Technological Forecasting & Social Change 110 (2016) 153–166

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Integrated roadmaps for strategic management and planning

Konstantin Vishnevskiy [a,*], Oleg Karasev [b], Dirk Meissner [a]

[a] National Research University Higher School of Economics, Russian Federation
[b] Lomonosov Moscow State University, National Research University Higher School of Economics, Russian Federation

ARTICLE INFO

Article history:
Received 6 July 2015
Received in revised form 17 October 2015
Accepted 27 October 2015
Available online 26 November 2015

Keywords:
Foresight
Roadmapping
Innovation strategies
Integrated roadmap
Market route
Scenario
Technology push
Market pull

ABSTRACT

Roadmapping is a complex long-term planning instrument that allows for setting strategic goals and estimating the potential of new technologies, products, and services. Until recently, roadmapping was used mainly for strategic planning, either from a technological or a market research perspective. Roadmaps emphasized either technological development or satisfaction of market demands but rarely both. Consequently, roadmaps either excessively stress the technology side, which might lead to technically sophisticated solutions that lack applicability, or overstress customer needs, neglecting business competence-building.

Therefore, this paper develops a new integrated roadmapping approach that combines these two perspectives: it focuses on strategic planning by firms and public authorities for the long run goals of social and economic development, bringing together the market "pull" and technology "push" approach. This dual technique provides the potential for alternative means of choosing the most effective resource allocation. Integrated roadmaps include the various development stages of prospective innovations, e.g. stages of the existing innovation value chain, including R&D, manufacturing, market entry, services, and market expansion as well as prospective stages, including new technologies, products and services.

The value of integrated roadmapping lies in its responsiveness to the challenges in innovation planning schemes for firms and sectors; it takes into consideration both future market requirements and the future resource basis for satisfying market needs, an approach not currently offered by traditional techniques. The paper develops a roadmapping methodology that can be used for planning firms' and public authorities' long-term innovation strategies.

1. Introduction

A widely used and powerful approach for strategic planning, integrating market and technology strategies, is roadmapping, which is seemingly suitable for meeting the challenges of the twenty-first century such as the emerging rapid and dramatically changing socio-economic conditions. These changes particularly affect knowledge-intensive industries, where extensive technological requirements and resource restrictions place pressure on firms to use reliable instruments for setting priorities. Motorola was the first to develop and introduce this approach in the late 1970s (Willyard and McClees, 1987). The technique then spread to other advanced large firms including Phillips, Corning, General Motors, Lockheed Martin, and Intel in the USA, Erickson in Sweden, and British Telecom in the UK (Lee et al., 2009a). Further, it was widely used for integrated product technology planning and technology roadmaps for firms, industries, and countries (Holmes and Ferrill, 2005). Consequently, small and medium-sized enterprises (SMEs) also began to employ roadmaps primarily for achieving benefits from the open innovation approach (Caetano and Amaral, 2011; Spithoven et al., 2011).

In addition to their application by firms, roadmaps have recently become an instrument used in the public sector, e.g. governments and public bodies involved in science, technology, and innovation (STI) policy. Here roadmaps aim to identify promising STI fields and the impact assessment of the decisions taken in this regard. Technology and the market dimension need to be integrated into one roadmap in order to shift the focus from developing pure technology to the application of technologies. Accordingly, there remains a need for improved and more sophisticated methodologies to make concrete innovation strategies based on roadmapping, which would include a comprehensive reflection of the technological and market prospects, taking into account expert knowledge from different fields (Vishnevskiy et al., 2015a; Khripunova et al., 2014).

A recent case study from Russian institutions provides reasonable evidence for the use and application of such integrated roadmaps (Karasev and Vishnevskiy, 2013). For example, the strategy of the Russian Corporation of Nanotechnologies (Rusnano) for 2020, points to the necessity of employing roadmaps for building a vision of innovations in the nanotechnology field: "Corporations participate in the development of mid- and short-term forecasts and plans of scientific,

* Corresponding author.
E-mail addresses: kvishnevsky@hse.ru (K. Vishnevskiy), k-o-i@yandex.ru (O. Karasev), dmeissner@hse.ru (D. Meissner).

http://dx.doi.org/10.1016/j.techfore.2015.10.020

technological and market nano-industry development, i.e. roadmaps. Roadmaps will be used by the corporation as an instrument for orientation and support of other participants of innovation process, and for development of investment projects" (Vishnevskiy et al., 2015a; Karasev and Vishnevskiy, 2013; Karasev et al., 2014).

The following paper proposes a methodological approach to roadmapping that is closely related to business planning and would allow public agencies and corporations to devise STI strategies. The paper is organized as follows. Based on a literature review we formulate the main research questions for our work, then provide our own methodology of integrated roadmaps including two elements — technology roadmap and business roadmap. Next, we describe the results of applying this concept to analyze a range of practical examples where roadmapping was used by corporate and public authorities. Finally, we discuss possible applications of our integrated roadmap and future for research.

2. Literature review

Although the first roadmaps were developed in the 1970s, significant methodological progress was achieved only in the 2000s when Rob Phaal published his book 'T-plan' (Phaal et al., 2001). This seminal work devoted to the new methodology of taking a market-pull approach, and gives a step-by-step outline on how to apply roadmapping in firms by using minimal resources. Consequently, his work became a fundamental framework for roadmapping for both market pull and technology push approaches (Phaal et al., 2001). The 'T-plan' is a special framework for roadmapping, which consists of three stages: planning, roadmapping, and roll-out stages (Phaal et al., 2001; Schaller, 2004). Phaal's approach is a tool for strategists to develop a roadmap quite quickly, gives an opportunity to combine the development of technologies and activities for their exploitation and commercialization. However, many companies are unable to launch roadmaps due to a lack of qualified staff for this process. In 2004, Phaal concluded that a qualified specialist in long-term planning should manage the roadmapping process (Phaal et al., 2004). The classic scheme of Phaal's roadmaps includes four main layers closely connected with the main research questions. The first layer involves identifying the business and market environment conditions that influence a company's behavior (know-why). The second layer (know-what) aims to visualize product and service development as well as the development of capabilities. The third layer (know-how) identifies the necessary resources for achieving the firm's goals. Finally, the fourth layer (know-when) provides a timescale for the roadmap (Phaal et al., 2001).

Although there have been a number of modifications over time to Phaal's approach (Albright and Kappel, 2003; Lee and Park, 2005; Daim and Oliver, 2008), the basic concept remains the same. The literature describes two main approaches to roadmaps — the market-driven and the technology-driven approaches (Fig. 1). The market-driven approach views the primary driver of R&D as market demand (see Holmes and Ferrill, 2005; Phaal et al., 2001; Albright and Kappel, 2003; Daim and Oliver, 2008; Lee et al., 2009b). The technology push approach starts with the most significant technologies and then defines the market needs that maybe served with the new technologies (see Lee et al., 2009a; Kim et al., 2009; Lee et al., 2007; Lichtenthaler, 2008).

Market-driven roadmaps start with identifying key needs of the marketplace and customers. It then considers the technologies and R&D requirements needed to meet that demand. A technology-driven roadmap in contrast starts with a key technology and seeks to determine the market needs that maybe served with that new technology (Albright, 2006).

Albright and Kappel (2003) followed the market pull approach outlining the experience of Lucent Technologies in developing and implementing technology roadmaps. The product-technology roadmap involves the product and technology program embedded in the market dimension including market analysis and competitive strategy. Based on this it defines the plan for the evolution of a product and elaborates the business strategy reflecting the evolution of product features. Eventually a summary/action plan charting out an action strategy and a risk roadmap is made. The main advantages of the roadmap lie in the analysis of the market and product drivers and in establishing a comprehensive view on the link between technology and products. However, this roadmap may not adequately consider the resources aspect; or, at least resources are not the focus of the analysis. Moreover, external factors are only partially included (Albright and Kappel, 2003).

Holmes and Ferrill (2005) modified the T-Plan methodology with an emphasis on the market pull approach and applied the proposed methodology to a pilot sample of 30 companies in different manufacturing sectors. Their methodology used a broader definition of technology that includes skills and competencies required to handle and develop technologies. Their surveys used semi-structured questionnaires and workshops, which involved company representative and external experts in the respective fields. The inclusion of technology soft skills is advantageous for the validity of the roadmap but inherits the danger of including too many different aspects and dimensions in the activity risking a miscalculation while setting priorities (Holmes and Ferrill, 2005).

Daim and Oliver (2008) introduced a process for developing technology roadmaps with an emphasis on potential markets. They discussed the particularities of implementing a roadmap in the energy services sector. They argued that companies need to include regular and targeted training for roadmapping the corporate human resources development programs, and in some cases, even integrate employee training as a phase in roadmapping projects. Currently they argue roadmapping is a time intensive exercise, which needs new developments to make it shorter and less resource consuming (Daim and Oliver, 2008).

Lee et al. (2009a) elaborated a methodological approach that gives special attention to future changes in consumer preferences. This methodology is applied to power line communications. They integrated expert knowledge from different fields using statistical methods for analysis such as conjoint analysis. The technological expert assessment was then combined with the market related findings by means of quality function deployment. The methodology provides a valuable approach towards determining the actual starting point for roadmapping

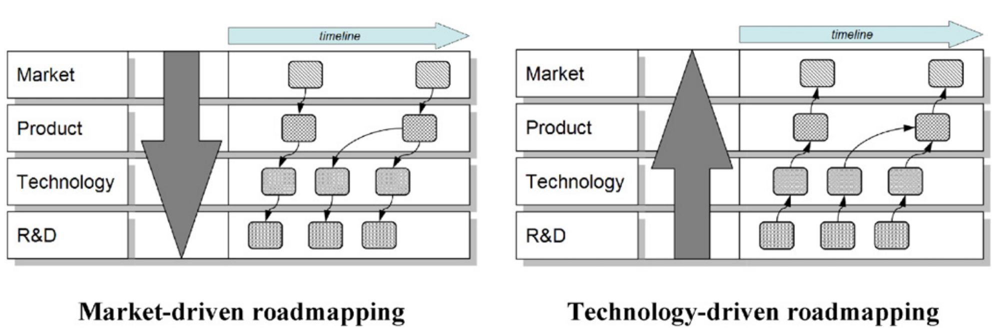

Fig. 1. Main approaches for roadmaps. Source: Lee et al. (2009a)).

by taking into account the maturity of technology and key elements of technology derived. However, this approach is also limited due to the inclusion of projected changes in customer wishes and expectations (Lee et al., 2009b).

Several papers take a technology push approach to study roadmaps. Lee et al. (2007) use the technology push approach for R&D planning and R&D strategy building. This approach allows the coordination of R&D programs and priority-setting of R&D projects on the basis of roadmaps for the Korean parts and materials industry. Their approach involves six phases with clearly defined inputs for each phase and their respective outputs but does not involve the exploitation of R&D outputs. Moreover, their roadmap highlights selected technologies but does not consider the interrelationships between different technologies. They identify the main weaknesses of their proposed approach, in relation to the timeframe and human resources invested in the roadmaps, the lack of integrated technology analysis and the integration of roadmapping in the overall spectrum of management tools. Eventually they stress that the roadmaps need to be objective, which requires the involvement of experts who are external to the organization. Consequently, the development of the roadmap requires more time and additional effort to secure the interface to external experts (Lee et al., 2007).

Kim et al. (2009)) analyze technology roadmaps developed on behalf of the Korean Ministry of Construction and Transportation (KMOCT) to identify construction related technology trends and derive proposals for R&D programs. Technology foresight, socio-economic prediction, market needs identification, and benchmarking of other related activities were used to develop roadmaps. They mainly analyze published knowledge in form of papers, surveys, and panel discussions as well as existing research roadmaps and strategies in other countries. Their approach is interdisciplinary in nature but (Lichtenthaler, 2008) in turn proposes an algorithm for implementing technology roadmapping in firms to establish appropriate strategic technology processes. However although he takes an integrated view on the technology and market dimension he presumes that technology is readily available hence actual activities for technology development are not included in the roadmap (Lichtenthaler, 2008).

Lee et al. (2009a)) introduced a broad approach to designing technology push roadmaps. They reveal the needs of technology-driven business by investigating the methods that allow firms to find new business opportunities based on technological capabilities. Patent data analysis as a proxy measure of technological capability is used in this approach. Patent data are used to develop actor-similarity map, actor-relations map, technology-industry map, and technology–affinity map. The use of patent data in their view increases objectivity and reliability of the respective roadmaps and ensures that information is gathered for solid strategy development. However, this neglects common limitations of patent data, embedded in unknown strategic patenting behavior of companies such as those that can potentially have a significant impact on the patent statistics analysis. Moreover, patent statistics show the previous state of the technological innovations but due to the time delay, granting and publishing patents do not fully cover the current state of technology (Lee et al., 2009a).

Eventually it maybe concluded that both approaches – the technology push and the market – have limitations (Table 1).

As shown in the table the market pull approach does not take into account technological development, while the technology push approach does not sufficiently reveal market demand for innovations. Although these limitations are well known, little work has been done so far to overcome these. Wells et al. (2004) use technology roadmaps for supporting strategic technology management and attempt to integrate the T-plan methodology into business planning using the example of Royal Mail (Wells et al., 2004). Brem and Voigt (2009) also try to develop a mechanism to integrate market pull and technology push approaches under the umbrella of corporate technology and innovation management. Still the number of works devoted to integrating the two roadmap approaches is still quite small. Hence a combined comprehensive approach of technology push and market pull roadmaps is lacking in academic discussion (Wells et al., 2004; Brem and Voigt, 2009; Konnola, 2007).

The predominant emphasis on only one approach is problematic as it emphasizes either manufacturing or satisfaction of market demands, not both. Consequently, such one sided roadmaps either excessively stress the technology side which might lead to technically sophisticated solutions that lack an applied element, or overstress customer needs which is good for the short-term but neglects businesses' future competence building. Thus, a combination of market pull and technology push approaches can overcome the limitations of the individual approaches. Therefore, a roadmap methodology is introduced considering a combination of different types of approaches to innovation strategy analysis based on: 1) technology push and 2) market pull. First, the market roadmap aims to identify new products, technologies, and services; second, the R&D focused technology roadmap is critical to achieving strategic goals. Finally, the business roadmap contains economic appraisal and compares alternative future development trajectories.

The literature review reveals a range of shortcomings related to the use of an integrated roadmapping approach. The main research question addressed in this paper is how to overcome the limitations of existing approaches to roadmapping, which mostly emphasize market needs and production capabilities. Another under-researched field is the structure for an optimal roadmap. Most existing roadmap strategies remain modifications of the classical Phaal approach. This article presents a new structure of roadmap combining in-depth research of technological properties, market dynamics, and risk analysis.

Finally, one of the most urgent and significant issues is the integration of roadmapping into business planning. We attempt to show the integration of roadmapping into decision making by providing a methodology for elaborating innovation strategies based on roadmaps. The paper concludes with the combination of special plans concerning all stages of the innovation generation chain (innovation process). Thus, the paper aims to elaborate a new methodological approach combining the benefits of both the market pull and technology push approaches.

3. Methodology

We elaborate a methodology from both theoretical and practical perspectives. We analyzed papers devoted to the Foresight methodology (Miles, 2002; Voros, 2003; Saritas, 2006; Hines, 2008; Popper, 2008;

Table 1
Potential and limitations of technology push and market pull approaches.

Approaches	Author/study	Potentials	Limits
Technology push	Lee et al. (2007), Kim et al. (2009), Lichtenthaler (2008), and Lee et al. (2009b).	• Comprehensive analysis of innovation technologies and products development. • Reveals in detail the dynamics of technologies' main properties.	• Insufficient consideration of future market requirements, customers'behavior and preferences.
Market pull	Albright and Kappel (2003), Holmes and Ferrill (2005), Lee et al. (2009a), and Daim and Oliver (2008).	• All-round study of possible market development within several scenarios. • Estimates what innovation products will be in future demand.	• Lacks consideration of the resource basis for satisfying market needs.

Meissner, 2012) and articles concerning roadmapping (Holmes and Ferrill, 2005; Lichtenthaler, 2008; Wells et al., 2004; Konnola, 2007; Clayton, 2008; Clayton, 2009). The proposed roadmapping methodology is shown in Fig. 2. It should be noted that this scheme is a framework, which should be adapted to the specific characteristics of a particular application field.

The process of developing the roadmap includes 5 main phases:

1. *Pre-roadmapping*. During this phase, the project domain and key priority directions of the subject field are defined. First, the need to implement innovative technologies, products, and services are explored through different surveys on preferences of citizens and experts. Employing the Delphi method with the participation of several thousand leading experts and studying key technologies is suitable to define a subject field for further roadmapping. It means areas characterized by leadership, market perspectives, and technology readiness can be chosen (Fig. 3). The main research directions of the roadmap are typically identified during a workshop.
2. *Desk research*. At this stage, all available and accessible codified knowledge in the respective field is analyzed. For this purpose, a literature review that provides initial information about prospective technologies and products is undertaken. Using a special toolkit of bibliometric and patent analysis, research fronts can be revealed to create an inventory of top-ranking experts and a list of prospective innovation related decisions for a subject field. Scanning enables the external factors that influence a research area to be analyzed for creating lists of risks. These risks will be discussed with experts in stage 3, and ways to manage these risks discussed in stage 4. Benchmarking includes: a study of analytical materials prepared by leading Foresight centers; official national documents (programs, forecasts, strategies); and data from Statistical Offices and other related sources of statistics. This stage is mainly driven by the technology push approach. More than 1000 original information sources are typically analyzed in the course of roadmapping projects. During the desk research, creation of a preliminary expert group is recommended.
3. *Expert procedures*. Special attention needs to be given to expert methods which lead to the discovery of "tacit knowledge" in the third phase. This includes a series of expert interviews with representatives of business circles, academia, and public authorities. An initial list of experts is formulated during the previous stages and expanded using the snowballing (co-nomination) technique. All experts (mainly scientific or technical experts) chosen to take part in the exercise must fulfill at least one of the following criteria:

- Publications in internationally reviewed scientific journals included in the ISI Thomson database, and an above world average citation index for the previous five years in the research field. This enables the most relevant scientists in the research field to be selected;
- Represent an enterprise or organization listed or recognized as a leading national name in the subject field, and is nominated as an expert by the appropriate organization/enterprise. This criterion helps to capture the most significant and influential representatives of organizations;
- Nominated as expert by at least three other previously selected subject field experts. Since the previous two criteria have some limitations, these metrics are used to identify other well-qualified experts.

Following expert interviews, a series of expert panels is organized to finalize the results of the respective procedures by reaching consensus between all stakeholders. To validate the results of the roadmapping exercise, international experts from leading organizations are interviewed. This stage allows R&D-technology-products-markets chains to be created using the integrated market pull and technology push approach.

4. *Creative analysis*. At this stage, all data collected in previous stages are analyzed by the roadmapping team with the help of appropriate experts. First, a SWOT-analysis is done to reveal the main potentials and limitations of the subject field developments. Backcasting provides the most attractive future visions and ultimately enables sequences of necessary decisions to be drawn up in order to realize this scenario. The use of wild cards and weak signals (WiWe) gives an opportunity to highlight so-called "bifurcation points": events with low probability but extremely high potential effect. This tool allows for the drafting of a future vision. The use of WiWe includes 3 main parts:

- the identification of wild cards and weak signals by analyzing strategic documents, research papers, and newspapers, as well as their classification and description;
- WiWe analysis presupposing the identification of key factors influencing the appearance and development of WiWe, and speculation into stakeholders' reaction to wild cards and weak signals;

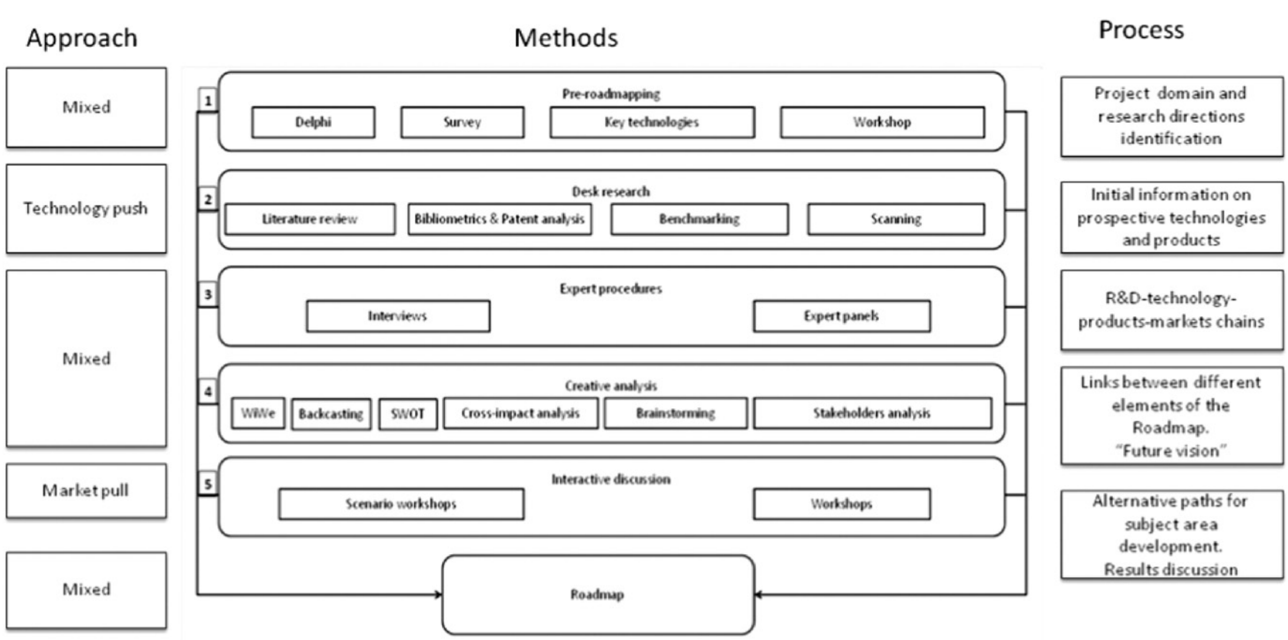

Fig. 2. Basic scheme of the roadmapping approach.

Fig. 3. Choice of areas for roadmapping.

- WiWe impact analyzing the potential influence of wild cards and weak signals on the field and recommended measures to address these challenges.

Next, the cross effects of introducing new technologies and products on the market are estimated. A stakeholders' analysis provides a list of the main roadmap beneficiaries and an estimate of the impact of the decision to innovate on their behavior and activities. During all these phases, the brainstorming technique is actively employed. Thus, it is an obvious example of a mixed approach combining the potential of market pull and technology push approaches.

5. *Interactive discussion*. This stage includes workshops that aim to discuss possible scenarios of subject field developments based on all previous stages and materials with the emphasis on market prospects for innovation products (market pull approach). We use a scenario approach to decrease uncertainty about the future. Next, a preliminary version of the roadmap is constructed and discussed with a broad range of roadmap beneficiaries including leading subject field experts, representatives of government bodies, business, and citizens

The core element of the integrated roadmap approach combining both technology push and market pull is a *cross-impact analysis*. We first estimate the major Consumer *P*roperties for different *T*echnologies (TCP structure). For this purpose, we use a special matrix completed by experts to rank the technologies' consumer properties (Table 2).

Then we assess the main Consumer *P*roperties for *M*arket *S*egments (CPMS) using a similar approach and qualified specialists' knowledge about the respective market development of the technology field (Table 3).

Next, we multiply matrices to estimate the correlation between *T*echnologies and *M*arket *S*egments (TMS) (Table 4).

Based on these matrices, we create the structure of a roadmap. The matrices illustrate the links between different layers and represent the mixed approach.

Implementing the suggested framework allows for a roadmap that includes the market pull and technology push approaches to be created. The integrated roadmap provides a detailed analysis of market pull, including the areas of the product's application, demand for technological solutions, specificities of different market segments, the adequacy of technological facilities and consumers' needs, the economic value of technology trajectories and recommendations aimed at supporting market-oriented technologies and products.

Moreover, it pays special attention to the description of technology push factors, e.g. technologies that provide competitive advantages, technological limitations, priority technology related tasks and technological «forks».

The approximate structure of the roadmap that integrates these factors is illustrated in Fig. 4. It takes account of Phaal's review of approaches to roadmap's visualization and combines different types of

Table 2
TCP structure.

Technologies	Consumer properties		
	Consumer property 1	Consumer property 2	Consumer property 3
Technology 1	Expert marks	Expert marks	Expert marks
Technology 2	Expert marks	Expert marks	Expert marks
Technology 3	Expert marks	Expert marks	Expert marks

Table 3
CPMS structure.

Consumer properties	Market segments		
	Market segment 1	Market segment 2	Market segment 3
Consumer property 1	Expert marks	Expert marks	Expert marks
Consumer property 2	Expert marks	Expert marks	Expert marks
Consumer property 3	Expert marks	Expert marks	Expert marks

Table 4
TMS structure.

Technologies	Market segments		
	Market segment 1	Market segment 2	Market segment 3
Technology 1	Results of matrix multiplication	Results of matrix multiplication	Results of matrix multiplication
Technology 2	Results of matrix multiplication	Results of matrix multiplication	Results of matrix multiplication
Technology 3	Results of matrix multiplication	Results of matrix multiplication	Results of matrix multiplication

technology roadmaps: product planning, service/capability planning, strategic planning (Phaal et al., 2004). The proposed roadmap goes beyond the existing approaches by incorporating a more detailed analysis of each layer's structure.

Consequently, the integrated roadmap includes four major layers:

1. *Technologies*. This layer describes the most promising technologies within a specific time scale. It provides a SWOT-analysis of these technologies highlighting the benefits and limitations of each technology. It also includes a forecast of target properties required to satisfy market needs and a set of the main tasks necessary to achieve these properties. In the final analysis, it gives an opportunity to illustrate the technology's prospects in terms of readiness for implementation and potential effect.
2. *Products*. This layer contains a brief description of prospective products in terms of readiness for commercialization and potential impact on the respective research field. It also estimates the time needed for commercialization and the most prospective market niches for each product.
3. *Markets*. The methodological approach implies that three scenarios of potential market development are drawn up: pessimistic, optimistic, and moderate (sometimes also referred to as 'realistic' or 'base case'). Scenarios provide an opportunity to take into account different variants of technological and product development and alternatives that are reflected in layers 1, 2 and 4. It also provides a brief description of the main market's features and possible strategies for each market. Thus, all markets are ranked in order of descending prospects.
4. *Alternatives*. The integrated roadmap also reveals possible developments of alternative products. It considers the dynamics of the main product properties, the export opportunities of these products, and their cost.

For each layer we consider goals and challenges, taking into account any associated risks. The roadmap outlines the most significant challenges for the research field. These challenges are analyzed so that innovative technologies and products that offer a way to overcome these challenges can be devised. Roadmap allows us to reveal all relevant conditions that could jeopardize developments in the research field. Roadmapping is a way to estimate the degree of threats for the respective field.

4. Theoretical implications

Based on our practical experience in Foresight and roadmapping, we assess all methods included in the methodological framework from two perspectives (Fig. 5). These are hardness (human efforts, financial costs etc.), and output (assessment of the method's contribution).

This framework can be adjusted to individual projects taking into account relevant restrictions which are likely to occur. Such limitations relate, primarily, to the resources available (financial but also human resources) and time constraints.

First, to assess the *hardness* we use seven metrics (Meissner, 2013):

i) *The complexity of experts' coordination* estimates the necessity to involve different kinds of experts or methods inside the team working on the roadmap (expressed on a scale from 1 — singular specialists to 4 — many experts);

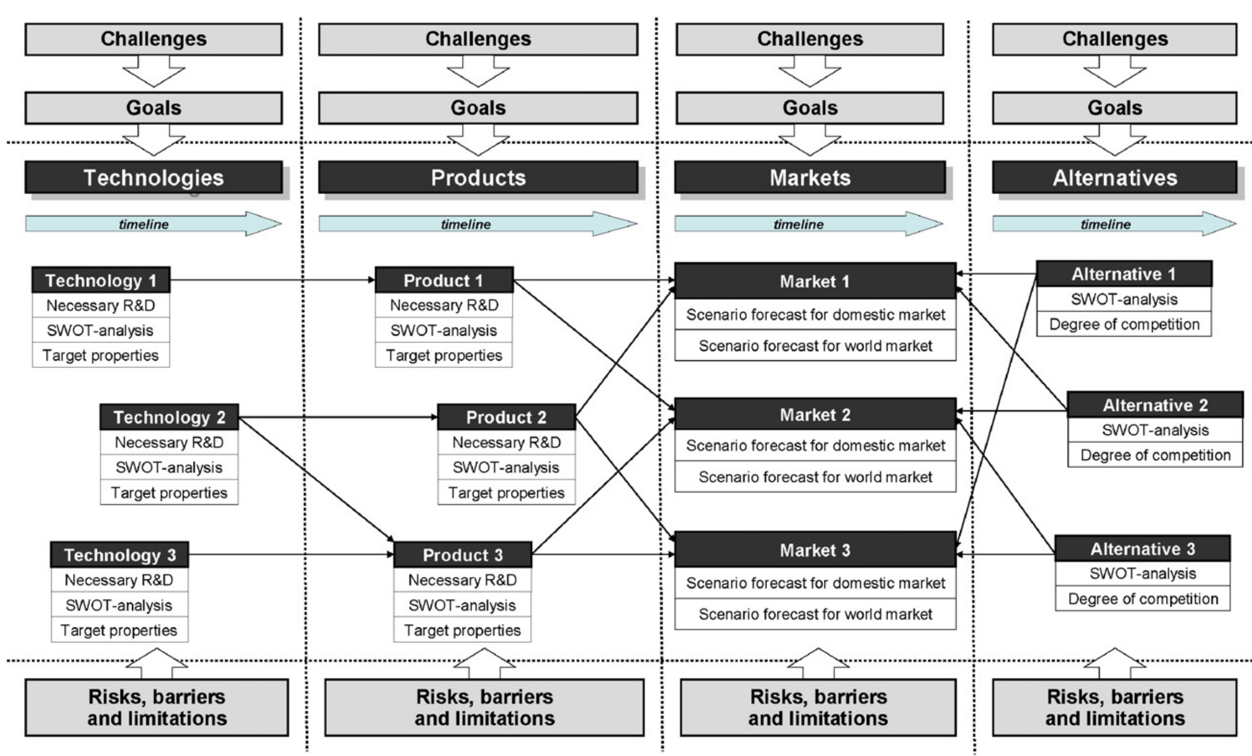

Fig. 4. Structure of integrated roadmap.

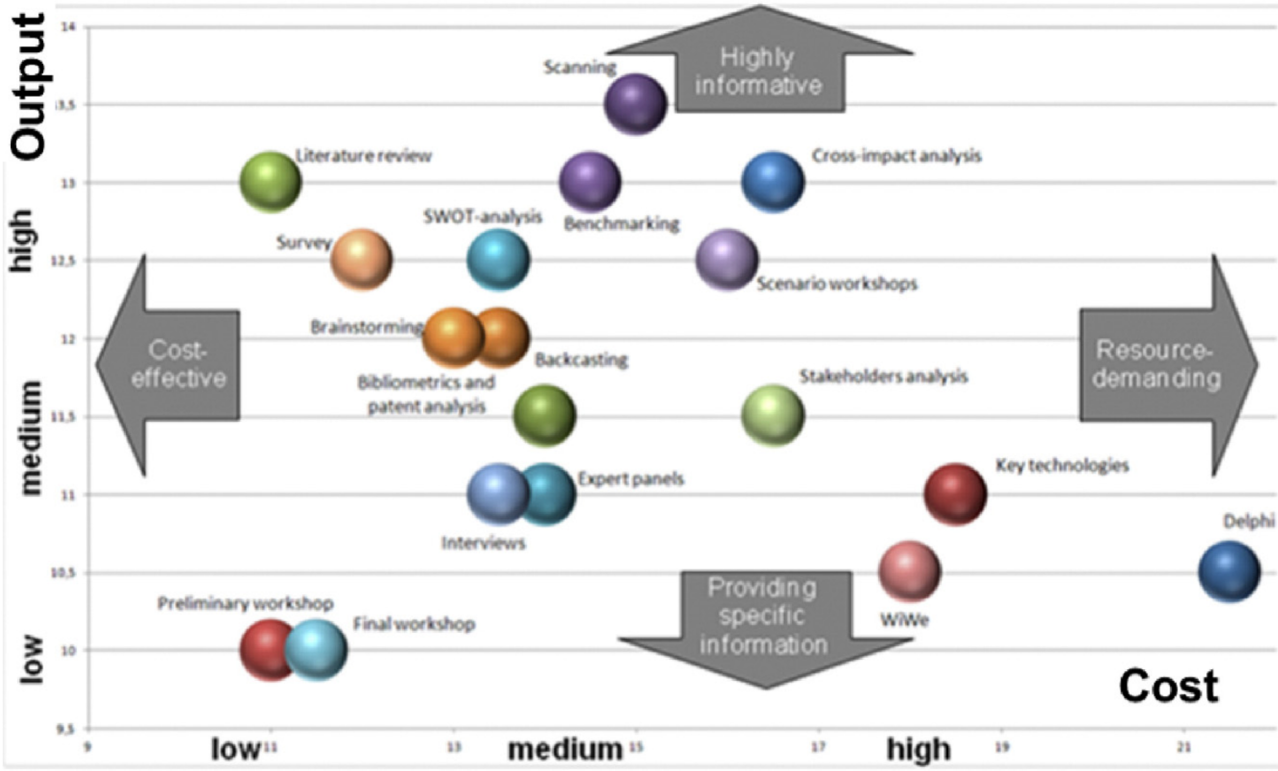

Fig. 5. Effectiveness of Foresight methods.

ii) *Special requirements for analysts* include the use of special skills for data processing (1 — general skills are sufficient, 4 — deep special skills);

iii) *Complexity of carrying out the activity* reflects the need for special events to implement the method (1 — special activities not required to 4 — complicated activities required);

iv) The *complexity of developing the methodological toolkit* indicates the need to develop a special analytical toolkit (1 — special toolkit not required, 4 — very complicated toolkit);

v) *Complexity of primary data searching and processing and the need for procurement of expensive databases* assesses the degree of using special databases (e.g. patent statistics and bibliometrics on a scale ranging from 1 — no special data required to 4 — expensive database procurement needed);

vi) The *complexity of results* analysis the degree of data processing difficulty (1 — relatively easy to 4 — complicated algorithms of analysis are required);

vii) *Necessity of involving expensive sub-contractors* estimates whether sub-contractors should be brought in from the perspective of the resources invested in sub-contractors and the management of interfaces with sub-contractors (1 — work is done by own personnel, 4 — sub-contractors need to be engaged).

Second, *output* is measured by evaluating their effectiveness and efficiency. Criteria for evaluating this include:

i) the *opportunity to use the results in decision-making* directly for estimating the extent to which the roadmap method is integrated into the decision-making process (1 — extra processing of data is necessary, 4 — direct use of data possible);

ii) the *effectiveness for technology analysis* which reflects the effectiveness of the method employed for the analysis of R&D and technologies (1 — low utility, hard to study the subject with this method, 4 — high utility);

iii) the *effectiveness for market analysis* showing the effectiveness of the analysis of product prospects and market dynamics (1 — low utility, hard to study the subject with this method, 4 — high utility);

iv) The *precision and objectivity of data* are evaluated by the degree of reliability of method's result (1 — precise and objective data not guaranteed, 4 — quite precise and objective data);

v) The *data completeness* criterion estimates the sufficiency of using data for the purposes of analysis (1 — completeness not guaranteed, 4 — full coverage of studied field);

vi) The *opportunity to receive new creative results* through generating new knowledge (1 — only systematization of existing knowledge, 4 — generation of new knowledge).

The overall assessment is done individually by all team members who were involved in creating the roadmap to assure objective evaluations. All sub indices and the opinions of each participant of the roadmapping process are weighted equally. The assessment shows that the different methodologies are suitable instruments at different stages of the roadmapping and Foresight project (Fig. 5).

This algorithm allows us to choose methods by comparing their difficulty and output. For example, we recommend highly informative and cost-effective methods (literature review, scanning, brainstorming etc.) as a first step. With more time and financial resources, deeper analyses employing wild cards, Delphi methods, and other methods can be carried out.

5. Practical implications

The practical significance of integrated roadmaps becomes evident when considering the broad range of applications arising from innovation strategies. Integrated roadmaps help to determine strategic goals for a thematic area, industry, or company estimate the contribution of innovation to achieving these goals (investigation of alternative ways, so-called “windows of opportunities”) and thus help to choose the most effective applications.

Another practical use of roadmapping is that it works as a way to coordinate stakeholders' actions and events to map out the moments when key decisions must be made.

To elaborate industrial and corporate innovation strategies, integrated roadmaps provide a set of special plans to trace further steps of innovation development.

- First, the *R&D plan* defines the company's or industry's prospective needs and provides a communication plan between producers and knowledge organizations (research institutes, universities and small and medium-sized enterprises). This plan also shows what the opportunities for R&D outsourcing could be.
- The *advanced manufacturing technologies plan* includes estimates of the technological level of the company or domestic industry and a masterplan of necessary actions, their sequence, and timing in this field.
- The *innovative products manufacturing plan* contains estimates of the product line in comparison with competitors and the assessment of links with R&D and the introduction of new technologies. It also takes into consideration possible procurement of production capabilities from abroad.
- The *sales and marketing plan* shows the main ways for distributing innovative products and shows how to create a sales promotion mechanism. It also helps to identify possible future customers.
- Finally, the *innovation commercialization/business plan* integrates all previous stages and provides a set of measures for successful market entry for innovation products, processes, services. The main emphasis is on large and emerging markets, taking into account barriers and constraints. Thus, roadmaps are becoming increasingly important and relevant for building innovation at each stage of the innovation value chain "R&D–technologies–products–markets".

Commercialization plans are assessed using risk-importance analysis (Fig. 6). The risk dimension has 3 gradations: low (necessary to monitor once in 5 years), medium (monitor every 2–3 years) and high (annual monitoring necessary) while the importance axis has the same gradations — low, medium, and high.

The axis 'importance' presupposes social impacts (including new job creation), strengthening actors' competitiveness, profitability, and range of applications (e.g. platform technologies). The larger the circle's diameter in Fig. 6 below, the greater the financial investment required for commercialization.

Fig. 6 shows that commercialization plans in the left quadrants 1–3 are not fruitful at all. The business plans in quadrants 4 and 5 should be regularly monitored since the external business environment is likely to develop in either direction. Hence the risk and importance could potentially change dramatically, which would have major implications for decisions regarding investment. In general, it is the right decision to invest in plans for innovation commercialization located in quadrants 6

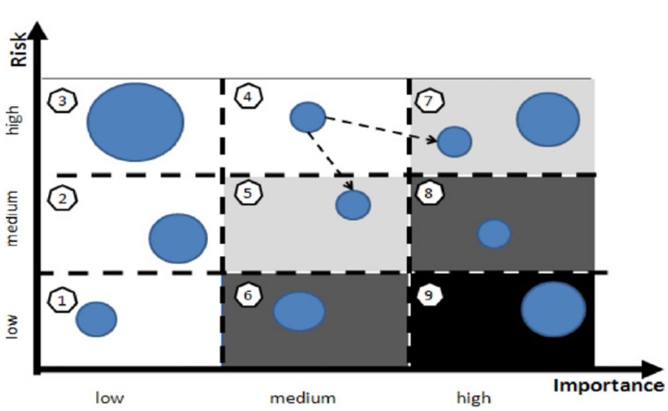

Fig. 6. Estimating the attractiveness of commercialization plans.

and 8, given adequate financial investment. Plans in field 7 are for venture capitalists because they are high risk yet offer high potential benefits. Finally, projects in quadrant 9 may well turn out to be the best investment opportunities. However, each investment decision needs to consider the strategic fit of the opportunity, e.g. the fit with the overarching corporate strategy.

6. Discussion

One of the most contentious questions is the issue of providing necessary resources for the implementation of one or more innovation commercialization plans. For this purpose, our approach presupposes the use of special development routes (Fig. 7) for prospective market segments in addition to basic visualization of the roadmaps. It helps to clarify which products have most potential and to identify these products' existing and target properties that make them competitive in the long-term enabling them to meet consumer demand. Our approach also gives an opportunity to choose the necessary R&D and other innovation-related activities for each year over the long-term and estimate related cost. Another useful feature of the development route is consumer requirements' rating that shows which characteristics are most significant for customers.

Development routes include stakeholders' actions such as intervention points when a decision has to be taken regarding the need to import technology or new equipment, or the need for government actions such as legislative changes that may be vital for further development. These stakeholders' actions should be made at each stage of the innovation/technology value chain — knowledge generation, production, and market. The roadmapping developers play a coordinating role in this process.

Thus, development routes show which decisions should be taken in the spheres of R&D and technology development in order to meet market requirements and make a commercialization plan successful.

6.1. Illustration of the technique using a case study of nanotechnologies in carbon fiber products manufacturing

The methodology was tested in more than 5 pilot projects for particular product groups (e.g. carbon fibers, light-emitting diodes, catalysts for oil processing) or whole industries (space and aircraft industry, nuclear energy, medicine, etc.). In this section, we describe a roadmap for nanotechnologies development for use in carbon fibers. The pilot application was based on a wide expert base and involved representatives of 40 key enterprises of the field, both manufacturers and consumers, and research institutions. The project participants had to meet strict qualification requirements:

i) to represent leading organizations in the sphere of R&D, manufacturing, and consumption of carbon fiber and derived products;
ii) to have objective results confirming their position (academic title, publications with a high citation index, regular participation in leading scientific events of the field) and a high professional reputation.

An expert group with 90 specialists was formed representing leading Russian organizations that specialized in carbon fiber design and production as well as a number of consumer organizations. Moreover, foreign experts participated actively in designing the roadmap. The pilot test considered the methodological approaches of leading Foresight organizations and analyzed subject related information and documents. The latter included "Toray's Strategy for Carbon Fiber Composite Materials" (Anon, 2008) and "Low Cost Carbon Fiber Research in the ALM Materials Program" (Warren, 2009). Each of the methods used contributed to achieving the overall goal (Table 5) and the roadmap was a conclusive document integrating the results of different analytical and expert procedures.

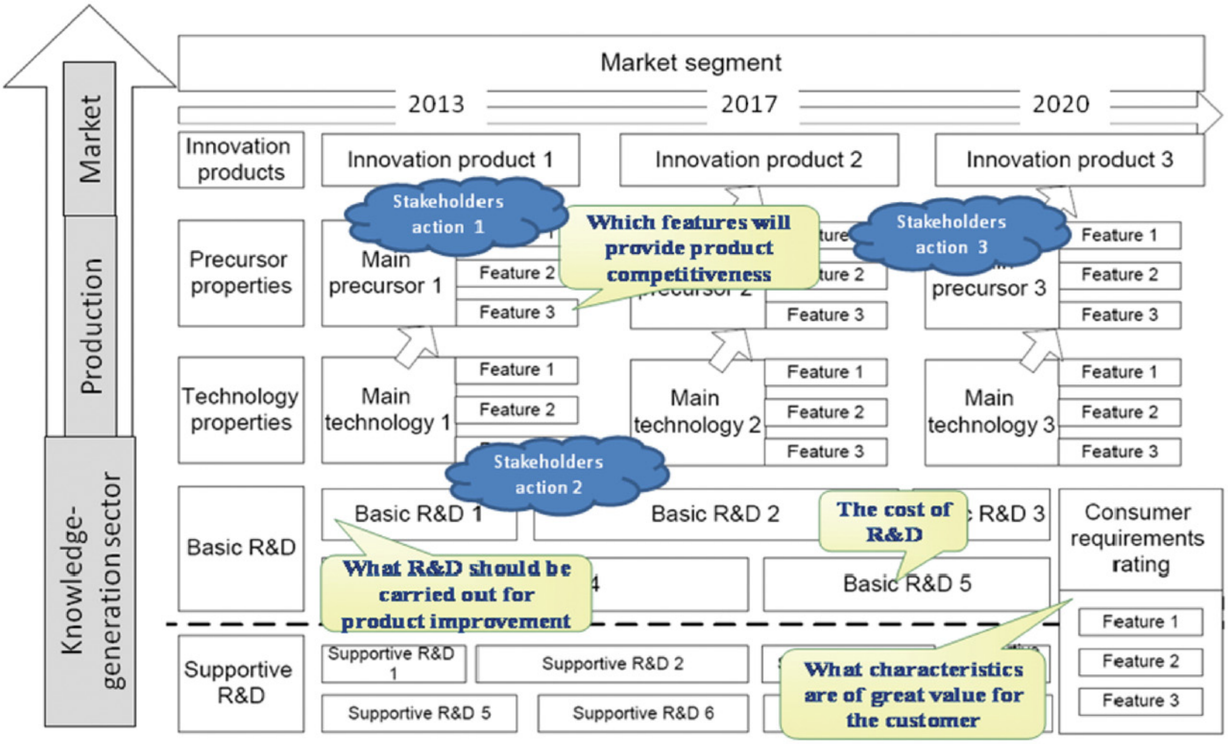

Fig. 7. Example of a development route.

As shown by the overview, the pre-roadmapping stage differs from the framework scheme described in the methodology chapter. This occurs because Delphi, surveys, and key technologies are used to choose the area for analysis (Vishnevskiy et al., 2015b).

A number of Foresight methods have influenced the structure of the final roadmap. Thus on the basis of desk research in the field of nanotechnologies, a preliminary version of the roadmap visualization was created, the key challenges for developing a product group were

Table 5
Characteristics of Foresight methods applied while designing the roadmap "Use of nanotechnologies in the manufacturing of carbon fiber products".

Method	Impact on achieving the research goal
Pre-roadmapping	
Workshop	• Main research directions drawn up
Desk research	
Literature review	• Study of existing roadmap methods, and identified 'best practices' in the research area • Collection of initial information for the description of prospective markets, products, technologies, scientific and technological resolutions.
Bibliometric and patent analysis	• Identified the modern trends and advanced products and technologies in the subject field • Preliminary list of Russian and foreign experts for expert group made
Benchmarking	• Determination of key development challenges for carbon fiber product group in Russia in the context of world-wide trends • List of perspective types of carbon fibers drawn up
Scanning	• External environment of carbon fiber and composites production analyzed
Expert procedures	
Interviews	• List of the most prospective products together with an indication of carbon fibers and their composites manufacturing and also high-important production technologies made • Collection of information about key characteristics and development prospects of carbon fibers and composites
Expert panels	• Verified list of the most important technologies and products • Discussion and assessment of future market dynamics and factors influencing market development in the long-term
Creative analysis	
Backcasting	• Idea about the expected state of the subject field developed
Cross-impact analysis	• Development of trajectories "R&D-production-market" • Assessment of interactions between products and technologies characteristics and also preferable consumer features in different segments of the market
SWOT-analysis	• Determination of strong and weak sides, assessment of opportunities and threats for the development of domestic carbon fiber and composites production
Wild cards and weak signals	• Determined carbon fiber application fields, the development of which can eventually lead to the appearance of new, large market segments
Stakeholders analysis	• Possible stakeholders of the roadmap and ways that they can use the roadmap identified
Brainstorming	• Linkages between different elements of the roadmap identified
Interactive discussion	
Scenario workshops	• Development of alternative paths of product group development
Workshops	• Public discussion of roadmap • Disseminate the main results among a broad spectrum of stakeholders
Roadmap	• Document that summarizes results of all previous steps of the research project

overcome, and a list of prospective types of carbon fibers created (Vishnevsky and Karasev, 2010; Vishnevskiy and Karasev, 2014).

In addition, expert interviews were carried out by qualified interviewers who had a clear understanding of the problem. In-depth interviews were useful for elucidating the positions of all concerned market participants engaged in the development, production, and consumption of carbon fibers. To solve the problems mentioned by interviewees, a number of expert panels were held to discuss the significant technological and broader problems of business management regarding new materials. These expert panels drew up a list of the most important and promising technologies and products along with detailed descriptions of necessary government actions.

A significant part of the research process was the creative analysis that made it possible to evaluate the interconnection between technology related decisions, consumer characteristics of products, and end consumers' needs. As a result, the indispensable measures for creating specific products and for stimulating demand in separate market segments of carbon fiber consumption were identified.

One of the most frequently used methods is admittedly scenario analysis, which enables alternative possibilities about the future. In creating the roadmap, scenario analysis helped in developing market size forecasts and analyzing development trajectories of alternative technologies that compete with carbon fiber in different market segments.

The roadmap was formed on the principle of layered grouping of its elements. By "layer", we mean a set of one-type elements of a roadmap — products, technological solutions, scientific research results — which are assessed against a common time scale. This makes it possible to forecast hypothetical time slots for the appearance of technologies and products, estimate the potential dynamics of segments of the carbon fiber market and to derive conclusions about the necessity and relevance of related R&D.

The Roadmap includes six major layers (see Fig. 8):

1. Main technological trends, innovations and alternative directions of development in the field of carbon fibers and respective composites;
2. Most prospective products based on carbon fibers and time of their anticipated market maturity;
3. Applications and market prospects of products based on carbon fibers, forecasts of volume, and growth rates of key market segments;
4. Alternative technologies, their competiveness and major competitive advantages;
5. Forecast of most important consumer and application properties of carbon fibers;
6. Main barriers and limitations for the carbon fiber industry

The roadmap (Fig. 9) discloses the correlations between the key technologies determining the progress of the carbon fiber industry, namely the properties of current and advanced carbon fibers and carbon fiber composites, and prospective products and their respective market shares (Vishnevsky and Karasev, 2010).

The central layer of the roadmap is based on an expert assessment of the long-term prospects of the carbon fiber market and its segments (3rd layer) – both existing and future market segments. The scenario analysis was most appropriate to assess market development. The roadmap reveals three possible market segments development paths — pessimistic, moderate, and optimistic. These scenarios were formed in accordance with the likely factors determining the future of the carbon fiber market. The most important factors are varying consumer preferences, regulatory restrictions, and political factors (e.g. the need to be present in strategic regions presupposes research into materials that are capable of withstanding extreme service conditions).

This case study shows that the main applications for carbon fiber are currently in the aerospace industry. However, its applications are expanding to other sectors such as construction, energy, and automobile industry. The roadmap helped to distinguish the most promising group of market segments. Here additional criteria such as the strategic and social importance of an application field, market volume and dynamics, and degree of competition from alternative materials were taken into account.

While defining the roadmap, special attention was paid to the analysis of alternative types of new materials that are, or might become, substitutes for carbon fiber, namely innovative composites such as basalt plastic derived from basalt fiber and traditional materials (e.g.

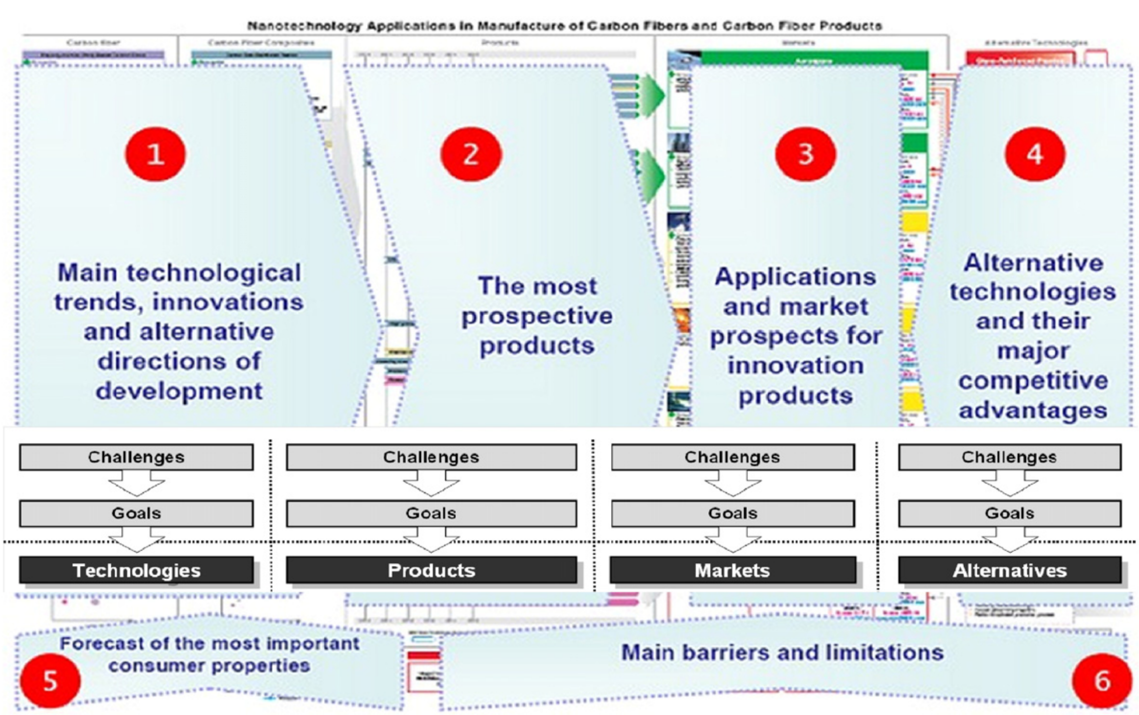

Fig. 8. Structure of the roadmap "Nanotechnology applications in the manufacture of carbon fibers and carbon fiber products".

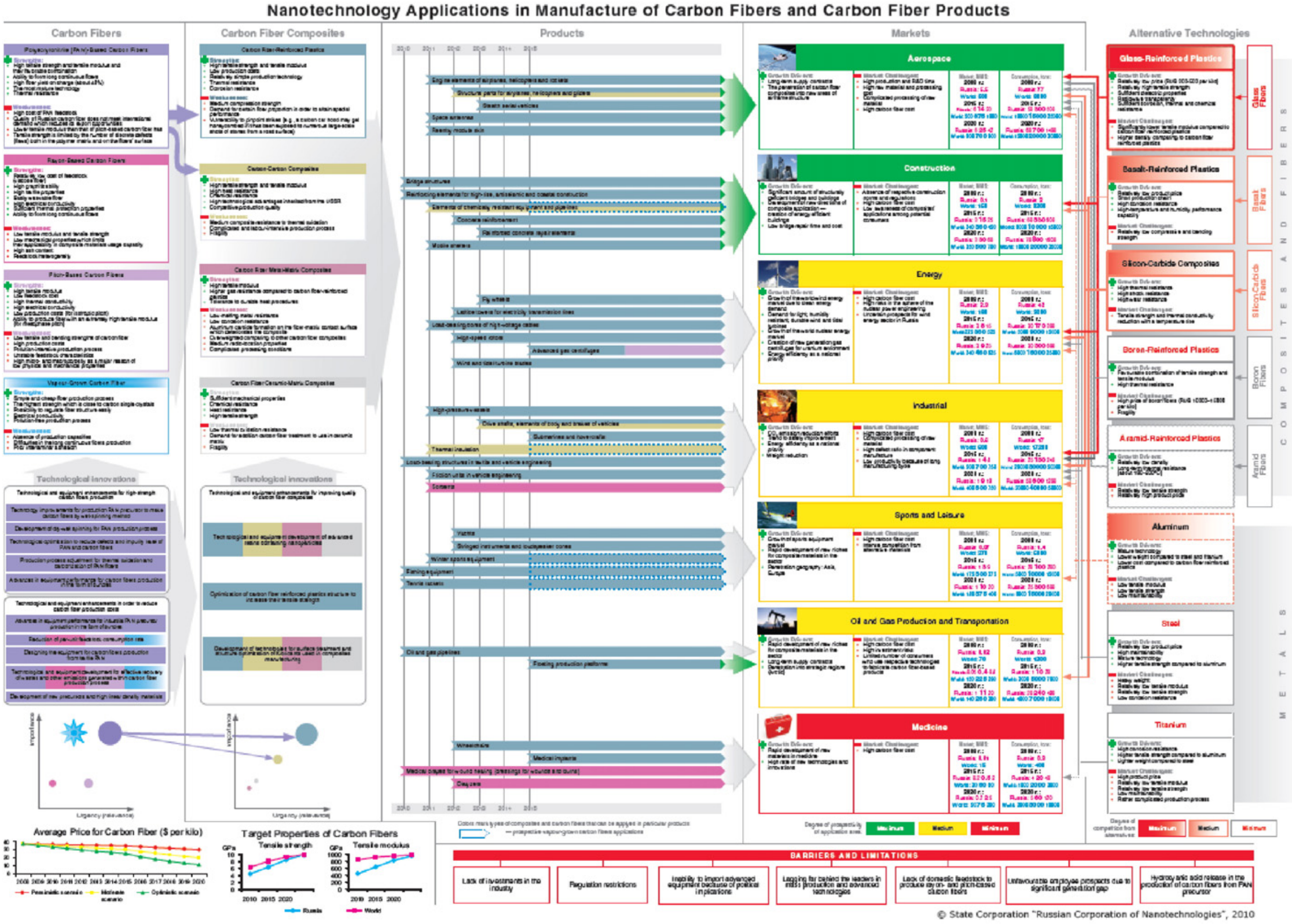

Fig. 9. Structure of the roadmap "Nanotechnology applications in manufacture of carbon fibers and carbon fiber products".

aluminum and steel). Moreover, the roadmap includes several examples of wild cards. The most obvious of them is the development of vapor-grown carbon fibers. These fibers are likely to have a broad market in future, but research into these technologies is not yet at the commercialization stage as there are a number of technological challenges hindering their commercialization.

A study of risks, barriers and other restrictions complemented the analysis of the technological and market prospects of carbon fiber in Russia. An example of such risks is the possible shutdown of the Baikal Pulp and Paper Mill that threatens the production of bleached cellulose, a raw material for the production of carbon fiber based on viscose. This analysis is useful for the early detection of potential obstacles that might emerge and hence should be considered carefully in the investment stage of supporting a new technology field.

Directions of innovative development in the carbon fiber field were elaborated in the roadmap and were later analyzed in more detail. Hence, the roadmap can identify paths for every market segment. A development route includes a sequence of actions for every stage of the technology development process, which eventually increases the likelihood of a successful entry into a market segment. Moreover, R&D approaches were identified which are indispensable for the development of carbon fiber and composites characteristics, their influence on consumer characteristics of products, and finally, market entry prospects of products with such features.

Development routes help to analyze the whole technology chain for innovative products, starting with R&D and concluding with the organization of mass production. Consequently, it is possible to estimate the kind of product that should be designed and the role of science and R&D for successful market entry.

However, it should be noted that market entry routes differ radically from each other. For example, for the creation of space equipment, materials with extremely high physicochemical characteristics are required. In contrast, for mass sport equipment, the low price of a final product plays an important role in ensuring competitive advantage over existing products. Therefore, the implementation of the two mentioned trajectories requires the production of carbon fibers with different consumer or application features that in turn presuppose a solution of different technological problems.

7. Results

The integrated roadmap can be used on the one hand, as a tool for external positioning, consolidation of efforts for the development of priority sectors and areas (external function) and on the other hand, as a mechanism for the development of strategic management within the corporation itself (internal function).

Roadmaps within the investment planning of corporations are designed to solve two types of problems:

- Creation of crucially new mechanisms for the projects' selection related to the active search for projects in priority areas by means of:
  - i. bids on technology projects;
  - ii. bids for the organization of the production of specific products;

iii. calls for proposals for the production of products within the priority areas.

- Development of existing mechanisms of expertise of projects proposed by applicants on their own initiative.

One of the main results of roadmapping is enabling corporations to estimate the future directions of possible roadmap results and their relevance to a wide range of key stakeholders in addition to direct customers (Fig. 10). An integrated roadmap can be useful for forecasting the development of innovative products, services, processes, and applications. It can also become an integrated part of business planning for companies and public authorities. There are four main roadmap beneficiaries:

1. *Federal and regional authorities (government)* could use the integrated roadmap's results to estimate the most likely directions of innovation development and respective policy making;
2. *Manufacturers of innovation products* may use integrated roadmaps as a tool to change their business orientation in periods of rapidly changing circumstances of business innovation and to produce goods that will be in reasonable demand in the future;
3. *Investors* can employ integrated roadmaps as an instrument to make well-founded choices about the most prospective investment opportunities and niches;
4. *Innovation networks* including the knowledge-generation sector and expert communities can develop their R&D programs based on integrated roadmaps to increase the probability of doing relevant and needed research.

The elaboration of integrated roadmaps and development routes made it possible to generalize experts' views on how to achieve innovative development in a sector. The pilot test favored concerted views on approaches to further actions at the level of all key organizations in the field of R&D and the real sector of the economy.

It is expected that the roadmap will favor the formation of civil markets for carbon fiber products and will help systematically improve its consumer characteristics to satisfy future demand. In the event of a fall in the price of carbon fiber, it will become possible to broaden its applications to other fields beyond nanotechnology. A rise in composite materials' quality in turn will make domestic carbon fibers increasingly competitive in comparison with foreign analogs, presenting a possibility for new types of final products including new generation aircrafts.

8. Conclusion

The integrated roadmap is a methodology supporting the assessment of innovation opportunities to choose the most effective application areas and achieve strategic goals. It describes the production and market entry perspectives for innovative products/processes/services with given characteristics based on comprehensive forecasts of markets, products, technologies, and science. Each of the elements of an integrated roadmap is assessed with an emphasis on the timeline for actions and events. We also combine normative and positive approaches: 'from the future to the present' and 'from the present to the future'.

The integrated roadmap aims to address two types of challenges: introducing new mechanisms of project generation related to active project search in the top-fields (such as announcing certain technologies production lots, holding calls of proposals for making products within the top-fields frame), and developing traditional mechanisms of investment project expertise.

It helps to reveal and visualize the goals and alternative development strategies for branches, product groups, and companies. Thus,

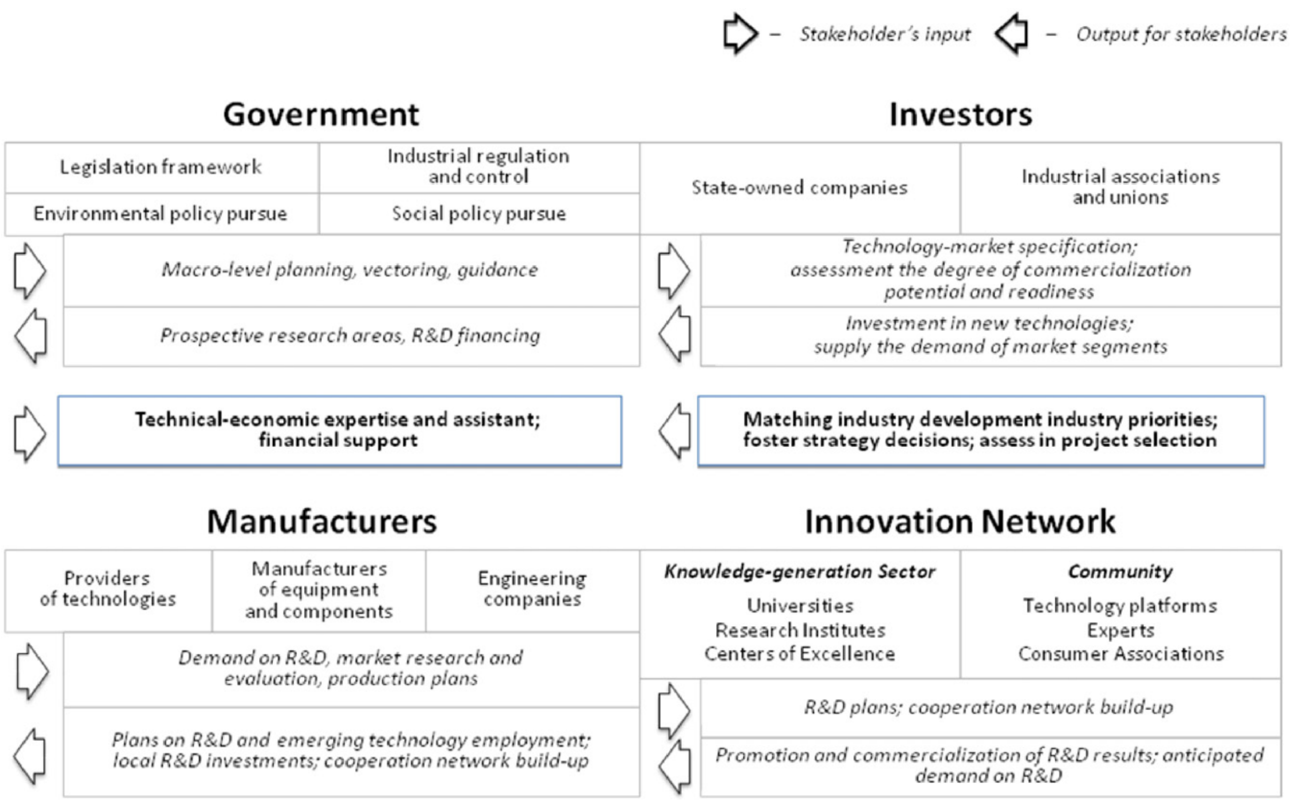

Fig. 10. Key roadmap stakeholders and directions of using roadmapping results.

integrated roadmaps provide a set of trajectories of innovation development and present an opportunity to make a scientifically grounded choice of preferred trajectories by building variants of interconnected consecutive innovation cycle stages. It coordinates all stakeholders' actions and shows their key decisions. In the final analysis, the roadmap is updated continuously which means it plays an important role in decision making.

The main limitation of the integrated roadmapping methodology is the quality of expert judgments. However, we try to eliminate this limitation by using both expert knowledge-based methods and also evidence-based, creative, and interactive methods. Another ongoing challenge is the comparison of costs and benefits of integrated roadmapping: sometimes strategists do not need detailed analysis. Rather, they could more effectively employ roadmaps that only identify the most preferred trajectories of innovation development. These limitations help us to formulate the following avenues for further research.

First, it appears that in order to enhance the usefulness of integrated roadmapping the use of trend monitoring as one source for roadmaps has potential. Trend monitoring is understood as the continuous analysis of technology development as well as political and society developments. Hence monitoring these trends provides valuable information for roadmapping. The problem of integrating trend monitoring into roadmapping is evident in the validity of information derived from trend monitoring currently, and the respective quality assurance, which is essential. Second, roadmapping has been sufficiently developed as a management tool and also as a strategy development method. We currently lack a profound discussion on the integration of roadmapping and strategy development and the resulting requirements of the optimal structure of roadmaps. Third, development and communication of roadmaps is a sensitive issue for companies since in most cases confidential corporate information may be included. Here the challenge arises to protect the roadmap against competitive intelligence, which implies careful handling and management of tacit expert knowledge provided by external specialists.

The latter issues provide reasonable room for future research and the development of next generation management tools.

Acknowledgments

The article was prepared within the framework of the Basic Research Program at the National Research University Higher School of Economics (NRU HSE) and supported by a subsidy granted to the NRU HSE by the Government of the Russian Federation for the Implementation of the Global Competitiveness Program. The authors are also grateful to Imogen Wade for editing and proofreading assistance.

References

Albright, R., 2006. Roadmapping convergence: on roadmapping for converging technologies: nanotechnology, biotechnology, information technology, cognitive science. In: Bainbridge, W.S., Roco, M.C. (Eds.), Managing Nano-Bio-Info-Cogno Innovations: Converging Technologies in Society. Springer.
Albright, R.E., Kappel, T.A., 2003. Technology roadmapping: roadmapping the corporation. Res. Technol. Manag. 46, 31–40.
Brem, A., Voigt, K.-I., 2009. Integration of market pull and technology push in the corporate front end and innovation management: insights from the German software industry. Technovation 29 (5), 351–367.
Caetano, M., Amaral, D.C., 2011. Roadmapping for technology push and partnership: a contribution for open innovation environments. Technovation 31, 320–335.
Clayton, A., 2008. Technology roadmaps: tools for development. Foresight-Russia 2 (3), 68–74.
Clayton, A., 2009. Roadmapping in developing countries. Foresight-Russia 3 (1), 48–57.
Daim, T., Oliver, T., 2008. Implementing technology roadmap process in the energy services sector: a case study of a government agency. Technol. Forecast. Soc. Chang. 75, 687–720.
Hines, A., 2008. Thinking About the Future: Guidelines for Strategic Foresight. Management Forum Series.
Holmes, C., Ferrill, M., 2005. The application of operation and technology roadmapping to aid Singaporean SMEs identify and select emerging technologies. Technol. Forecast. Soc. Chang. 72 (3), 349–357.
Anon Toray's strategy for carbon fibre composite materials. Tokyo: Toray Industries, Inc. (2008) (URL: http://www.toray.com/ir/pdf/lib/lib_a136.pdf Accessed at: 27–04-2015).
Karasev, O., Vishnevskiy, K., 2013. A toolkit for integrated roadmaps: employing nanotechnologies in water and wastewater treatment. In: Meissner, D., Gokhberg, L., Sokolov, A. (Eds.), Technology and Innovation Policy for the Future — Potentials and Limits of Foresight Studies. Springer, Berlin Heidelberg, pp. 137–159.
Karasev, O., Vishnevskiy, K., Sokolov, A., 2014. Foresight in Russia. Baltic Rim Economies (6), 49.
Khripunova, A., Vishnevskiy, K., Karasev, O., Meissner, D., 2014. Corporate foresight for corporate functions: impacts from purchasing functions. Strateg. Chang. 23 (3–4), 147–160.
Kim, C., Kim, H., Han, S.H., Kim, C., Kim, M.K., Park, S.H., 2009. Developing a technology roadmap for construction R&D through interdisciplinary research efforts. Autom. Constr. 18, 330–337.
Konnola, T., 2007. Innovation roadmap: exploring alternative futures of industrial renewal. Conference of Corporate R&D (CONCORD), Seville, 8-9th October.
Lee, J., Lee, C.-Y., Kim, T.-Y., 2009b. A practical approach for beginning the process of technology roadmapping. Int. J. Technol. Manag. 47 (4), 306–321.
Lee, S., Park, Y., 2005. Customization of technology roadmaps according to roadmapping purposes: overall process and detailed modules. Technol. Forecast. Soc. Chang. 72, 567–583.
Lee, S., Kang, S., Park, Y., Park, Y., 2007. Technology roadmapping for R&D planning: the case of the Korean parts and materials industry. Technovation 27, 433–445.
Lee, S., Yoon, B., Lee, C., Park, J., 2009a. Business planning based on technological capabilities: patent analysis for technology-driven roadmapping. Technol. Forecast. Soc. Chang. 76 (6), 769–786.
Lichtenthaler, U., 2008. Integrated roadmaps for open innovation. Res. Technol. Manag. 51, 45–49.
Meissner, D., 2012. Results and impact of national Foresight studies. Futures (44), 904–913.
Meissner, D., 2013. Instruments to measure Foresight. In: Meissner, D., Gokhberg, L., Sokolov, A. (Eds.), Science, Technology and Innovation Policy for the Future — Potentials and Limits of Foresight Studies. Springer, Heidelberg/New York/Dordrecht/London, pp. 43–62.
Miles, I., 2002. Appraisal of alternative methods and procedures for producing regional foresight. Report Prepared by CRIC for the European Commission's DG Research Funded STRATA — ETAN Expert Group Action. CRIC, Manchester, UK.
Phaal, R., Farrukh, C., Probert, D., 2001. T-plan: the fast start to technology roadmapping: planning your route to success. Institute for Manufacturing, University of Cambridge, Cambridge, UK.
Phaal, R., Farrukh, C., Probert, D., 2004. Customizing roadmapping. Res. Technol. Manag. 47 (2), 26–37.
Popper, R., 2008. How are foresight methods selected? Foresight 10 (6), 62–89.
Saritas, O., 2006. Systems Thinking for Foresight, PhD. Thesis. Policy Research in Engineering Science and Technology (PREST), The University of Manchester, UK.
Schaller, R., 2004. Technological innovation in the semiconductor industry: a case study of the International Technology Roadmap for Semiconductors (ITRS) PhD dissertation .
Spithoven, A., Clarysse, B., Knockaert, M., 2011. Building absorptive capacity to organise inbound open innovation in traditional industries. Technovation 31 (1), 10–21.
Vishnevskiy, K., Karasev, O., 2014. Foresight and roadmapping as innovative tools for identifying the future of new materials. Maint. Probl. 91 (4), 5–14.
Vishnevskiy, K., Karasev, O., Meissner, D., 2015a. Integrated roadmaps and corporate foresight as tools of innovation management: the case of Russian companies. Technol. Forecast. Soc. Chang. 90, 433–443.
Vishnevskiy, K., Meissner, D., Karasev, O., 2015b. Strategic foresight: state-of-the-art and prospects for Russian corporations. Foresight 17 (5), 460–474.
Vishnevsky, K., Karasev, O., 2010. Identifying the future of new materials with the use of Foresight methods. Foresight Russia 4, 58–67.
Voros, J., 2003. A generic foresight process framework. Foresight 5 (3), 10–21.
Warren, C.D., 2009. Low cost carbon fibre research in the ALM materials program. Oak Ridge National Laboratory, Oak Ridge.
Wells, R., Phaal, R., Farrukh, C., Probert, D., 2004. Technology roadmap for a service organization. Res. Technol. Manag. 47, 46–52.
Willyard, C.H., McClees, C.W., 1987. Motorola's Technology Roadmap Process. Res. Manag. 30 (5), 13–19.

Konstantin Vishnevskiy is the Head of the Department for Private–Public Partnership in Innovation Sector at the Higher School of Economics (Moscow, Russia). He holds a PhD from Moscow State University, Faculty of Economics. Topic of his dissertation: "The Role of Foresight in Government Innovation Policy". Konstantin has long standing experience in the development of roadmaps, the elaboration of Foresight methodology and corporate innovation development programs, the integration Foresight into government policy as well as financial and econometric modeling. He participated and led groups in many high-level research projects on Foresight of S&T development on national and regional level both in Russia and abroad. He authors about 50 scientific publications on long-term planning and Foresight, roadmapping, macroeconomic regulation and government policy, programs of innovation development for business. He made about 50 reports on professional conferences and workshops concerning Foresight, roadmapping and innovations.

Oleg Karasev is the deputy director of the Foresight Center at the National Research University — Higher School of Economics (HSE) Moscow. Prior joining HSE Oleg was a deputy director of Chair of macroeconomic regulation and planning at Moscow State University. He holds a PhD from Moscow State University, Faculty of Economics. He has long lasting experience in macroeconomic forecasting, Foresight, development of corporate innovation strategies and recommendations related to state innovation policy. Oleg elaborated the concept, methodology and instruments for different Foresight studies including technology roadmaps, forming of S&T and innovation priorities using Delphi survey and critical technologies. He participated and led different research projects on Foresight of S&T development on national and regional level, creation of innovation strategies for leading Russian corporations, study of future innovation markets, improvement of Foresight methodology.

Dirk Meissner is the Deputy Head of the Laboratory for Science and Technology Studies at HSE. He has 15 years of experience in research and teaching technology and innovation management and policy. He has a strong background in science, technology and innovation for policy making and industrial management with a special focus on Foresight and roadmapping; science, technology and innovation policies; funding of research; and priority setting. Prior to joining the HSE, Dirk was responsible for technology and innovation policy at the presidential office of the Swiss Science and Technology Council. He also has long experience in top-level consulting to key decision makers in industry; headed the business unit industry studies and research with T.A. Cook Consultants, which he successfully established; and was management consultant for technology and innovation management with Arthur D. Little. Dirk was and is a member of international working groups on technology and innovation policy. He represented Switzerland and, currently, the Russian Federation at the OECD Working Party on Technology and Innovation Policy.