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Diversity in foresight: Insights from the fostering of innovation ideas

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Abstract

Foresight activities have often provided support for objectives such as priority-setting, networking and consensual vision-building. In this paper, we draw upon complementary evolutionary perspectives and discuss these objectives from the viewpoint of *diversity* which may be vital in contexts characterized by technological discontinuities and high uncertainties. We also argue that although the scanning of weak signals has been widely advocated in such contexts, the solicitation of ideas for prospective innovations may provide more focused, action-oriented, and comparable reflections of future developments. For the analysis of such ideas, we develop a collaborative foresight method *RPM Screening* which consists of phases for the generation, revision, multi-criteria evaluation, and portfolio analysis of innovation ideas. We also report experiences from a pilot project where this method was employed to enhance the work of the Foresight Forum of the Ministry of Trade and Industry in Finland. Encouraging results from this project and other recent applications suggest that *RPM Screening* can be helpful in foresight processes and the development of shared research agendas.

Keywords: Foresight; Innovation processes; Internet-based consultation; Multi-criteria decision analysis; Portfolio modeling; Path dependence

1. Introduction

In the 1980s, publicly funded foresight activities were largely seen as an instrument for assisting in the development of priorities for S&T resource allocation [1]. Later on, stakeholder participation and

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networking have been viewed as increasingly essential dimensions of foresight activities for 'wiring up' the innovation system [2]. Reports from recent participatory foresights, in turn, have emphasized the importance of common vision-building as a step towards the synchronization of the innovation system [3].

These overarching trends can be regarded as complementary dimensions of how foresight can strengthen the long-term performance activities of the innovation system. They are also reflected in the taxonomy of Barré [4] who distinguishes between objectives for (i) setting scientific and technological priorities, (ii) developing the connectivity and efficiency of the innovation system, and (iii) creating a shared awareness of future technologies. Yet, because these objectives tend to be inherently consensual, it is pertinent to draw upon evolutionary perspectives which recognize the historical accumulation of innovation capabilities (e.g., [5]). In particular, these complementary perspectives emphasize the importance of evolutionary flexibility and adaptability of innovation systems, especially in contexts characterized by technological discontinuities and high uncertainties. We therefore posit that a key issue in foresight activities for the fostering of innovation capabilities and activities is *diversity*; defined as the condition or quality of being diverse, different, or varied [6].

Diversity is likely to be crucial during the early development stages of innovation cycles characterized by multiple alternatives and dissimilar beliefs [5]. This notwithstanding, attempts to promote diversity need not resort to fragmental 'anything goes' approaches that would thwart the exploitation of economies of scale, for instance (e.g., [7]). Rather, they call for the explicit recognition of diverse perspectives on techno-institutional co-evolution and the purposeful formation of new coalitions with specific technological trajectories [8], with the aim of creating viable alternatives for existing dominant designs and also for escaping conditions of techno-institutional 'lock-in' [9–11]. Indeed, Grabher and Stark [12] observe that too dense or too extensive networks may decrease the adaptability of an economic system. This suggests that an adequate level of balance is desirable in the structuring of 'loosely coupled' networks.

The relevance of diversity for foresight objectives has important implications for methodological choices and management activities. For instance, the ability to anticipate alternative different futures may be enhanced by various dimensions of diversity, of which the open-ended consultation of different stakeholder groups and the analysis of variability in their statements are but two examples. Interestingly enough, consultation processes of this kind are integral to the methods for the scanning of weak signals which, however, tend to produce relatively unstructured pools of 'signals' [13,14]. Arguably, such processes can provide results that are more amenable to subsequent analyses if a narrower characterization is adopted in the definition of the relevant 'units of analysis', for instance by focusing on innovation ideas that can be viewed as reflections of weak signals. Also, because the resulting ideas can be contrasted more meaningfully than loosely defined 'signals', they can be subjected to systematic evaluations with regard to multiple perspectives [15].

In this paper, we develop a new foresight methodology *RPM Screening* which consists of distributed generation, mutual commenting, iterative revision, multi-criteria evaluation and portfolio analysis of innovation ideas. This method – which builds on the Robust Portfolio Modeling methodology [16] – responds to diversity considerations in that it engages different stakeholder groups, encourages them to submit ideas on prospective innovations, and explicates multiple perspectives in the evaluation and analysis of these ideas. We also report experiences from the use of this method in the Foresight Forum of the Finnish Ministry of Trade and Industry. In this Forum, *RPM Screening* was employed to support expert groups working on three themes i.e. (i) nutrigenomics, (ii) health care and social services and (iii) services for the provision of personal experiences. Parallel processes were conducted with postgraduate students in a course on decision analysis at the Helsinki University of Technology. Experiences from these processes suggest that *RPM Screening* can provide support for networking, vision-building and agenda-setting, particularly when used in conjunction with workshops and other face-to-face communication activities [17].

2. Diversity and foresight objectives

Several authors (e.g., [18–21]) emphasize the importance of diversity in innovation systems. Here, we employ diversity in reference to existing innovation activities as well as emerging innovation capabilities based on new technological options, visions, and value networks [8]. The diversity of technological options subsumes both physical technologies in the form of technological artifacts and infrastructures, as well as social technologies [22] such as routines, hierarchies, and institutions.

The relevance of diversity is apparent in view of path-dependent selection processes at different levels of the innovation system, including its organizational, sectoral, regional, national, and international dimensions. Both evolutionary and institutional economists (e.g., [5,23,24]) have identified dynamic path-dependent processes that are driven by the economies of increasing returns and institutional acculturation. These processes – which may lead to 'lock-ins' to existing production and social systems [9–11] – are often characterized by the emergence of standards, dominant designs, and practices which reduce uncertainties of later actions while creating stable expectations concerning the behavior of others. Such evolutionary perspectives are further amplified by the "bounded" or "procedural" rationality [25,26] and satisficing behavior of individuals (i.e., rules of behavior are changed only when they no longer lead to satisfactory outcomes [27]). At the organizational level, path-dependencies and satisficing behavior tend to strengthen the surveillance, mental, and power filters of information [28], thus gradually diminishing the organization's ability to identify signals of change.

While technological and institutional path-dependence may support the efficient exploitation of present resources [24], it can limit the range of technological options, visions and value networks, thus reducing innovation capabilities in the long term. Feldman and Audretsch [29], for example, report empirical evidence that specialized innovation activities within a narrow industry are less fertile than diverse activities across complementary economic activities and industries. Diversity is therefore likely to be particularly vital in times of discontinuous radical changes that replace existing components or entire systems and, at the same time, destroy old competences and create new value networks [8].

In more concrete terms, diversity can be linked to widely discussed foresight objectives (i.e., priority-setting, networking and common vision building) as follows:

- Priority-setting supports the identification of common future actions and the efficient allocation of resources [1] whereby attention is often given to the economies of scale (e.g., [7]). Yet, excessive prioritizing may decrease the diversity of options that challenge conventional approaches and dominant designs (e.g., [30]). This may increase the level of inertia within techno-institutional systems and cause them to become increasingly dependent on their historical paths due to the paucity of available alternatives [9–11,24,31]. In such settings, foresight needs to support the generation of ideas on new alternatives and recognize the full range of valid perspectives in priority-setting [32,33].

- Networking enhances the connectivity of the innovation system and can improve its performance [2,34]. However, excessive emphases on the strengthening of *existing* networks (e.g., [12]) and the optimization of their efficiency may create path-dependencies which, at the extreme, establish techno-institutional conditions that lock-out alternative technological options [10]. Thus, apart from strengthening existing networks, foresight should contribute to the creative restructuring and even the destruction of lock-in conditions by engaging different stakeholders in the proactive generation of rivaling visions [8]. Such activities can foster the emergence of competing coalitions based on different value networks and encourage the envisioning of different architectures, configurations, features and standards [35].
- Building a consensual vision of the future and its technologies reduces uncertainties and helps synchronize the strategies and joint actions of different stakeholders (e.g., [3]). Yet, the pursuit for a consensus on the most probable future and its technologies may lead to conservative and abstract results [33,36], to the effect that existing path-dependencies are further strengthened. Nor are general abstractions readily actionable, especially if responsibilities are not clearly identified [37]. The search for a consensual vision of the future should therefore be complemented with – or even be replaced by – the exploration of alternative futures and respective techno-institutional arrangements [8].

At the methodological level, emphases on priority-setting, strengthening of existing networks and common vision-building tend to be coupled with approaches that contribute more to convergence than the creation of diverse coalitions that reflect different technological trajectories [5], rivaling technological options, or disparate visions and value networks. Indeed, many foresight methods tend to solicit diverse viewpoints at the outsets [38] and then converge towards more consensual statements. In the Delphi-method (e.g., [39]), for example, the participants' individual statements are synthesized into collective estimates through an iterative process of feedback, reflection, and revision, whereby some of initial disparities among the participant's statements are lost.

3. Innovation ideas as reflections of weak signals

The attempt to accommodate diverse perspectives on the future is central to the methods for the scanning of weak signals [13,14,40]. Ansoff [28] defined weak signals as "imprecise early indications about impending significant events". Later on, this definition has been expanded to accommodate additional characteristics, such as *new*, *surprising*, *uncertain*, *irrational*, *not credible*, *difficult to track down*, *related to a substantial time lag before maturing and becoming mainstream* [13,14,41].

The above characterizations, however, are highly subjective, which is one of the reasons for why the scanning of weak signals may result in an extensive and elusive set of fragmental issues that are not amenable to systematic analyses. The absence of a shared interpretative framework, in particular, may make it difficult to see how the signals relate to one another, or what they signify to different stakeholders. In consequence, it may be helpful to adopt a more focused characterization by soliciting signals that convey ideas about future innovations instead of charting future-oriented statements with a less specific focus. Indeed, in his seminal discussion Ansoff [28] already stressed short descriptions of "issues" focused on opportunities and threats. Such issues have close parallels to mini-scenarios – or nodes of discussion – that portray alternative future paths [42].

The focus on innovation ideas is also aligned with the *systemic* and *action-oriented* nature of innovation processes:

- The systemic nature of innovations derives from the recognition that innovations emerge in the wider context of techno-institutional co-evolution [43] where the 'success' of an innovation is contingent on the complex interplay among the supply of S&T knowledge, industrial production and societal demand, among others [5]. Thus, because innovations (and innovation ideas) combine numerous such elements in various ways, they can manifest a much broader set of weak signals, albeit indirectly.
- The action-oriented nature of innovation makes it possible to ask under what conditions and in what ways envisaged innovation ideas can be best promoted; such an analysis can suggest yet other signals. Furthermore, action-oriented ideas may provide seeds for initiating systemic changes among fragmental decision-making entities [44].

Motivated by the above remarks, *RPM Screening* developed in this paper is based on the open-ended solicitation of ideas on prospective innovations that may reflect other, more loosely defined signals. Specifically, the solicitation of weak signals by recourse to innovation ideas may not cover all phenomena (in a direct sense), but helps obtain a pool of material consisting of comparable 'units of analysis' that can be meaningfully assessed with regard to multiple perspectives [15].

4. A foresight project with diverse perspectives

In mid-2004, the Ministry of Trade and Industry in Finland established a Foresight Forum which was conceived as an open-ended instrument for facilitating the generation, dissemination, and assimilation of information in support of innovation activities. Through this instrument – the second phase of which was started in Spring 2005 – the Ministry invited experts from several stakeholder groups to theme-specific expert groups, workshops and seminars. The theme groups were also supported through communication channels such as e-mail lists and a dedicated website.[3] These activities, it was hoped, would contribute to an enhanced understanding of technological, societal, and economic developments over the next 10 to 15 years, allowing the participants to act in recognition thereof in their respective organizations.

In co-operation with the Forum co-ordinator, we planned and facilitated a 6-month pilot project for supporting the three theme areas in the Forum, i.e., (i) nutrigenomics, (ii) health care and social services, and (iii) services for the provision of personal experiences. Specifically, our pilot project sought to (i) engage a larger number of participants in the theme area work, beyond the some 10–20 named participants who were closely involved in the work of each theme area, (ii) to develop a systematic foresight method for the scanning, elaboration, evaluation and analysis of weak signals in view of multiple perspectives; (iii) to deploy this method in each theme area and (iv) to disseminate the results to a wider audience. We also organized parallel processes on the same theme areas with about 60 postgraduate students in a course on decision analysis at the Helsinki University of Technology.

After 2 months into the project, the objectives of the pilot project were slightly adjusted, in recognition that responsiveness in foresight management may be warranted [17]. Instead of scanning across a broad spectrum of all sorts of weak signals, without additional clarification on what kinds of signals would be of interest to the Forum, it was deemed pertinent to focus on innovation ideas which, as we have argued

[3] Finnish Foresight Forum (in Finnish), www.ennakointifoorumi.fi.

above, can be regarded as indications of weak signals. Specifically, the participants were encouraged to submit *"concrete and context-specific ideas for innovations that (i) are related to the theme area (e.g., nutrigenomics), (ii) are new to the participant or have received insufficient attention in his/her opinion, (iii) may be related to technological discontinuities, (iv) are interesting in light of present observations, (v) may provide an opportunity for the development of an innovation (an applicable new technology, concept, method or practice) within 10–15 years, and (vi) may require collaboration among different actors."*

Internet-based decision support tools were employed extensively in the generation and evaluation of innovation ideas. This choice was made because the generation of diverse ideas in face-to-face meetings can be difficult and time-consuming for organizers and participants alike [17,45]. In contrast, Internet-based distributed work can provide efficient and systematic support for stakeholder participation while allowing for features such as anonymity and flexibility in terms of time and place [46]. Due to the limitations of the Internet as a platform for social interaction, however, the Internet-based process was run in connection with workshop meetings. The activities in the pilot project thus consisted of Internet-activities, based on *RPM Screening*, and subsequent face-to-face meetings among invited experts within each theme area. Because the novelty of the project lies in its methodological advances, we focus on the Internet-based activities and the use of RPM [16] in the analysis of innovation ideas.

4.1. Phases of the project

An Internet-based consultation process was carried out in each theme area with the aim of engaging diverse participants (e.g., developers, researchers, users, students) in the collaborative generation, revision and evaluation of innovation ideas. In each theme area about 50 participating experts were invited from the following stakeholder groups:

- industry ~10%,
- government ~40%
- research ~30%,
- commerce and non-governmental organizations ~10%, and
- technology entrepreneurs and investors ~10%.

In addition, about 60 postgraduate students were engaged in a parallel processes that were organized in conjunction with a course on decision analysis that Helsinki University of technology.

The above rationale for the selection of participants can be linked to Stirling's [47, p. 42] analysis of three interlined dimensions of diversity, i.e., *variety* (number of categories), *balance* (apportionment to categories) and *disparity* (differentness of categories). That is, the selected participants represented several stakeholder groups (variety), whereby an attempt was made to secure a sufficient number of participants from each (balance). The parallel processes with postgraduate students brought additional perspectives that clearly differed from those represented by the recognized experts (disparity).

For the Internet-based consultation process, a project website was set up for the purpose of soliciting ideas with the Opinions-Online© decision support tool. In the later phases, the evaluation results were analyzed with the RPM Solver© software tool [16]. The participation in all the processes was reasonably active, even though the theme 'services for the provision of personal experiences' suffered from the lack of participation, mainly because of the busy holiday season for tourism entrepreneurs at the time when the consultation process was organized. The participants' contributions in the different phases of the internet-

Table 1
Proposed innovation ideas in the Internet-based consultation process

Themes	Participants			Proposed innovation ideas
	Phase 1	Phase 2	Phase 3	
Services for the provision of personal experiences	2	–	–	6
Health care and social services	11	16	7	28
Nutrigenomics	7	2	4	12
Services for the provision of personal experiences (Students)	9	8	9	45
Health care and social services (Students)	8	7	8	41
Nutrigenomics (Students)	6	6	4	34
Total	43	39	32	166

based consultation process are summarized in Table 1. In each theme area, the process was consisted of the following four phases.

(i) Generation of innovation ideas

The Forum coordinator sent an e-mail to the invited participants, requesting them to read instructions on the project website and to submit 1–7 innovation ideas. It was estimated that the writing of innovation ideas (max. 250 words per idea) would take about 15–20 min. The website for submitting these ideas remained open for 2 weeks. The participants were able to add new ideas in several separate sessions.

(ii) Commenting and elaboration of ideas

In the second phase, the participants were invited to work with the help of two websites. The first website provided support for commenting other participants' ideas and for revising one's own ideas, while the second website made it possible to read the other participants' comments. These websites were open for 2 weeks, and the participants could visit them as often as they wanted to.

(iii) Evaluation with regard to multiple criteria

In the third phase, the participants were asked to evaluate proposed innovation ideas with regard to three criteria using the Likert scale 1–7: (i) *Novelty* — How new is the idea? (ii) *Feasibility* — How feasible is the idea? (iii) *Societal relevance* — How extensive and desirable impacts would the innovation lead to?

To keep the workload of participants at a reasonable level, the number of evaluation criteria was limited to three. The criteria were selected so that they would be meaningful for the evaluation of different ideas and comprehensive enough to cover diverse evaluation perspectives [15]. The participants could freely choose the ideas that they would evaluate, in order to ensure that the evaluation task would not call for an excessive effort: thus, we could expect that the evaluations would pertain to ideas the evaluators were most interested in. The evaluators were encouraged to augment their numerical statements with written comments and to provide suggestions for actions through which the ideas could be promoted.

(iv) Multi-criteria portfolio analysis

After the Internet-based participatory phases, the results were analyzed with RPM software tools,[4] in order to synthesize the participants' multi-criteria evaluations and to develop tentative priority-lists

[4] Robust Portfolio Modeling, www.rpm.tkk.fi.

consisting innovation ideas that seemed particularly interesting in view of these evaluations. The results of this analysis were then discussed in workshops for the three theme areas.

4.2. Diverse perspectives in the analysis

Following Ansoff's idea of weak signals, an innovation idea must be viewed as relevant by some participants if it is to be treated as a weak signal. However, if an idea receives consistent and extensive support, it is less surprising and possibly indicative of a trend-like phenomenon that is unlikely to be missed.

More formally, it is possible to outline archetypal categories by using the means and variances of the participants' evaluation ratings. When an idea has a high mean and low variance it is likely to reflect a trend; and when it has a very low mean (and hence low variance, too, because only positive scores are possible), it may be considered as noise. However, when an idea has a sufficiently high mean but a high variance, it may qualify as a weak signal, because it is strongly supported by some experts while others regard it as less relevant.

While the above discussion parallels the earlier literature on weak signals, our case was different because innovation ideas were evaluated with regard to not one but *three* criteria (novelty, feasibility, and societal relevance), resulting in six criterion-specific measures for each innovation idea (three means and three variances based on the participants' ratings on the three criteria). The explication of multiple criteria thus brought additional perspectives into the analysis; but it also raised the question of how the different criteria should be weighted: for example, innovation ideas that are not very novel may be societally relevant and therefore interesting.

Because it may be difficult to justify 'true' or precise criterion weights, it seems that analyses for identifying 'most interesting ideas' should accommodate different interpretations about what criterion weights are feasible. In consequence, we adopted the RPM methodology [16] in the analysis of innovation ideas, because this methodology explicitly admits incomplete information about criterion weights. Thus, apart from the consultation of multiple stakeholder groups, diverse perspectives could be brought into the analysis of innovation ideas not only by considering multiple criteria (means and variances of the participants' ratings), but also by incorporating different interpretations of how important the criteria were relative to each other.

4.3. Robust portfolio modeling

In its standard formulation, RPM [16] supports the selection of project portfolios in the presence of resource constraints and possibly incomplete information about (i) the relative importance of evaluation criteria and (ii) the projects' performance with regard to these criteria. In the Forum, the RPM methodology was employed by regarding innovation ideas as 'projects' and collections of ideas as project portfolios, respectively. The task of identifying subsets of most promising ideas for subsequent workshop discussions was thus modeled as a project portfolio selection problem with incomplete information about the relative importance of evaluation criteria.

In RPM, the overall value of each idea is expressed as the weighted average of its criterion-specific scores (i.e., evaluation ratings); moreover, the total value of a portfolio is obtained by summing the overall values for the ideas contained in it. The identification of 'most interesting' ideas (or projects) is based on the computation of non-dominated portfolios (i.e., portfolios such that there does not exist any other portfolio with a higher total value with regard to all feasible criterion weights). Thus, a key feature of RPM is that it provides measures for the attractiveness of individual ideas, based on analyses that are carried out at the portfolio level.

4.3.1. Formal development of RPM

In technical terms, the portfolio selection problem can be formalized as follows. Let $X=\{x^1,\ldots,x^m\}$ denote the m ideas that are to be evaluated with regard to n criteria. The score of the jth idea with regard to the ith criterion is $v_i^j \geq 0$, while w_i denotes the relative importance of the ith criterion. Following the usual convention in multi-criteria decision analysis, the components of a feasible weight vector $w=\{w_1 \ldots w_n\}$ are non-negative and add up to one so that they belong to the set $S = \left\{w \middle| \sum_{i=1}^{n} w_i = 1,\ w_i \geq 0\right\}$.

The overall score of the jth idea can now be defined as the weighted sum of its scores

$$V(x^j, w) = \sum_{i=1}^{n} w_i v_i^j.$$

A portfolio is a subset of all ideas X (i.e., $p \subset X$). The total value of a portfolio p of ideas can be obtained by summing the overall scores of the ideas in it, that is

$$V(p, w) = \sum_{x^j \in p} V(x^j, w) = \sum_{x_j \in p} \left(\sum_{i=1}^{n} w_i v_i^j \right).$$

In the Foresight Forum, we sought to identify subsets of most interesting innovation ideas, whereby the resource constraint was derived from the question of how many ideas from each theme area could be taken forward for further work. This requirement corresponds to the observation that if no more than $R<m$ ideas can be taken forward, only portfolios with at most R projects are feasible. The set of feasible portfolios is therefore $P_F=\{p \| p| \leq R\}$ where $|p|$ denoted the number of ideas in portfolio p.

The corresponding optimization problems can be formulated with the help of integer variables z_j such that z_j equals one if the idea x^j is in the selected portfolio and zero if this is not the case, i.e.,

$$z_j = \begin{cases} 1, \textit{if}\ x^j \in p \\ 0, \textit{if}\ x^j \notin p \end{cases}.$$

Multiplying the overall value $V(x^j,w)$ for each idea by the corresponding integer variable z_j, the total portfolio value is equal to the sum $\sum_{j=1}^{m} z_j \left(\sum_{i=1}^{n} w_i v_i^j \right)$. When the feasibility constraint $\sum_{j=1}^{m} z_j \leq R$ is also accounted for, it follows that for a given weight vector $w=\{w_1 \ldots w_n\}$, the portfolio with the maximum total value is obtained as a solution to the problem

$$\max_{z_1 \ldots z_m} \sum_{j=1}^{m} z_j \left(\sum_{i=1}^{n} w_i v_i^j \right)$$

$$\sum_{j=1}^{m} z_j \leq R$$

$$z_j \in \{0, 1\}\ \forall\ 1 \leq j \leq m.$$

In the presence of incomplete weight information, feasible weight vectors belong to the set $S_w \subset S$ which is defined by preference statements about the relative importance of the criteria. Moreover, portfolio p dominates portfolio p', denoted by $p \succ p'$, if and only if (i) the total value of p is higher than or equal to that of p' for all feasible criterion weights $w \in S_w$ and (ii) its value is strictly higher for some feasible weight vector $w \in S_w$ (i.e., $p \succ p' \Leftrightarrow [V(p,w) \geq V(p',w) \forall w \in S_w \wedge \exists w' \in S_w$ such that $V(p,w') > V(p',w')]$). The set of non-dominated portfolios P_N consists of those portfolios for which there is no other feasible portfolio with a higher total overall value for all feasible criterion weights (i.e., $P_N = \{p \in P_F | \neg(p' \succ p) \forall p' \in P_F\}$).

Information about the desirability of an innovation idea can be provided by examining in how many non-dominated portfolios it is contained. This information is conveyed by the Core Index $\mathrm{CI}(x) = \{p \in P_N | x \in p\} / |P_N|$, defined as the ratio between (i) the number of the non-dominated portfolios that the idea belongs to and (ii) the total number of non-dominated portfolios. Thus, if an idea belongs to all non-dominated portfolios, it has a Core Index 100%; conversely, if it does not belong to any non-dominated portfolios, it has a Core Index 0%. Ideas with a Core Index 100% merit further scrutiny, since they would, in view of the given evaluation scores, belong to the optimal portfolio of innovation ideas even if further information about the relative importance of criteria were obtained. Likewise, ideas with a Core Index 0% can be disregarded, because they would not belong to the optimal portfolio even if additional information was obtained.

4.3.2. Complementary approaches for screening innovation ideas

Early on in the pilot project, we anticipated that the participants in each theme area would generate about 50 ideas, of which some 15–20 (approximately one-third) could be taken forward due to time constraints and the need to focus on the potentially most promising ideas. The size of feasible portfolios was therefore constrained by placing an upper bound $R \approx m/3$ on the number of ideas in feasible portfolios.

In the screening of innovation ideas, Core Indexes were used as an indicative measure of how interesting the ideas were in view of the participants' statements. But since the variability of the participants' ratings can be of considerable interest, too, two complementary approaches were developed building on different notions of what 'most interesting' can mean:

1. The *consensus-oriented approach* helped identify ideas that performed rather well with regard to all criteria, in view of their criterion-specific means and incomplete information about the relative importance of these mean values.
2. The *dissensus-oriented approach* served to highlight ideas on which the participants held different viewpoints, as measured by the variability criteria based on criterion-specific variances.

We now formulate these two approaches in more detail. The weights of the ith mean and variance criterion are denoted by w_i^A and w_i^V, respectively, and the criterion-specific means and variances of the participants' ratings for the jth idea are denoted by $\bar{a}_{ij}$ and σ_{ij}^2.

Consensus-oriented approach: Maximize criterion-specific means

$$\max_{z_1 \ldots z_m} \sum_{j=1}^{m} z_j \left(\sum_{i=1}^{n} w_i \bar{a}_{ij} \right)$$
$$\sum_{j=1}^{m} z_j \leq R$$
$$z_j \in \{0,1\} \ \forall \ 1 \leq j \leq m$$

Dissensus-oriented approach: Maximize criterion-specific means and variances

$$\max_{z_j \ldots z_m} \sum_{j=1}^{m} z_j \left(\left(\sum_{i=1}^{n} w_i^{\mathrm{A}} \bar{a}_{ij} \right) + \left(\sum_{i=1}^{n} w_i^{\mathrm{V}} \sigma_{ij}^2 \right) \right)$$

$$\sum_{j=1}^{m} z_j \leq R$$

$$z_j \in \{0,1\} \forall 1 \leq j \leq m$$

The consensus-oriented approach helps identify innovation ideas that, on the average, perform consistently rather well in view of the participants' ratings across all the criteria. The approach is therefore suitable for promoting ideas about which there is a reasonably high degree of consensus among the participants. However, because one of the objectives of the Forum was to explore how the participants' perspectives differed, the dissensus-oriented approach was of considerable interest. Apart from piloting these two approaches, we carried out additional analyses to identify innovation ideas that performed particularly well on selected perspectives (criteria). This was achieved by carrying out analyses with regard to selected subsets of criteria, and by putting constraints on the feasible weight set $S_w \subset S$: for example, the statement that the ith criterion was more important than the jth criterion corresponded to the constraint $w_i > w_j$.

For every idea, the means and variances of the participants' ratings for each criterion were calculated; this resulted in six different scores for an idea. These scores were employed in subsequent analyses, as illustrated by the following examples of consensus and dissensus approaches, as well as additional examples based on the use of two criteria only. The legend for indices is as follows: Novelty = 1, Feasibility = 2, Societal relevance = 3 (e.g., w_1^{A} is the weight associated with the mean of participants' novelty ratings, w_2^{A} is the weight associated with the variance of feasibility ratings).

(i) Analysis with consensus-oriented approach

Innovation ideas were analyzed by maximizing criterion specific means of innovation ideas. All the criteria were considered equally important. Thus, the set of feasible criterion weights was

$$S_w = \left\{ w \,\middle|\, \sum_{i=1}^{3} w_i^{\mathrm{A}} = 1, w_i^{\mathrm{A}} \geq 0 \right\}.$$

(ii) Analysis with dissensus-oriented approach

In the dissensus-oriented approach, attention was given to the variability in the participants' ratings, within the aim of identifying ideas about which they held different perceptions. Towards this end, variance scores were regarded more important than the respective means for all criteria; moreover, novelty was considered more important than feasibility which, in turn, was considered more important than societal relevance. To ensure the relevance of all criteria (in terms of attaining a strictly positive weight), the weight of each criterion was constrained from below by the lower bound 1/36 (i.e., one sixth of the average component of a feasible weight vector):

$$S_w = \left\{ w \,\middle|\, \sum_{i=1}^{3} \left(w_i^{\mathrm{A}} + w_i^{\mathrm{V}} \right) = 1, w_i^{\mathrm{A}} \geq 0, w_i^{\mathrm{V}} \geq 0, w_i^{\mathrm{V}} \geq w_{i'}^{\mathrm{A}} \text{ and } w_1^{\mathrm{A}} \geq w_2^{\mathrm{A}} \geq w_3^{\mathrm{A}}, w_i^{\mathrm{A}}, w_i^{\mathrm{V}} \geq \frac{1}{36} \right\}.$$

(iii) Analyses with specific criteria

We also explored alternative ways of combining consensus and dissensus approaches through additional analyses based on different weight constraints on the mean and variance criteria. In the first of these analyses, only variance criteria were accounted for, without additional statements about which variances were more important than others. Second, attention was given to the novelty and feasibility only, whereby novelty was treated as the more important one while variances were considered more important than means. Third, the same analysis was carried out in view of novelty and societal relevance, with societal relevance replacing the role of feasibility in the second analysis:

1. Maximize variances: $S_w = \left\{ w \middle| \sum_{i=1}^{3} w_i^{\mathrm{V}} = 1, w_i^{\mathrm{V}} \geq 0 \right\}$
2. Maximize novelty and feasibility: $S_w = \left\{ w | w_1^{\mathrm{A}} + w_1^{\mathrm{V}} + w_2^{\mathrm{A}} + w_2^{\mathrm{V}} = 1, w_i^{\mathrm{V}} \geq w_{i'}^{\mathrm{A}} \right\}$
3. Maximize novelty and societal relevance: $S_w = \left\{ w | w_1^{\mathrm{A}} + w_1^{\mathrm{V}} + w_3^{\mathrm{A}} + w_3^{\mathrm{V}} = 1, w_i^{\mathrm{V}} \geq w_{i'}^{\mathrm{A}} \right\}$

There three latter analyses were conducted in an experimental fashion, in order to check if additional innovation ideas would come to fore apart from the ones that were contained in the priority-lists resulting from the consensus and dissensus approaches described above.

4.4. Selected results

Overall, the pilot project produced 166 prospective innovation ideas of which many were quite promising: for example, several ideas were adopted into the Delphi-process of a regional foresight project. The ideas were also disseminated to enterprises, universities, research centers, ministries and regional development centers through websites, workshops and seminars. After the pilot project, all the innovation ideas were disseminated through an interactive Internet-based decision support tool *RPM Explorer©* which permits the participants to specify their own preferences about the relative important of the decision criteria and to obtain a corresponding priority-list of innovation ideas. This tool and all the results were made available on the website for the Foresight Forum.[5]

To illustrate RPM analyses, we consider the performance of two rather different ideas. Fig. 1 shows results for the “Health care and social services” by presenting the innovation ideas in a descending order according to their Core Indexes. Criterion-specific means and variances for chosen innovation ideas #18 and #23 are illustrated in Table 2. Idea #18 was concerned with the role of the third sector and voluntary organizations in the supply of health care services, while idea #23 proposed that the administrative linkage between the resident’s municipality and the right to health care in other municipalities should be eliminated.

With the *consensus approach*, idea #18 was the first with a Core Index of 100%, while idea #23 was 18th with a Core Index of 7%. However, with the *dissensus approach* – which emphasized the variability of the participants’ ratings – idea #18 was 14th with a Core Index of 26%, while idea #23 became first with a Core Index of 100%.

These differences were discussed by the workshop participants. They noted that idea #18 was clearly stated and suitable for implementation, while idea #23 was promising but more difficult to implement and

[5] The RPM Explorer is available at www.rpm.tkk.fi/explorer/, with user instructions at address www.rpm.tkk.fi/explorer/docs/rpm-explorer_instructions.pdf. Results from the pilot projects are available at www.rpm.tkk.fi/explorer/html/index_ennakointifoorumi.html (in Finnish).

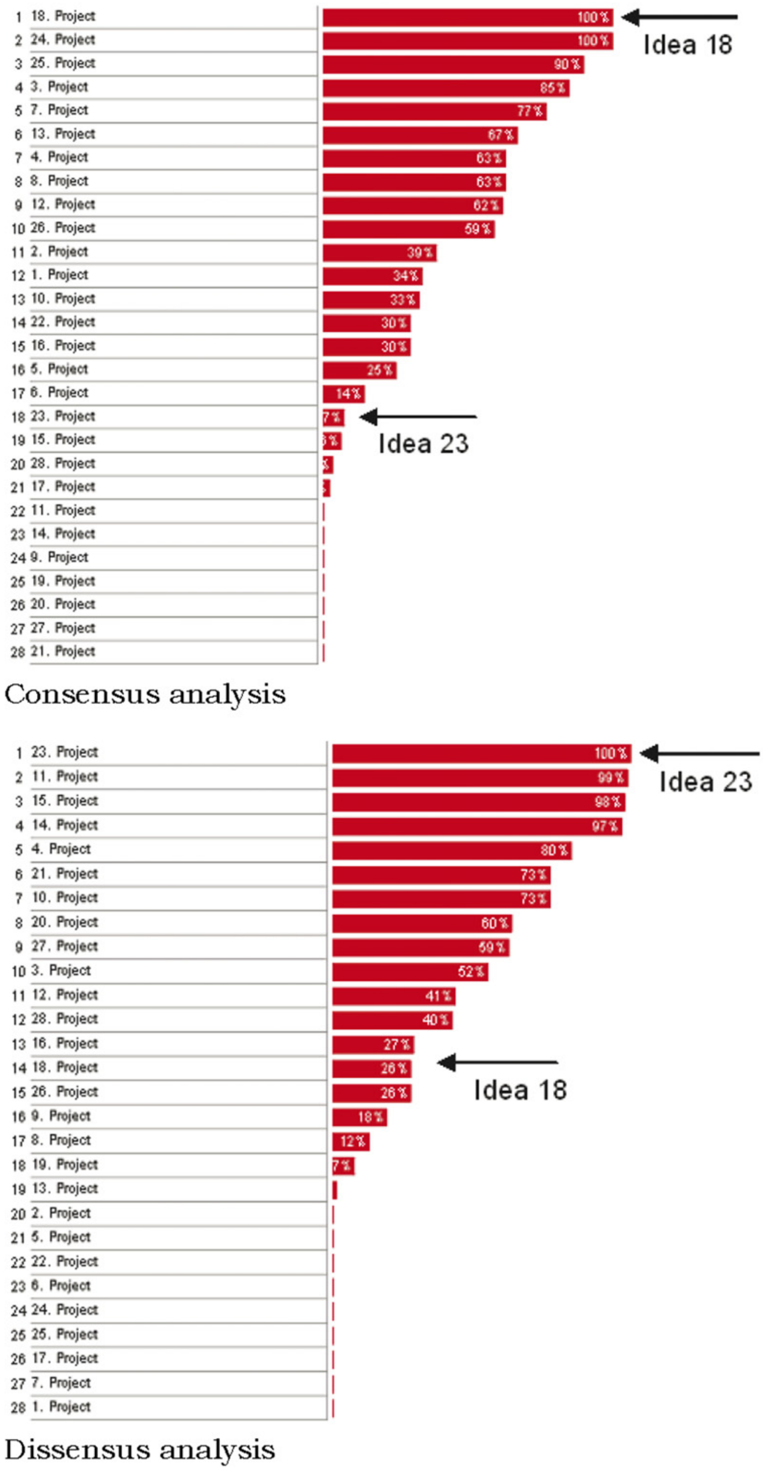

Fig. 1. Core indices of ideas within the theme “Health case and social services” with regard to consensus and dissensus analyses.

Table 2
Means and variances of the criterion specific evaluations of the innovation ideas 18 and 23 within the theme "Health case and social services"

Innovation idea	Mean scores			Variance scores		
	Novelty	Feasibility	Societal relevance	Novelty	Feasibility	Societal relevance
#18	4.00	4.86	5.29	2.29	0.41	0.20
#23	4.00	3.17	3.43	4.00	3.47	3.39

even controversial. The differences can also be understood in view of the score information in Table 2, as innovation idea #18 has a high mean especially on societal relevance and feasibility, but low variance scores for all criteria. On the other hand, the more controversial innovation idea #23 has moderate mean scores but high criterion-specific variance scores. Thus, if we emphasize mean criteria, innovation idea #18 will have a high Core Index; but if we account for the three variance criteria and state that (i) variances are more important than means and (ii) novelty is more important than societal relevance, idea #18 receives a rather low Core Index while idea #23 receives the highest possible Core Index of 100%. Thus, the analyses reflect the implications of criteria selections and weightings in an adequate and understandable manner, despite the rather different content of these innovation ideas. In general, the workshop participants noted that the Core Indexes were instructive and in keeping with the substantive content of proposed innovation ideas.

Further examples of proposed innovation ideas in the theme area "Health care and social services" included proposals for integrated portals which would serve as centralized information repositories; diagnostic tools which would allow the users to analyze their symptoms in the Internet; mobile messaging tools which would automatically remind patients to take their medications on time; low-intensive health care units where patients can stay in pleasant surroundings when they no longer need intensive care but cannot be sent from hospital to home; and regularly conducted preventive check-up visits to the elderly. In the theme area on "Nutrigenomics", the generation of innovation ideas resulted in proposals for computerized expert systems which would assist users in closely following personally tailored diets; development of additive substances to provoke enhanced resistance to bacterial attacks in unusual conditions (e.g., tourism); and systematic monitoring of ancestral diseases and living habits among young adults, in order to prevent or postpone the emergence of diseases such as diabetes.

In the theme area "ideas for "Services for personal experiences", the students were particularly productive in terms of generating innovation ideas. Examples with high Core Indexes included proposals for matching persons with similar interests to help them share their leisure time (e.g., theater evenings); taking delinquent youths to prisons for short voluntary visits (which might even preempt criminal behavior); using multimedia technologies for projecting famous paintings on the walls in one's home; organizing interactive games where the player would act as a detective; and developing virtual games where the participants could experience what world-class athletes really feel and see when performing exhilarating sports (e.g., ski jumping, gymnastics, pole vault). Innovation ideas with lower Core Indexes included proposals for making diving excursions to sunken shipwrecks; providing makeshift opportunities for young women to work as photo models; and developing Disneyland-like parks for young pre-school children. While these examples are not exhaustive, they are nevertheless indicative of the kinds of innovation ideas that they suggested. Moreover, many of the more interesting ideas were eagerly commented on by others, which helped establish a collaborative learning process concerning the perceived innovativeness, commercial viability and technological feasibility.

The results of the process were validated primarily through structured discussions in the final workshop that were organized at the end of pilot project in each theme area. In these discussions, the workshop participants noted that *RPM Screening* had been helpful, because it enriched the work of the Foresight Forum by bringing in relevant contributions from many more participants than what would have been possible without the use of Internet-based tools. The quality of innovation ideas was favorably evaluated, too, as many ideas were deemed not only interesting but even surprising and worthy of further development. Finally, the *RPM Screening* process was relatively easy to manage (because communication materials could be re-used across theme areas, for instance) and permitted various comparisons between the theme areas.

4.5. Comparison with other approaches

While the use of multi-criteria methods [32] and consideration of variability measures [28] have been proposed for foresight processes earlier on, *RPM Screening* is novel in that it combines these two aspects with the modeling of incomplete information and portfolio effects:

- *Multi-criteria portfolio analysis*: *RPM Screening* is a *portfolio* methodology for the generation of tentative priority-lists, in contrast to earlier uses of multi-criteria methods in contexts such as foresight processes (e.g., [32]), *ex ante* evaluation of innovation policies [48,49], and charting of stakeholders' value preferences [47]. In particular, portfolio analysis facilitates the development of priority-lists of desired length, because the number of innovation ideas in feasible portfolios can be defined *a priori*. One can also categorize innovation ideas in view of technologies or other characteristics and formulate constraints that pertain to these characteristics; this gives additional possibilities for managing the process of generating priority-lists that match predefined requirements (e.g., constraints such as 'at least 25% of innovation ideas must pertain to ICT services'). There are also interesting links to the use of multi-criteria analysis in efficiency evaluation (e.g., [50]) and RTD portfolio management (e.g., [51,52]).
- *Use of incomplete information: RPM Screening* admits different interpretations about the importance of criterion weights (e.g., [53]) and is therefore suitable for settings where complete information about the relative importance is difficult to acquire or justify. In the pilot project, for instance, results from five different RPM analyses could be presented based on different criteria and different interpretations about their relative importance. *RPM Screening* can also be linked to other forms of analysis, for instance by using incomplete information to subsume *all* the participants preferences as captured by 'multi-criteria mapping' (e.g., [47]), or to identify what ideas would by supported by the different stakeholder groups [54]. Overall, *RPM Screening* resembles preference programming approaches in that incomplete information is modeled through set inclusion and synthesized through dominance concepts and decision rules (e.g., [16,55,56]).
- *Consideration of variability measures*: The consideration of variability in the participants' ratings (by way of using variance criteria) is central to the methods for the scanning of weak signals [13,14,40]. *RPM Screening* differs from these approaches in that (i) it accounts for the variability measures that pertain to *multiple* criteria, and (ii) these variability measures can be flexibly *combined* with the additive model which has separate criteria for the participants' mean ratings. This makes it possible to

carry out consensus or dissensus oriented analyses, whereby the importance of individual criteria can be adjusted by constraining their weights.

- *Combination of distributed and face-to-face interaction*: *RPM Screening* combines several modes of interaction: for instance, results from Internet-based consultation process in the pilot projects were examined through interpretative and deliberative work in face-to-face workshops where overlaps, interactions, and synergies among innovation ideas could be examined. Such work is needed because the identification of interesting ideas is not merely about the examination of isolated ideas, but also a search for combinations (or portfolios) of ideas that should be promoted in conjunction (e.g., [57]). In these settings, multi-criteria methods hold considerable potential as communication tools [32], because they combine the acclaimed benefits of analytic and deliberative modes of work (see e.g. 'deliberative mapping', [58]).

The above considerations also suggest several ways of extending *RPM Screening*. For instance, the interests of stakeholder groups can be secured through portfolio constraints such that feasible portfolios must contain, say, at least a minimum but no more than a maximum number of innovation ideas proposed by the participants from these groups. If the process seeks to set a concrete agenda for the implementation of ideas, the participants can be asked for estimates about how much time and money would be needed to implement the ideas; when these estimates are employed in RPM analysis, the resulting priority-lists would fit within available budgets and time-frames. One can also introduce additional requirements by placing constraints on individual ideas (e.g., exclusion of ideas that do not meet pre-specified threshold levels on some criteria) or combinations of ideas (e.g., exclusion of mutually incompatible ideas). In general, *RPM Screening* is applicable in many other contexts where there is a need to develop indicative priority-lists from a large number of comparable 'units of analysis' that are evaluated with regard to multiple criteria.

5. Conclusion

Foresight activities have often sought to enhance the performance of innovation systems by emphasizing consensual priority-setting, networking and vision-building. But just as in the case of scenario work [59], the elaboration of controversial and even conflicting ideas can be vital in preparing for alternative futures. Drawing upon these two lines of thinking, we have argued that consensual foresight objectives and diversity considerations are complementary perspectives which are both needed in attempts to enhance the performance of innovation systems: for example, the implementation of S&T policies may call for a sufficient degree of consensus about appropriate policy instruments (e.g., RTD programs), while preparedness for the future can be promoted through the diversity of activities within such instruments (e.g., projects based on rivaling coalitions and different technological arrangements [35]). In this setting, the development of *RPM Screening* is motivated by both these perspectives which, in concrete terms, can be accounted for through the introduction of corresponding evaluation criteria and weight constraints.

Although developed in a pilot project that focused on innovation ideas, *RPM Screening* is readily applicable across many other contexts. In the European Forest-Based Sector Technology Platform, for example, we have employed it to help develop national priorities for the Strategic Research Agenda[6] which outlines how the future R&D roadmap for this sector is to be implemented [60]. In WoodWisdom-Net[7] –

[6] See www.forestplatform.org and www.sra.tkk.fi.

[7] See www.woodwisdom.net and www.woodwisdom.tkk.fi.

which is one of the ERA-NETs for building the European Research Area – we have supported analogous processes towards the development of an international research agenda that will be implemented through joint collaborative projects in the field of wood material science. Even more generally, the advancement of socially warranted technologies involves decisions that are complicated by high uncertainties, multiple objectives and numerous options, [61]. We contend that such decisions call for collaborative learning processes (e.g., 'horizons scanning' [62]) that can benefit from the deployment of systematic approaches such as *RPM Screening*.

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