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A methodology for the identification of prospective collaboration networks in international R&D programmes

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Abstract: The planning of publicly funded research and development programs can benefit from participatory foresight processes where research issues are evaluated with regard to multiple criteria. However, few approaches have been developed for the shaping of collaborative research networks through which the resulting priorities are implemented. We therefore develop a methodology for the *joint* shaping of thematic priorities and prospective collaborative networks. Our methodology helps identify networks that are aligned with the thematic priorities and consist of research groups with shared interests. The proposed PRM-Networking approach is demonstrated with a case study on the planning of a multi-national research program.

Keywords: multiple criteria decision analysis; project portfolio optimisation; collaborative network design; technology foresight; R&D programmes; networking; priority setting; ERA-NET; RPM; robust portfolio modelling.

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1 Introduction

Publicly funded R&D programmes are among key instruments for the implementation of national and international innovation policies (see e.g., Clark and Guy, 1998; Klaassen et al., 2005). In comparison with many other instruments of innovation policy (e.g., tax subsides, legislative measures), they are particularly suitable for channelling resources to research issues that are deemed important in view of societal and industrial needs (e.g., Salmenkaita and Salo, 2002). Partly for this reason, considerable attention has been devoted to the question of how foresight activities could be organised within R&D programmes to establish thematic priorities that reflect broader Science and Technology (S&T) priorities (e.g., Irvine and Martin, 1984; Salo and Salmenkaita, 2002). Moreover, the fostering of corresponding collaborative research networks has been an increasingly relevant objective in the implementation of R&D policies and R&D programmes (see e.g., Barré, 2002).

In international contexts, the preparation of policy instruments entails additional challenges due to the large number of horizontal and vertical interfaces that exist *between* and *within* national innovation systems (see e.g., Webster, 1999; Jewell, 2003; Keiser and Prange, 2004; Koschatzky and Sternberg, 2000). Indeed, as the number of prospective stakeholder groups grows, the diversity of the objectives and strategies that they pursue grows, too, implying that it may become increasingly difficult to synchronise them. Further considerations such as geographical dispersion of research units, as well as differences in organisational cultures, established routines, and administrative practices may impede the successful launching of collaboration activities (e.g., Camarinha-Matos and Afsarmanesh, 2007; Könnölä et al., 2008).

Attempts to improve the quality of decision-making processes have spurred the development of generic multi-criteria methods that can be deployed to determine priorities in various problem contexts, of which the preparation of R&D programmes is but one (see e.g., Henriksen and Traynor, 1999). A major benefit of these methods is that they offer a systematic framework within which future opportunities can be systematically addressed and brought to bear on the evaluation of potential research projects; this, in turn, is more likely to contribute to the transparency and coherence of strategy design and implementation (e.g., Salo et al., 2003). There are, in effect, many reports on case studies where multi-criteria methods such as the Analytic Hierarchy Process (AHP) (Saaty, 1980; Poh et al., 2001), Rank Inclusion in Criteria Hierarchies (RICH) (Salo and Punkka, 2005; Salo and Liesiö, 2006) and Robust Portfolio Modelling (RPM) (Liesiö et al., 2007, 2008; Könnölä et al., 2007, 2008) have been deployed to support priority setting within R&D policy instruments.

In contrast, far fewer case studies have been reported on the use of decision-support aids for the creation of new networks in publicly funded R&D programmes (e.g., Hellström et al., 2001; Camarinha-Matos and Afsarmanesh, 2007). There is some related methodological research on the design of optimal collaborative networks in the context of virtual enterprises and virtual organisations (e.g., Camarinha-Matos and Afsarmanesh, 2003, 2005; Lau and Wong, 2001). Yet, these methodologies are not readily applicable to R&D programmes, which tend to offer fewer possibilities for data collection, and are hence less amenable to the deployment of quantitative optimisation models. The formulation of networking models for multi-national R&D programmes involves even greater challenges, because data on the interests and competencies of researchers in different countries may not be readily available, and because any such model would have to be accepted by many participating organisations whose administrative practices may differ considerably (see e.g., Prange, 2003; Kuhlmann and Edler, 2003).

In view of the above, key questions in supporting the preparation of multi-national R&D programmes include

- What kinds of methods of knowledge elicitation and thematic prioritisation can be used in support of *networking*
- How these methods can explicitly account for *international* aspects (e.g., balance of priorities among countries).

Motivated by these questions, we develop a systematic approach where the viability of new prospective networks is treated as an explicit evaluation criterion. Our approach – called *RPM-Networking* for short – is founded on the RPM framework (Liesiö et al., 2007, 2008), which is capable of addressing important portfolio considerations, for example by addressing resource and even other constraints in the identification of thematic priorities and associated networks.

We also describe a case study that was carried out within one of the European ERA-NETs (in general, ERA-NETs[1] seek to promote collaboration among national and regional research programmes organised by the ministries and funding organisations of the Member States). Specifically, we applied RPM-Networking to the extensive data set that was generated during a participatory consultation process in WoodWisdom-Net (Brummer et al., 2008).[2] This ERA-NET – which has 18 partners from eight countries – seeks to advance networking and integration of national programmes in wood material science and engineering; hence, it has been the main user of our network analyses in support of the establishment of multi-national[3] research programme. The WoodWisdom-Net is also of broader interest, because the need for systematic methods for supporting networking is equally manifested in other ERA-NETs and international R&D policy instruments, indeed, owing to the large number of participating countries and stakeholder groups.

The rest of this paper is organised as follows. Section 2 discusses earlier consultation processes and their methodological characteristics. Section 3 presents the Wood Wisdom-Net case study where RPM-Networking was deployed. Section 4 illustrates some of the results from this case study. Section 5 discusses the broader implications and limitations of the methodology, and Section 6 concludes this paper.

2 Collaboration and networking in international R&D programmes

Collaboration among different parts of the innovation system is a key element of successful innovation strategies (e.g., Fritsch and Lucas, 1999; Kauffmann and Tödtling, 2001). In foresight – which provides important inputs to these strategies – objectives such as common vision building and networking have been stressed as important contributors to the enhanced performance of an innovation system (e.g., Barré, 2002) by the way of processes of technology transfer (e.g., Chataway et al., 1999) and related learning activities (Kuhlmann and Edler, 2003). It has also been noted that the fostering of new contacts among stakeholders facilitates radical and incremental innovations alike (e.g., Love and Roper, 2001).

In this setting, publicly funded R&D programmes facilitate collaboration among stakeholders of innovation system. Especially in R&D programmes that are funded jointly by several funding organisations, the fostering of collaboration activities through the creation of new research networks is often important objectives (see e.g., Arranz and Fernández de Arryoabe, 2006). In international programmes, collaboration may take place at multiple levels both within and between national innovation systems (Keiser and Prange, 2004). It is consequently a highly prioritised objective in several innovation policy instruments (e.g., Kuhlman and Edler, 2003): examples include instruments such as Technology Platforms and ERA-NETs that the European Union has established towards the building of the European Research Area (ERA) (European Commission, 2003).

Within the ERA, Arranz and Fernández de Arryoabe (2006) identify three main classes of international joint R&D projects, i.e., invention, innovation and diffusion projects. Innovation projects usually have a strong thematic focus and yield products through well-structured networks; invention and diffusion projects, in turn, are carried out within less-structured open networks, involve a large number of participants, and result in patents or scientific publications, respectively (Arranz and Fernández de Arryoabe, 2006). In this taxonomy, publicly funded R&D programmes with less-structured open networks are arguably best characterised as invention or diffusion projects that are not necessarily strongly coordinated in terms of their collaboration activities.

The apparent low level of coordination, however, is partly inconsistent with the objective of promoting intensive collaboration among national innovation systems through European coordination tools (e.g., Prange, 2003; Pochet, 2005). One reason for the relatively low level of coordination (in terms of supporting the formation of new networks) may be that adequate and well-tested methodologies for creating new research networks have not been readily available (e.g., Hellström et al., 2001). Yet, such methodologies have been found helpful in other settings, for instance in virtual organisations that seek to select their partners optimally to attain specific business (e.g., achievement of technological standards). Because of their complexity, however, many of these methodologies (see e.g., Camarinha-Matos and Afsarmanesh, 2005; Liang et al., 1999) tend to be better suited for focused innovation programmes than for less-structured invention or diffusion programmes.

For the very earliest phases of the innovation activities, several conceptual but less-formal methodologies have been suggested to support networking around sets of diverse research issues. Könnölä et al. (2006), for instance, propose Prospective Voluntary Agreements (PVAs) as a tool for promoting cooperation in large complex systems that are on the verge of potential technological breakthroughs. But, while PVAs seek to promote cross-organisational collaboration by encouraging the development of a common vision and the participants' commitment to it, the aim in the preparation of R&D programmes is to characterise particularly promising research areas and to facilitate the emergence of potential research projects that merit funding. Viewed from this perspective, PVAs may be more suitable for negotiations about whether a specific R&D programme should be started at all, rather than for leveraging advanced methodological support to the actual preparation phase.

In the preparation of publicly funded R&D programmes, the prioritisation of thematic research areas is widely viewed as a key objective that calls for adequate methodological support (e.g., Salo and Salmenkaita, 2002; Poh et al., 2001). Relevant approaches to priority setting vary from straightforward portfolio allocations (e.g., Stewart, 1991; Oral et al., 1991) to multi-stage participatory processes where the research agenda is first prepared before actual funding decisions are then taken about submitted project proposals (e.g., Tian et al., 2005; Salo and Liesiö, 2006). Especially in large multi-national R&D programmes (to which resources are contributed by several funding organisations), such multi-stage approaches may be beneficial also because they permit the broad participation of representatives from the research community and industry (e.g., Tian et al., 2005). Such participatory processes can be structured around the solicitation, mutual commenting, and multi-criteria evaluation of prospective research themes (e.g., RPM-Screening; Könnölä et al., 2007, 2008; Brummer et al., 2008).

One of the aims of international joint R&D projects is to deepen international collaboration. This can be achieved either by building new research networks or by strengthening earlier ones, subject to the following realities:

- Within funding organisations, different organisational practices, shifting emphases on thematic research topics, and varying attitudes towards international collaboration may cause misunderstandings about what the most promising research issues are and how they should be best approached (e.g., Prange, 2003; Kuhlmann and Edler, 2003). In consequence, the organisations may find difficulty in fully realising the potential benefits of shared research projects that could be pursued through new research networks.
- Within the research community, the identification of prospective research collaborators may involve considerable costs owing to the efforts of acquiring information on the interests and capabilities of candidate collaborators. That is, researchers may not be well aware of which other groups are interested in related topics, wherefore they may be intent on collaborating with partners that they have worked with earlier (e.g., Prange, 2003; Kuhlmann and Edler, 2003).
- Even when researchers and funding organisations are willing to collaborate, the establishment of new research networks and the dissemination of their results may pose difficulties. The planning and implementation of joint R&D projects tend to be temporary with interdependent but separately administered phases (see e.g., Arranz and Fernández de Arryoabe, 2006), which entails the risk that the results from the preparatory activities are not fully carried out to the implementation phase (which often involves a slightly different set of stakeholders). There is also a risk in that if the prospective research themes are duly identified, their full potential is not

fully realised unless they are pursued through networks that are most capable of doing so.

The above challenges imply that systematic analyses of not only prospective research themes but also related prospective *networks* are needed. On the one hand, such analyses give funding organisations an enhanced understanding of research issues that are best suited for collaboration, motivated by prospective industrial and societal demands, and feasible in terms of sufficient interest and competencies in the research community. On the other hand, researchers can benefit from these analyses by using them for finding new collaborators, which may reduce overall administrative overheads, thanks to the lower costs of identifying collaborators and entering contractual relationships with them.

Because new collaborative networks come to fruition through research projects, one can argue that the processes for building these projects should be linked to the definition of thematic priorities. Thus, instead of developing separate processes for the definition of thematic priorities and the building of collaborative networks, it may be beneficial to address these two aspects jointly in the planning and implementation of R&D programmes. This makes it possible, for instance, to focus the R&D programme on topics that call for and are amenable to the formation of new research networks. Motivated by this recognition, the RPM-Networking methodology developed in this paper is based on the joint consideration of thematic priorities and collaborative networks within an integrative framework that extends the RPM-Screening approach to network structures (Könnölä et al., 2007).

3 Woodwisdom-Net consultation process

WoodWisdom-Net[4] – which is one of the European ERA-NETs – was launched in 2004 to

> "deepen the collaboration between the European funding organisations in the field of wood material science in order to coordinate the use of research funds, and to integrate research resources from different countries in order to promote the competitiveness and sustainability of the European forest cluster".

In terms of structure and organisation, WoodWisdom-Net is truly international: its member organisations consist of 18 funding organisations from eight countries (Austria, Denmark, Finland, France, Germany, Norway, Sweden, and UK).

Already at its earliest phases, one of the key objectives of WoodWisdom-Net was to launch a transnational research programme on wood material science. The preparation of this programme had to be supported through a systematic consultation process that would generate a wealth of information about potentially interesting research issues and would thus contribute to the development of the research agenda. The overall structure of the consultation process – which engaged more than 400 participants and was run in 2005–2006 with the title "Collaborative Shaping of Research Agendas in WoodWisdom-Net" – is reported in detail in Brummer et al. (2008).

In this paper, we focus on the RPM-Networking methodology that was developed to foster the identification of new networks and, specifically, to inform the funding organisations of what kinds of networks could probably be built around alternative thematic priorities. These analyses were produced by using the data inputs that the participants submitted through internet-based tools and in the workshops. However, RPM-Networking is a generic methodology that can readily be applied even in other related contexts.

Drawing upon experiences from earlier foresight processes (Salo et al., 2004; Könnölä et al., 2008), the WoodWisdom-Net consultation process was structured into consecutive phases where the participants had clearly defined roles and responsibilities (see Table 1). It was partly inspired by the RPM-Screening (Könnölä et al., 2007) methodology that made use of internet-surveys and multi-criteria analyses, as well as participatory workshops where the results from all the preceding phases were examined in some detail.

Specifically, the participants represented the following stakeholders:

- *researchers* include leading researchers at universities, research institutes and industrial research organisations
- *industrial leaders* include R&D and business managers in the forestry-related industry
- *representatives from funding organisations* include experts from the members of WoodWisdom-Net (i.e., the funding organisations that would commit resources to the multi-national research programme).

Table 1 Phases of the consultation process

Task		*Participants*	*Schedule*
1	Solicitation of research issues	Researchers	Mid-July – Mid-October 2005
2	Assessment of research issues	Researchers	December '05 – Mid-January 2006
3	Assessment of research issues	Industrial leaders	Three last weeks of January 2006
4	Initial screening of research issues	Project team	January – February 2006
5	Three one-day workshops for Researchers and Industrial leaders	10–12 Researchers and Industrial leaders/workshop	Mid-February 2006
6	A one day workshop for funding organisations	Representatives from funding organisations	End of March 2006

The main phases of the consultation process were as follows. In the first phase, researchers from eight countries submitted well over 300 research issues through internet-based tools, whereby they also linked their proposals to a pre-defined taxonomy that consisted of 22 research sub-areas. In the second phase, they assessed the proposed issues with regard to the criterion *Novelty* by using a 7-point Likert-scale; they also indicated how interested they would be in participating in a possible research project on the given research issue (assuming that such a project would be launched at a later time), by using the scale 0 – No interest, 1 – Some interest, 2 – Considerable interest and 3 – Tentative commitment. In the third phase, selected industry leaders (which were identified by the funding organisations) assessed the proposed issues with regard to *Industrial relevance* and *Suitability for WW-Net*; both of these criteria were measured through a 7-point Likert-scale. In the fourth phase, issues were analysed with the

RPM-methodology (Liesiö et al., 2007, 2008) to derive suggestions for thematic priorities.

The results of all preceding phases were discussed in four workshops. The first three workshops were held among selected researchers and industrial leaders (again, the participants were appointed by the funding organisations), while the last one was held among the representatives of funding organisations. In this final workshop, the funding organisations also gave indications about the amount of the funding that they would be willing to commit to the programme. They also formed three working groups, built around research sub-areas that contained high-priority themes, which were of shared interest to several funding organisations. Finally, these working groups prepared the Calls-for-Proposals for the multi-national research programme. In early 2007, some 70 project proposals were received in response to these Calls-for-Proposals.

4 Identification and evaluation of prospective research networks

Within WoodWisdom-Net, one of the objectives was to promote development of new collaborative research networks. The identification of these networks could be supported through the information the researchers had supplied during the consultation process, because in Task 1 they had identified themselves when submitting research issues, while in Task 2 they had expressed their tentative interests in working on these issues. In effect, this information made it possible to identify prospective networks consisting of researchers that would be keen on working on similar research issues.

Because the research issues were also evaluated with additional criteria (i.e., researchers assessed them with regard to *Novelty*, and industrial leaders assessed them with regard to *Industrial relevance* and *Suitability for WoodWisdom-Net*), the consideration of shared interests could be linked to a complementary analysis of research issues based on other merits. Thus, taken together, the systematic multi-criteria evaluation of research issues and the consideration of the level of expressed interest supplied enough quantitative information for delivering analyses in response to questions such as follows:

- Which researchers have expressed shared interests in similar research issues?
- What kinds of researchers networks could be built around issues that seem promising based on the multi-criteria evaluation in view of *Novelty*, *Industrial relevance*, and *Suitability for WoodWisdom-Net*?
- Which research issues (and associated researcher networks) seem most viable, in view of the multi-criteria valuation *and* the level of expressed interest in pursuing them?

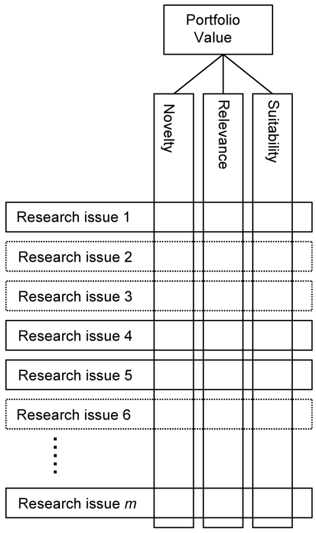
Out of these three questions, the last one is the most advanced one, given that it combines analyses from the multi-criteria evaluation of the research issue *per se* with an evaluation of the network that one might built around it.

4.1 RPM-networking model

The model for the analysis of thematic priorities and networks was based on RPM (Liesiö et al., 2007, 2008), partly because this methodology is capable of providing indicative results about the attractiveness of candidate proposals (such as research issues) even if complete information about the relative importance of criteria or criterion-specific values of these proposals are not available. Thus, RPM makes it possible to deal with imprecise preference statements (such as *Novelty* is more important than *Industrial relevance*) that are often easier to elicit than precise numerical estimates.

In the RPM framework (Figure 1), a portfolio is a subset of proposed research issues. The overall value of a portfolio is taken to be the sum of values that are associated with the research issues it contains. For each issue, this value is computed by summing its criterion-specific scores, multiplied by the respective criteria weights (e.g., Lindstedt et al., 2008; Liesiö et al., 2007, 2008; Könnölä et al., 2007, 2008).

Figure 1 RPM model



In the development of decision recommendations, attention can be restricted to *non-dominated* portfolios. Specifically, a portfolio is non-dominated if

- it satisfies feasibility constraints (e.g., bounds on the number of issues that can be included in the shortlist of priorities)
- there does not exist any other feasible portfolio that would offer a higher overall value for all combinations of feasible scores and criteria weights.

Thus, for example, the portfolio that maximises the overall value of research issues subject to all stated constraints, preferences and score information is one of these non-dominated portfolios.

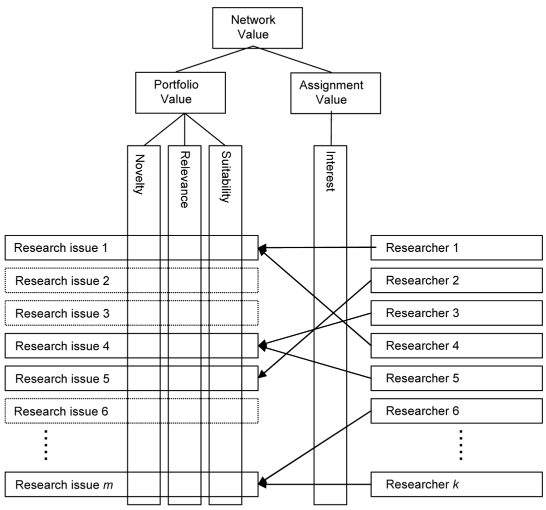
Once all the non-dominated portfolios have been computed, recommendations about the attractiveness of individual research issues can be communicated through their *Core Index* values, defined as the ratio between

- the number of non-dominated portfolios in which a given issue is contained
- the number of all non-dominated portfolios.

Thus, if this ratio is one, the issue is an attractive candidate, because it would be contained in the optimal portfolio even if additional information were to be acquired. Conversely, if this ratio is zero, the issue is not attractive, because for any portfolio containing the issue it would be possible to find another portfolio that would yield more value, but would *not* contain the issue being examined.

For the analysis of networks in WoodWisdom-Net, the RPM methodology (Figure 2) was extended by introducing different kinds of criteria: the first three criteria (i.e. *Novelty*, *Industrial relevance* and *Suitability for WoodWisdom-Net*) modelled the attractiveness of each issue based on their criterion-specific scores. The fourth criterion, *Networking*, served to capture how keen the participating researchers were on pursuing the issue in view of their expressly stated interests. Mathematically, the score for this fourth criterion was computed by assigning researchers to research issues through an optimisation algorithm (see Appendix A), and by summing the levels of interests that the assigned researchers had attached to this issue. For instance, in a situation where five researchers were assigned to an issue so that four of them had specified their interests as three (tentative commitment) and one as two (considerable interest), the total score of the networking criterion would have been $4 \times 3 + 1 \times 2 = 14$. Finally, these resulting numbers were scaled so as to ensure that scores for each criterion would belong to the interval [0, 1].

Figure 2 RPM-network model



In this formulation, the value *value* of a network (defined as a portfolio of issues, combined with an assignment of researcher to these issues) thus consisted of two components:

- *portfolio value* (obtained as the weighted sum of the values that the issues in the portfolio assumed with regard to these three criteria)
- *networking value* (computed as the aggregate level of interest among researchers that would be assigned to these issues in the optimal assignment).

Information about the relative importance of criteria were elicited through interviews with WoodWisdom-Net management whose representatives noted that *Suitability for WoodWisdom-Net* and *Networking* were both more important than *Industrial relevance* which, in turn, was judged to be more important than *Novelty*. This incomplete rank ordering (see Salo and Punkka, 2005) – which clearly placed a strong emphasis on the development of international collaborative networks – resulted in the following constraints on criteria weights

$$w_{\text{Suitability for WW-Net}} \geq w_{\text{Industrial relevance}}$$
$$w_{\text{Networking}} \geq w_{\text{Industrial relevance}}$$
$$w_{\text{Industrial relevance}} \geq w_{\text{Novelty}}.$$

The above statements do not, however, explicate how much more important *Networking* would be in comparison with *Industrial relevance*, or whether *Suitability for WoodWisdom-Net* is more important than *Networking*. This illustrates the possibilities of addressing incomplete preference in portfolio decision-making.

In WoodWisdom-Net, the analyses were carried out separately for each of the 22 research sub-areas with which the research issues had been associated. To derive indicative priorities, it was assumed that the financial resources in the programme would make possible to support no more than a third of the proposed issues within each sub-area. Mathematically, this assumption was imposed by assuming that

- all research issues would consume an equal amount of resources
- feasible portfolios would contain no more than a third of proposed research issues in any given sub-area.

For the determination of non-dominated assignments of researchers to research issues, three additional constraints were introduced. Because a single research (or research group) cannot participate many research projects in the programme at the same time, an upper bound of $H = 2$ was placed on the number of issues that a single researcher would be assigned to. Also, to identify networks of sufficient but not of excessive size, the number of researchers in any network for a given issue was bounded from below by $\underline{U} = 3$ and from above by $\overline{U} = 5$.

The RPM-Networking analyses were based on the computation of all non-dominated networks. Specifically, a network is non-dominated if

- it is feasible (i.e., it satisfies portfolio and assignment constraints)
- there is no other feasible network that would yield a higher overall value for all feasible weights and scores.

On the basis of these non-dominated networks, the corresponding implications for decision-making were conveyed through Core Index values that showed

- thematic priorities for research issues
- corresponding assignments of researchers to these issues (as in standard RPM, the Core Index of an issue/assignment is the share of the non-dominated networks in which the issue/assignment is contained).

More specifically, both research issues and researcher assignments can be classified into three distinct sets:

- *Core issues and assignments* that appear in all non-dominated networks can be strongly recommended.
- *Borderline issues and assignments* that belong to some, but not all non-dominated networks. These issues and associated assignments can be interesting, especially if they exhibit other merits and appear in a large share of non-dominated networks.
- *Exterior issues and assignments* that are not in any non-dominated networks.

These issues and associated assignments are not recommended, because one could readily identify other outperforming issues and assignments, for example by looking at the networks in the other two sets above.

4.2 Results from RPM-Networking

Because there were 22 research sub-areas that contained well over 300 issues, and some 400 researchers had indicated to what extent they would be interested in pursuing these, the task of developing thematic priorities and information on corresponding researcher networks was challenging in terms of computation and communication of results.

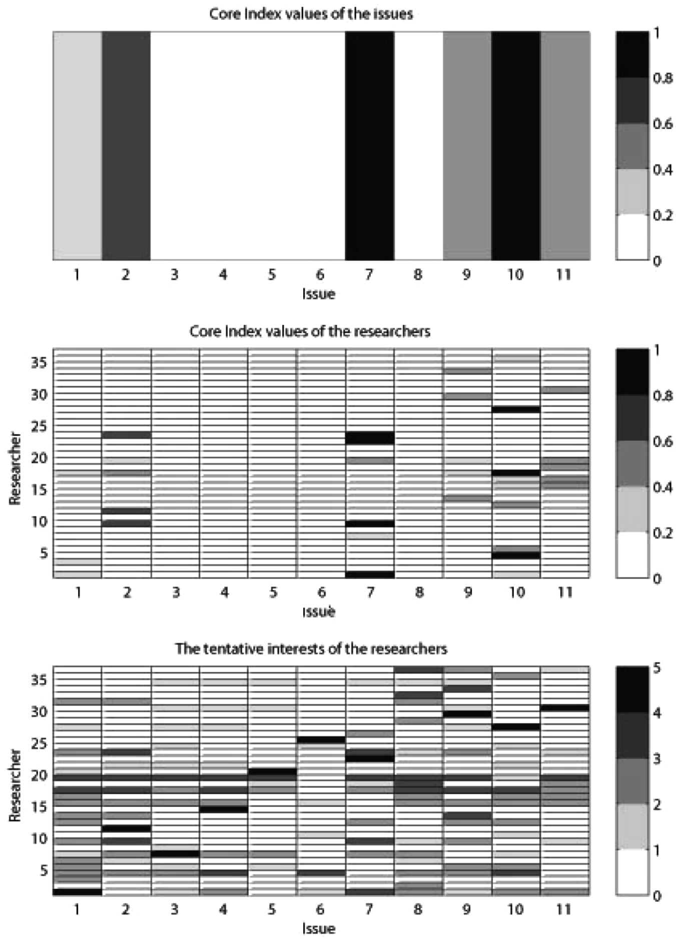
For communication purposes, Core Index values were calculated within each sub-area for each issue and assignment of researchers to issues. Specifically, three diagrams were created within each sub-area. Figure 3 shows an example of results for sub-area 1.1 (wood-based biopolymers to composites) where 36 researchers had expressed tentative interest in participating in one or more of the 11 research issues. The need to identify the most highly prioritised issues was modelled through the constraint that any non-dominated portfolio would contain at most 4 issues out of 11 (i.e., owing to the constraint that no more than a third of issues would be contained in feasible portfolios).

In Figure 3, the diagram at the bottom shows how interested the researchers were in pursuing these issues, based on their statements from the assessment of research issues in Task 2. In this diagram, the research issues are shown as vertical columns, while the 36 researchers correspond to horizontal lines. The coding of the colours in the diagram is such that the darker the colour, the greater the level of interest (0 – No interest, 1 – Some interest, 2 – Considerable interest, 3 – Tentative commitment, 5 – Researcher has proposed the issue): for example, issue No. 8 has attracted considerable interest among most researchers, and researcher No. 19 has indicated interest in almost all issues.

The uppermost diagram shows the issue-specific Core Indices, calculated by using all four evaluation criteria (i.e., *Novelty*, *Industrial relevance*, *Suitability for Wood Wisdom-Net*, *Networking*). Here, issues No. 7 and No. 10 are contained in all non-dominated networks, while issue No. 2 is contained in most of them: thus, these three issues are rather interesting ones, as well as issues No. 1, No. 9 and No. 11 that are contained in some non-dominated networks. Other issues receive less support and do not seem to merit as much attention.

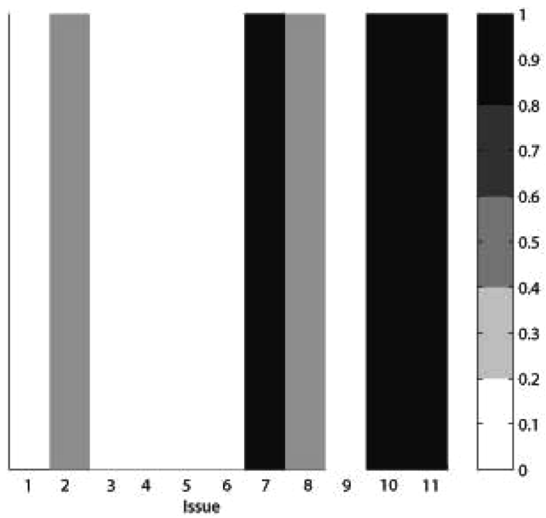
The diagram in the middle illustrates the Core Index values for assigning researchers to issues. This diagram can be read in much the same as the uppermost one, except that for each issue the rows correspond to possible assignments of researchers to it: thus, if issue No. 10 was to be selected for further development based on the uppermost diagram, one could readily note that in all non-dominated networks researchers No. 4, No. 5, No. 17 and No. 18 would be assigned to this issue. They are consequently interesting candidates for network buiding if this issue is to be taken further.

Figure 3 Core Index values calculated by including network effects



For the sake of comparison, we also computed Core Index values without the networking criterion (see Figure 4). A look at Figures 3 and 4 shows that the consideration of networks does provide additional information, because the Core Index values for many research issues are rather different. For example, the high level of interest in research issue No. 2 is reflected in the rather high Core Index value in Figure 3, while it has a much lower Core Index value in Figure 4. Conversely, the case for research issue No. 11 is just the opposite, because there is less interest in this issue although it is attractive in view of the three assessment criteria. In this way, the RPM-Networking model supports the identification of research issues that not only contribute to the evaluation criteria, but also account for the level of expressed interest among researchers.

Figure 4 Core Index values calculated without the consideration of networks



5 Discussion

High level of networking is a central contributor to the performance of innovation system and hence also one of the main objectives in the preparation of R&D programmes. It, therefore, follows that the fostering of new collaborative research networks should assume a central role in the preparation of these programmes, especially in the case of multi-national programmes where the very diversity of cultural and organisational backgrounds may complicate the development of such networks. The development of these networks can be facilitated by deploying systematic methodologies, which help attain other desirable characteristics, too, such as increased transparency and improved manageability (e.g., scalability in terms of the number of issues that are addressed, or the number of participants that are engaged).

Motivated by the above observations, we have developed RPM-Networking to support the formation of new research networks. The methodology contributes to collaboration activities by supporting the shaping of thematic priorities and the formation of new networks, based on multi-criteria analyses of proposed research issues, whereby the expressions of interests by potential programme participants are also examined. The results can fulfil several functions in the preparation of R&D programme managements: i.e., they

- convey information to funding organisations about the viability of alternative research topics in terms of their perceived attractiveness and prevailing level of interest
- help possible programme participants to identify potential collaborators with complementary interests and, as a result
- facilitate the launching of projects that are aligned with expressed priorities, which in turn makes it easier to implement these priorities.

As for the first of these three functions, the systematic collection and analysis of prospective research topics informs funding organisations about the level of interest in these topics, which is more likely to help them take decisions about just how much funding they should commit to multi-national programmes. This helps mitigate the risks of

- not having a sufficiently strong response to large Calls-for-Proposals (in which case funds might be allocated to projects of a lower quality than desired), or of
- receiving a disproportionately high number of proposals (in which case an exceptionally high proportion of proposals might be rejected owing to the lack of funds).

In multi-national programmes, the underlying 'bottom-up' activities through which the information is generated are additional benefits, because all funding organisations are engaged on an equal footing: this may mitigate the risks of possible biases that might arise if, for example, stronger funding organisations seek to impose their viewpoints on others.

Second, the results of RPM-Networking help identify which researchers are interested in similar issues from complementary and multidisciplinary perspectives: for example, based on the calculated Core Index values, funding organisations can compile and disseminate e-mail lists of those researchers who have expressed similar interests. Apart from their instrumental use within the given R&D programme, these lists make it easier for the researchers to locate new potential collaborators also in view of other prospects for potential collaboration. In comparison with more conventional approaches to the fostering of networks (most notably workshops), the combination of internet surveys and network analyses is transparent and can be quite cost-efficient, especially because international workshops are quite costly. Furthermore, because the identified networks are based on shared interests (and less so on earlier collaboration histories), the risk of getting proposals from previously established and possibly nationally focused networks may diminish.

Third, one of the main advantages of RPM-Networking is that the results contain explicit suggestions about how the priority issues could be best implemented by researchers who are potentially interested in these issues. This is important because it helps mitigate the major concern and even pitfall in many foresight process – how can one best turn the foresight conclusions into action? By examining the results of networking analyses, one can readily identify networks of those researchers who are linked to the corresponding priorities; this, in turn, can be harnessed in the implementation of R&D programme priorities.

Yet, we see that quantitatively oriented internet-surveys and the ensuing multi-criteria analysis should have a subordinate role in relation to other forms of consultation activities, such as facilitated workshops. This is because these surveys do not readily capture all aspects that are relevant to thematic priorities (e.g., skills and competencies of proposing researchers); also, without workshops, it may be difficult to identify possible redundancies, overlaps, and omissions among the submitted research issues. Still, network analyses are instructive in that they convey information about what issues and associated networks are most attractive also in view of expressed interests. Moreover, the range of aspects could be extended through additional evaluation criteria for skills and competencies, as well as other relevant considerations. The model could also be applied to actual project funding decisions by making explicit assumptions about resource constraints and project costs, as well as what value is more likely to be acquired from the projects in view of relevant evaluation criteria (including the value of networking).

In the consultation process "Collaborative shaping of Research Agendas in WoodWisdom-Net", results from the application of RPM-Networking were disseminated to the funding organisations that consulted them in the preparation of Calls-for-Proposals. Had the methodology been available already during the earliest phases of this process, it could have been possible to apply it even more intensively (now, many of the networking analyses were conducted only after many thematic priorities had been defined). Notwithstanding, the results were found quite useful. It would be interesting to carry out additional case studies to evaluate the main benefits and also the limitations of the methodology, and to assess in what contexts it is particularly suitable, and in which ones it is less so. For example, it seems that the successful mobilisation of the research community, the solicitation of a sufficiently extensive set of research issues, together with high-quality evaluations thereof, are all vital pre-conditions for the successful deployment of the methodology.

6 Conclusions

The synchronisation of national innovation systems through common vision building, future-oriented priority setting and collaborative networking is arguably one of the key challenges that R&D policy-makers are presently faced with. Multi-national collaboration activities, in particular, are widely seen as increasingly important characteristics of successful innovation systems (see e.g., Jewell, 2003). This recognition, among others, has spurred the forceful development of policy initiatives such as the ERA, established with the explicit aim of promoting collaboration among national innovation systems. Still, despite the broad consensus on the benefits of international collaboration and the many influential policy measures, the literature is scant in outlining systematic methodologies for supporting the joint development of thematic priorities and collaborative networks within R&D programmes.

In this paper, we have responded to this need through the RPM-Networking methodology, which can be deployed both in national and multi-national R&D programmes, to identify jointly thematic priorities as well as prospective collaborative networks through which these priorities can be best pursued. Specifically, this methodology allows funding organisations to take an active role in building research networks that are focused on the stated thematic priorities and, at the same time, structured around researchers who share complementary interests in these priorities. Promising experiences from WoodWisdom-Net suggest that the proposed methodology is viable, and that additional research is called in terms of further case studies as well as methodological development.

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Notes

[1]http://cordis.europa.eu/coordination/era-net.htm

[2]http://www.woodwisdom.net/

[3]Here, the term multi-national means that the researchers will, as a rule, obtain resources from their national funding organisations, although the programme priorities are defined at the international level and projects can be funded only if they exhibit a high degree of international collaboration.

[4]http://www.woodwisdom.net

Appendix A: Optimisation formulations in RPM-Networking

For the formal development of RPM-Networking, we assume that there are m research issues $X = \{x^1, \dots, x^m\}$ that are evaluated with regard to n criteria. The *score* of a research issue x^j with regard to the ith criterion, denoted by v_i^j, is obtained as the mean of criterion-specific evaluations provided by the respondents. The overall value of the issue x^j is expressed by an additive value function $\sum_{i=1}^{n} w_i^p v_i^j$, where the weight w_i^p measures the relative importance of the ith criterion. A research issue is preferred to another if it has a higher overall value than the other.

A portfolio $p \subseteq X$ of research issues is a subset of all proposed issues. The overall value of this portfolio is approximated by summing the overall values of those issues that are contained in it. Thus, for a given score matrix v and criterion weights w, the overall portfolio value of p is

$$V(p, w^p) := \sum_{x^j \in p} \sum_{i=1}^{n} w_i^p v_i^j = \sum_{i=1}^{n} w_i^p \sum_{j=1}^{m} z^j v_i^j \tag{1}$$

where z^j is a binary variable such that $z^j = 1$ if $x^j \in p$ and $z^j = 0$ otherwise.

Let c^j be the amount of resources consumed by research issue x^j and b the total amount of available resource. A portfolio p is feasible if its research issues do not consume more resources than what is available, i.e., $\sum_{x^j \in p} c^j \le b$.

We assume that there are h researchers $F = \{f^1, \dots, f^n\}$, and that r_k^j denotes the level of interest that the kth researcher has in the jth issue. An *assignment* $l \subseteq X \times F$ associates researchers with one or more research issues. The networking value of an assignment is approximated by summing the levels of interest that the researchers have in these issues according to the assignment, multiplied by the weight of the Networking criterion w^l, i.e.,

$$V(l, w^l) = w^l \sum_{(x^j, f^k) \in l} r_k^j = w^l \sum_{j=1}^{m} \sum_{k=1}^{h} y_k^j r_k^j . \tag{2}$$

Here, the binary variable $y_k^j = 1$ if the kth researcher is assigned to the jth issue (i.e., $(x^j, f^k) \in l$) and $y_k^j = 0$ otherwise.

A *network* is a portfolio of research issues p combined with an assignment l of researchers to the portfolio. The overall network value consists of the values of research issues plus the networking value of the assignment. Thus,

$$V(p,l,w) = V(p, w^p) + V(l, w^l) = \sum_{i=1}^{n} w_i^p \sum_{j=1}^{m} z^j v_i^j + w^l \sum_{j=1}^{m} \sum_{k=1}^{h} y_k^j r_k^j , \tag{3}$$

where $w = (w_1^p, \ldots, w_n^p, w^l)^T$. Without loss of generality, these weights can be scaled so that

$$w \in S_w^0 = \left\{ w \in R^{n+1} \mid \sum_{i=1}^{n} w_i^p + w^l = 1, \quad w_i^p, w^l \geq 0 \right\}.$$

Definition 1: A network (p, l) is feasible if and only if it satisfies the constraints

$$\sum_{j=1}^{m} c^j z^j \leq b \qquad \text{(Resource constraint)}$$

$$\sum_{k=1}^{h} y_k^j \leq \overline{U} z^j, \forall j \text{ (Upper limit for researchers per issue)}$$

$$\sum_{k=1}^{h} y_k^j \geq \underline{U} z^j, \forall j \text{ (Lower limit for researchers per issue)}$$

$$\sum_{j=1}^{m} y_k^j \leq H, \forall k \text{ (Upper limit for issues per researcher)}$$

The set of feasible networks is denoted by N_F.

A network is feasible if

- the portfolio is feasible (i.e., it can be afforded with available resources)
- each issue in the portfolio has at least $\underline{U}$ but no more than $\overline{U}$ researchers assigned to it
- each researcher is assigned to at most H issues
- researchers are assigned only to issues that are in the portfolio p.

These constraints help eliminate unrealistic situation where some issues would be addressed through excessively large networks, some researchers would be working on too many issues, or where some issues would not be pursued at all. More technically, these constraints can be written as follows.

If complete information about the criteria weights w were available, it would be possible to compute the optimal network as a solution to the Zero-One Linear Programming Problem (ZOLP)

$$\max_{(p,l)\in N_F} V(p,l,w), \tag{4}$$

where $V(p, l, w)$ is given by equation (1) and linear constraints to ensure $(p, l) \in N_F$ by Definition 1.

Because complete weight information may be difficult if not impossible to obtain, RPM-Networking deals with sets of feasible weights $S_w \subseteq S_w^0$ that are consistent with the DMs' preferences. However, because the problem (2) does not have a single optimal solution in the presence of incomplete weight information, it is meaningful to define the following dominance relation for the identification and comparison of non-dominated networks:

Definition 2: Network (p, l) dominates network (p', l') with regard to feasible weight set S_w, denoted $(p, l) \succ (p', l')$, if $V(p, l, w) \geq V(p', l', w)$ for all $w \in S_w$ and $V(p, l, w) > V(p', l', w)$ for some $w \in S_w$.

A rational DM who seeks to maximise the overall network value would not choose a dominated network, because by definition there would exist another network that would yield a greater overall value for all feasible weights. Therefore, dominated networks can be discarded and the attention can be focused on the non-dominated ones, denoted by N_N:

$$N_N = \{(p,l) \in N_F \mid \text{there does not exist } (p',l') \in N_F \text{ such that } (p',l') \succ (p,l)\}. \tag{5}$$

In the extension of the standard RPM to the analysis of networks, the computation of non-dominated networks remains a ZOLP problem with incomplete information on the weights of the $n + 1$ criteria. As a result, the non-dominated networks can be computed with algorithms developed for non-dominated portfolios in Liesiö et al. (2007a, 2007b). Also, after the non-dominated networks have been computed, the Core Index values can be readily computed both for individual research issues and assignments:

$$\text{Core Index of issue } x^j \quad : CI(x^j) = \frac{|\{p \mid (p,l) \in N_N, x^j \in p\}|}{|N_N|}$$

$$\text{Core Index of allocation } (x^j, f^k) : CI((x^j, f^k)) = \frac{|\{l \mid (p,l) \in N_N, (x^j, f^k) \in l\}|}{|N_N|}.$$