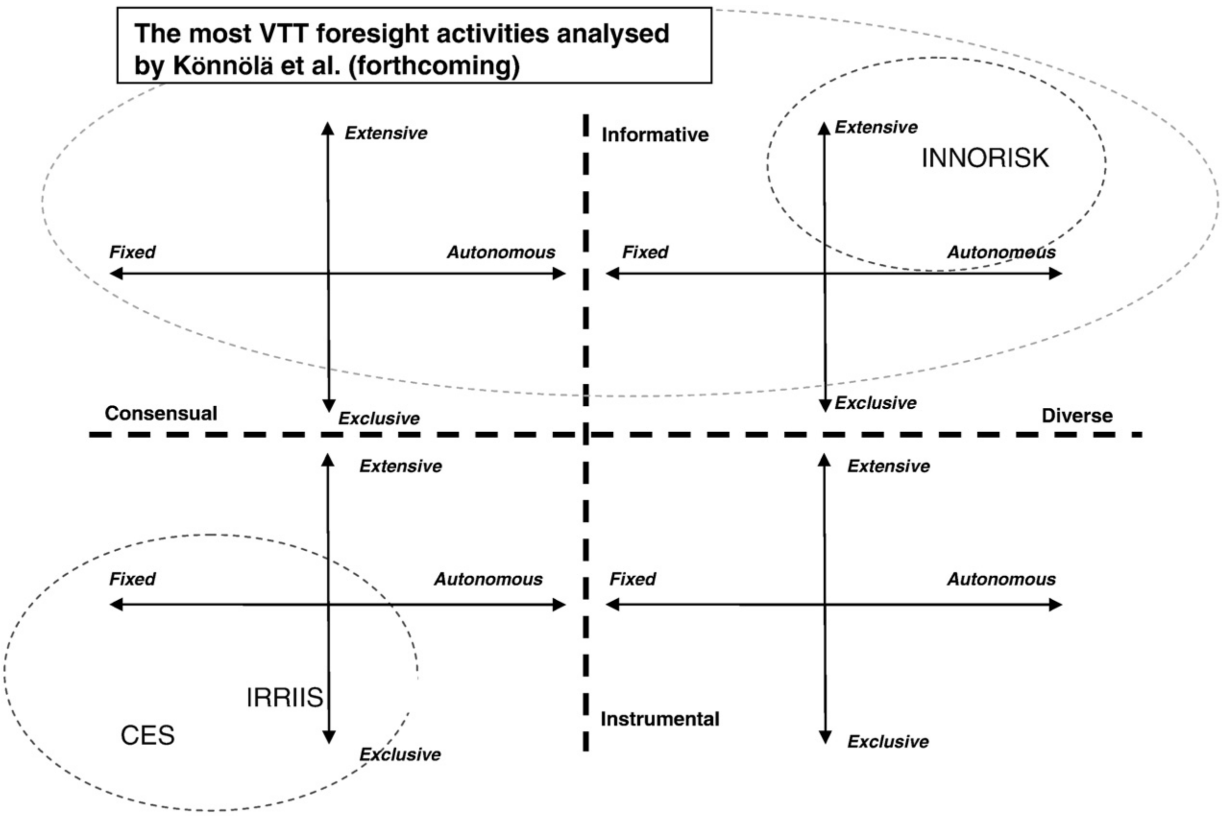

Fig. 4. Case projects positioned in view of the dimensions of outcomes (informative vs. instrumental), future perspectives (consensual vs. diverse) and in the coordinate system of stakeholder engagement (extensive vs. exclusive) and management (autonomous vs. fixed).

Box 1 [2].

- **Instrumental vs. informative outcomes**
  - ***Instrumental outcomes*** refer to the use of foresight to support the specific foreseen decision making situation, for example related to resource allocation or the formation of strategic partnerships/joint actions.
  - ***Informative outcomes*** refer to the use of foresight to improve the understanding of present and future challenges of the innovation system and its parts. Thus, the informative outcomes do not refer to the expectations that foresight activity would necessarily lead to specific actions.
- **Consensual vs. diverse future perspectives**
  - ***Consensual future perspectives*** refer to the creation of common understanding on priorities, relevant collaborative networks and future actions.
  - ***Diverse future perspectives*** refer to understanding diverse ideas, opinions and perspectives in priority-setting, identifying and fostering alternative and competing coalitions and value networks as well as exploring alternative futures and generating rivalling visions.
- **Fixed vs. autonomous management**
  - ***Fixed management*** can be characterised as centralised approach in which co-ordinators fix the scope and methods of the exercise at the outset and control the process, which is often the case for example in Delphi exercises.
  - ***Autonomous management***, in turn, refers to the process intermediated by the co-ordinators, who facilitate autonomous and evolving participant-led continuum of meetings and other activities, which maybe the case for example in expert panel work.
- **Extensive vs. Exclusive stakeholder engagement**
  - ***Extensive stakeholder engagement*** refers to the approach in which the actual number of participants is high, the stakeholder participation is encouraged and open for all the interested stakeholders and many kinds of stakeholders are invited to participate in the process.
  - ***Exclusive stakeholder engagement*** which means that stakeholder participation is limited and thus not open for all the stakeholders interested.

The positioning of the case projects in the Fig. 4 can be explained by the types of projects: CES project, for example, stresses the operational level risk assessment whereas the INNORISK project's starting point is corporate strategic decision making. On the operational level, fixed risk analysis methods are useful and dominate the analysis, while on the strategic decision making level the autonomous methods are convenient. The analysis of this small amount of project material indicates that systematic risk assessment methods tend to direct the analysis towards instrumental, consensual and exclusive analysis of the future. As resulted in the IRRIIS project, it is also challenging, and therefore not always productive, to apply systematic risk assessment methods together with more loosely formulated foresight approaches in order to illustrate the potentiality of the future and possible future risks.

The challenge of making a bridge between foresight and technical risk analysis methods lies perhaps mostly on people's experience of using different methods in these two parallel traditions. It is difficult to melt the experiences of the experts of different lines. Experts of their fields may not know deep enough the usage of the methods. For instance the multitude of the methods in both traditions may be difficult to see: risk analysis expert may know e.g. roadmapping method, but does not understand that it is the most usable only in the prescription phase of the foresight process. The same goes to the risk analysis methods: some methods are better in scanning the situation in the early stage of the risk assessment process and some other methods are better in analysing the case more detailed.

Cases are also in different scales, which tend to shift the method use into certain direction: abstract level strategic design goes towards foresight methods and concrete level case studies follow the technical risk assessment tradition.

4. Towards an integrated approach

4.1. Risk assessment and FTA process — seeking common ground

There are constitutive similarities between risk assessment and FTA processes. Both processes start with the scope definition/pre-foresight phases, where the scope and objectives of the analysis are defined. Recruitment phase of the FTA is also included in the scope definition phase in risk assessment, when possible and relevant experts and stakeholders are collected. The generation phase or the prognosis phase of the FTA process resembles the hazard/risk identification phase in risk assessment, especially in terms of methodological variety which is large in both approaches. Hazard/risk estimation and evaluation phases, in turn, are phases where identified risks are estimated and evaluated by modelling them either quantitatively, semi-quantitatively or qualitatively. The same kind of activity is happening in the FTA action phase. The ultimate meaning of this phase is to arrange the knowledge in such a form that it is easy to use in decision making. Also the action proposal and risk reduction/control phases share similarities to the practices and activities in the FTA action or prescription phase. The last phase of the FTA process — namely the renewal phase — is also present in the risk assessment process, but it is not normally expressed in engineer-style descriptions as in

Fig. 1. However, the normal monitoring and evaluation actions are conducted in order to find out the relevance and accuracy of the analysis.

The foresight process as well as the risk assessment process is a knowledge making process. SECI and SLC models give foresight and risk analysis studies a common theoretical ground. Both models organise the knowledge making in three dimensional space generating the knowledge from personal and proprietary to common sense and public, from tacit to explicit knowledge through sense making and field building, dialogue and interaction. The core idea is to share the knowledge and create in that way developed knowledge which is more than the sum of its elements.

In the method scale the common ground is seen in the multitude of the methods and in the hierarchy of methods: scanning or mapping like methods are used in the early phases of the foresight or risk analysis processes and more detailed analysis are applied in the later phases.

In practice it seems that wild card and weak signal analysis are very near to risk analysis ideology. Wild cards and weak signals can be compared to early warnings or near miss situations in industrial safety. One core idea in risk management is to find out early warning signals and near miss situations and learn lessons from them in order to avoid accidents to happen. The same idea goes to foresight exercises where wild cards and weak signals reveal the potential future or give tips for the future.

4.2. Contingent and holistic processes

Foresight activities and methodologies may have benefits that will support the risk analysis methods and activities in the development towards a more holistic approach. This development is especially needed to manage the new emerging risks, such as those that nanotechnologies, population aging, or climate change will pose to the society. In addition, business, policy making and the whole broad spectrum of decision making call for future-oriented technology analysis as well as risk assessment. Foresight methods and activities approve the uncertainty linked to the different futures and take also the different pathways to the possible futures. The weaknesses, threats, opportunities and strengths of the different futures are identified and ways how to cope and/or exploit these potentials are identified.

The core benefit of risk assessment methods is absolutely the strict systemic character of the risk analysis techniques. Although the somehow vague character is needed in the foresight exercises seeking for the unknown future, foresight studies may also benefit the systemic process common to the risk analysis processes.

Risk assessment methods are traditionally fixed approaches, e.g. focused on a certain industrial plant or specific chemical or event (Fig. 5). They typically are short-term studies, maximum time period being for instance the lifecycle of the industrial plant. Fig. 5 also shows that the assessment of new emerging risks demands longer time-frame and a more contingent examination approach.

The studies related to new emerging risks may be the core case studies where the integration of foresight and risk assessment traditions will be profitable — at least the integration process would be easiest to carry on in this environment, because emerging risks field is closest to the foresight exercises compared to the picture 5. To build the bridge between foresight and risk assessment traditions in emerging risk assessment would then help in applying the more contingent and holistic approach in more fixed and short time risk assessment exercises. Here the use of resilience engineering would certainly benefit from the traditions the foresight tradition would offer. Instead of scanning the risks in the future by studying the process component by component a more holistic viewpoint would be possible.

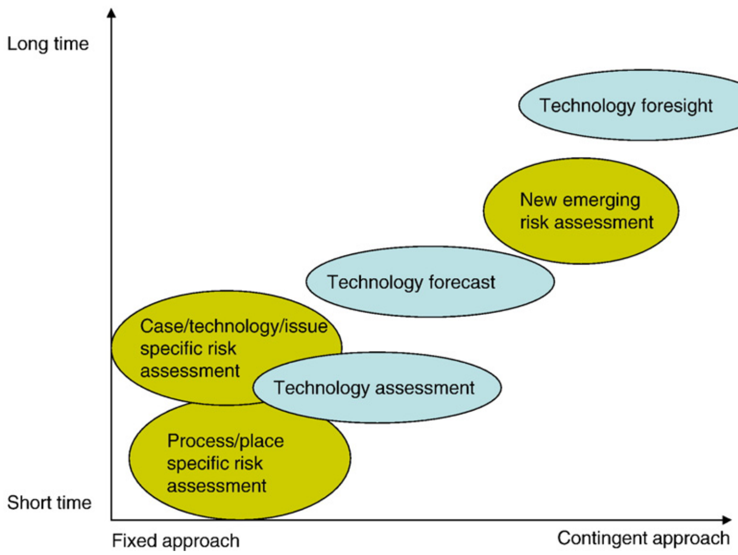

Fig. 5. The relationships between risk assessment and FTA methods according to the time frame and approach.

4.3. Lessons learned from the case projects

The basic lessons learned from the case projects are shown in Table 1.

The case projects of this paper (IRRIIS, INNORISK, and CES) show that it is not easy to integrate systematic risk assessment and foresight methods. In IRRIIS project the results show that risk assessment methods are too detailed for analysing loosely constructed scenarios. Risk assessment methods require detailed description of the analysis target, at least a plan. The future target, e.g. a scenario, may not have a sufficient level of detail. It was also noticed that both processes, FTA or risk assessment processes can be very detailed processes focusing on certain area or place, or they can be large scanning processes. For instance, scenario analysis may be just a little part of the whole foresight process and, therefore, conducting risk assessment only to the produced scenarios may be difficult. Another option may be to keep the risk assessment approach in the process during the whole foresight exercise.

In some way the technology assessment is close to risk assessment methods, but the scope might still be vaguer than in risk assessment processes in industrial applications. IRRIIS and CES especially reveal the gap between the future-oriented analysis and the technological system stressed risk assessment processes. In INNORISK project the challenge has somehow been easier, probably because the risk assessment methods applied have been in a more general and not so detailed level. For example, risk map methodology is more general than for instance the HAZOP method. However the case projects show that there is potential in integrating the risk assessment and the FTA methodologies.

In our view, the most promising benefit in integrating risk assessment and FTA approaches seems to be the aspect of creating safety and opening up new future possibilities. The holistic future-oriented technology assessment or foresight methodologies tend to assess and create the future simultaneously. The same idea belongs also to the holistic risk management where safety is created in the process by evolving the intrinsic safety potential of the process. In both technology and risk assessment this is made by changing mindsets, building trust among actors and developing better preparedness for the change, which is constantly present.

The second benefit may come from the participatory and networking approach of different expert analyses. Since future and risks are always ontologically unknown to us, there exist no facts about the future and risks are always contingent. Therefore, we are forced to collect and construct the knowledge — create an understanding and share it — in networks of people. Futures and safe situations, or at least safety predispositions, are created by people. That is why network building is the crucial part of assessment processes and methodologies. We can cope with the uncertainty by collecting and creating the best possible knowledge of the future and risks, and being all the time aware of the possible threats and opportunities of the complex world, ready to mitigate the risk or to adapt to a changing situation, or take advantage of it.

5. Conclusions

This paper has compared the basic characteristics of FTA and risk assessment processes, and discussed the attempts to integrate these two approaches. As a result, it has been discovered that both approaches seek to manage the uncertainty of potential futures, and to create knowledge to help decision making in defining management strategies concerning the changes the future may cause. Information on changes in the environment, in business and in the society in general is crucial for both FTA and risk assessment. There is, therefore, a common ground shared by both approaches.

Common ground is found also methodologically; models, workshops, brainstorms, interviews, literature reviews and other such methods are used in both approaches. However, risk assessments utilize more systematic and standardised methods, especially in risk identification phase. Risk assessment process requires also a more detailed description of the target of the analysis

Table 1
The lessons learned from the case projects.

Project/questions	IRRIIS	INNORISK	CES
How case studies contributed to risk analysis methodology?	Scenarios should be as accurate as possible in order to be able to be processed by risk analysis techniques.	PPA/POA and risk map methods were applied in a foresight process.	A new risk analysis framework was created.
How case studies contributed to risk assessment methodologies?	A good modelling tool would be helpful to model the future interdependencies.	Roadmap, SWOT analysis and Signpost foresight methods were integrated in the risk assessment process.	Risk analysis methods and climate change scenarios were integrated.
How case studies contributed to risk management methodology?	The results show that the integration of proactive risk assessment and scenario methods is challenging.	The study showed that risk management is not just about identifying and assessing risks, but also about being able to respond quickly and effectively to the realised threats.	The new framework help companies to create climate change strategies.
How case studies contributed to risk resilience thinking?	Scenario building was based on large and vague trend analysis.	The innovation process was seen as a whole.	No contribution: the energy production process is noticed component by component.

Table 2
The main characteristics, differences, similarities and future expectations.

	Risk assessment (focus on the context of industrial safety)	Future-oriented technology analysis
Aim	• To identify and assess risks now and in the future. The risk is caused by a failure, deviation, malfunction or error in an industrial system or operation. • To create and arrange the knowledge about risks in order to help the corporate decision making.	• To identify possible future developments, driving forces, emerging technologies, barriers, threats and opportunities related to a broader socio-techno-economic system. • To arrange the knowledge in such a format that is easy to use in decision making.
Results	• A report where identified, assessed and classified risks are described: Risk = f(Probability, Consequences), the biggest risks are tried to be managed first.	• Outlooks, proposals of the future developments, scenarios, visions, roadmaps, action recommendations.
Time horizon	• 0–5 years	• 5–50 years
Phases	• Scope definition, risk identification, risk estimation (probability, consequences), risk evaluation	• The pre-foresight phase, the recruitment phase, the generation phase
Standards	• BS 8800, OHSAS 18001, ISO guides, IEC standards	• None existing, creative openness
Methods	• Hazop • Potential problem analysis • Index methods • Environmental risk analysis ➔ Totally over 60 reported risk analysis methods	• Delphi, SWOT analysis, benchmarking, expert panels (new knowledge creation) • Technology roadmaps, backcasting, narrative scenarios (visions of the future) • Constructive technology assessment, discursive technology assessment, consensus conferences, brainstorming, expert workshops and interviews
Development and future expectations of the approach	• New approaches like inherent safety and resilience engineering address the complex nature of industrial processes. • Process safety is not anymore seen purely as a creation of component by component study, but a socio-technical complex system also interacting with its environment and the whole society.	• The focus has shifted from positivist and rationalist technology-focused approaches towards broader concerns including the whole innovation process with its environmental, social and economic perspectives. • From fixed modelling and management towards more contingent and participatory approaches.

than the FTA process. In turn, there is a shift towards a more contingent approach also in risk assessment as is in FTA approach. Hence, fixed component by component way of doing the analysis may give place to other kinds of methods, which is more common nowadays, for instance, in FTA approach.

Either way, both approaches may benefit methodologically from each other in developing better methods for assessing the futures. For example, in case of emerging risks new methods applying the sufficient features of as well risk assessment as FTA approaches are welcome. The new approach future-oriented impact assessment (FIA) is also seen promising in integrating methodologically risk assessment into the whole innovation process. In Table 2 the characteristics and typical processes and methods of risk assessment and future-oriented technology analyses, as well as future expectations concerning their development, are summarised and compared.

In general FTA approach encourages to build new risk analysis techniques which are more capable of taken into consideration the longer time frames than have been common in risk analysis tradition before. Risk assessment and management will benefit from the FTA approach by gaining more holistic viewpoints.

Due to the need of developing more holistic risk management processes responding the continuous change, the future risk assessment shows up as a methodology that should increasingly adapt supplementary elements from many different approaches such as FTA. When the contribution of FTA is emphasized on revealing technological changes and their impacts in the future, the contribution from other areas is also needed. This may, for example, concern integration of theories of networks or organisational culture in risk management more solidly. In sum, cross-boundary thinking is not only required when forming a risk management team, but also when forming the methodology and tools for the use of these teams. These notions open many challenges where further studies may be beneficial. In practice to succeed to build the solid bridge between the foresight and risk analysis methods new case studies would be needed.

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