Lyubov Y. Matich[1]

ROADMAPS AS A TOOL FOR MODELING COMPLEX SYSTEMS

Today roadmaps are becoming commonly used tool for detecting and designing a desired future for companies, states and the international community. The growing popularity of this method puts tasks such as identifying basic roadmapping principles, creation of concepts and determination of the characteristics of the use of roadmaps depending on the objectives as well as restrictions and opportunities specific to the study area on the agenda. However the system approach, e.g. the elements which are recognized to be major for high-quality roadmapping, remain one of the main fields for improving the methodology and practice of their development as limited research was devoted to the detailed analysis of the roadmaps from the view of system approach.

System analysis can make the process of roadmap development easier because it identifies six key stages, the implementation of which is necessary for the construction of any roadmap. Two case studies undertaken in the paper demonstrate the implementation of system approach for roadmap creation in the Russian companies and industries.

JEL classifications: O21, O31, O32.

Keywords**:** technology roadmap, roadmapping, systems analysis, system modeling

[1] National Research University Higher School of Economics, lmatich@hse.ru

Introduction

Roadmaps have gained popularity as a tool for forecasting and planning in many countries during the last decade. For example, the United States, Canada, the EU, Japan, China, Korea, Singapore, Malaysia and other countries develop roadmaps to identify the most effective actions targeted at supporting technologies, products and their combinations in order to develop and maintain national competitive advantage and reduce the influence of negative challenges.

For more than 20 years innovation leaders such as Intel, Microsoft, SAP, Samsung, as well as international associations and agencies like International Energy Agency, and National Aeronautics and Space Administration use instrument “roadmaps” to plan the release of innovative products [NASA, 2015; IEA, 2011]. Roadmaps demonstrate a high level of flexibility

and adaptability to the specific objectives of the organization, customizable design activities carried out by the experts (Delphi method, thematic workshops, expert panel), and as a result, extensive integration and coordination of opinions (interests) professionals from multidisciplinary fields. Today the tool is used on almost every level including national, sub-national, regional, sectoral and corporate [Vishnevskiy et al, 2016].

The increasing complexity of social and economic relations – which often form the objects of roadmapping — determines an increasing complexity of roadmap development, e.g. roadmap structure and contents are becoming increasingly complex which is why instead of sole products and technologies whole product groups and alternative development paths are analyzed. Also for strategic decision-making it isn’t sufficient anymore to employ individual roadmaps but developed system or a series of roadmaps [Phaal et al, 2011]. The complexity of goal-setting, strengthening the relationship between the different areas confirm the growing role of the roadmap methodology, a significant contribution to the development of which was made by R. Phaal, D.R. Probert [Phaal et al, 2001]; S.J.P. Farrukh [Phaal et al 2004], D. Fenwick, T.U. Daim [Fenwick et al, 2009]. R. Phaal, based on long experience of research in this field, has developed several approaches of building a recreation center, the most famous of which is T-plan, aimed at simplifying and formalizing roadmapping [Phaal et al 2001]. A modified version of this, characterized by a more dynamic, flexible and operational approach was proposed few years later [Phaal et al, 2004; Gerdsri, Kocaoglu, 2007].

Scholary discussion has developed a wide range of approaches towards roadmapping including differing process models and methods (Table 1).

Tab. 1. Leading organizations and researchers, developed approaches to roadmapping

Organizations	Researches
The Danish Technological Institute	T-plan R. Phaal
Technology Futures	Modified T-plan R. Phaal
The British Petrolium Company	Four-part schema R. Albright
University of Manchester	B. Park
The Institute for Systems and Innovation Research Fraunhofer	O. H. Bray and M. L. Garcia
United Nations Industrial Development Organization (UNUDO)	B. A. Vojak and F. A. Chambers
The Institute for Prospective Technological Studies of European Commission	N. Gerdsri and D.F. Kocaoglu
	S. Lee and Y. Park

Source: HSE

Analysis 15 development technology roadmaps approaches (see Table 1) revealed a number of parameters in which they differ including the result of the process, methods used and number of participants, adaptation to the goals of the organization and importance of consensus. Accordingly the three groups of approaches can be formed:

– *Approaches focused on the process of roadmap development.* These are relatively simple approaches, each of which is a modified version of the previous one — the standard development process R. Phaal roadmap (T-plan), four-part schema R. E. Albright and a modified T-plan R. Phaal [Albright, 2003]. They are characterized by a relatively rapid identification of information necessary to the technology roadmap (four to five seminars without the involvement of a large number of experts). Their main disadvantage is the risk of neglect of opening to the opportunities and challenges the organization.

– *Approaches aimed at reaching a consensus* (B. Park approach, the Danish Technological Institute, University of Manchester, British Petrolium Company, UNIDO, the Institute for Systems and Innovation Research Fraunhofer, etc. [Park, 2007; Fenwick, Daim, 2009]). The approaches of this group are characterized by a complex process: the use of a wide range of different types of methods (oriented interaction, evidence, creativity and expertise), attracting a large number of experts from multidisciplinary areas, serious analytical work. Roadmaps on the basis of these approaches, as a rule, are developed by specialized organizations and are used to determine the priorities of development of industries or solving complex interdisciplinary problems.

– *Approaches focused on compliance with the objectives and strategy of the company*. These approaches are, first and foremost, approach British Petroleum, method development technology roadmap for research planning and development approach and S. Lee, Y. Park [Park, 2007; Lee et al, 2007; Lee, Park, 2005]. They are focused on the adaptation of the roadmap's structure to specific objectives, but require a high level of professionalism roadmap developers and do not always imply participation of external participants.

The information contained in the public domain on each of the approaches of these groups, characterized by certain aspects of the development of roadmaps and does not form a complete picture of all the key stages of roadmapping. For example, different approaches offered various stages of development roadmap. Approach TechStrategy has developed by S. Lee and Y. Park, including four basic steps of creating a roadmap: 1) initiation, 2) assessment of operational needs, and 3) development of technological behaviors, 4) a report of the TRM [Lee et al., 2007]. C. Cagnin select another three key stages of the process: 1) diagnosis, 2) prognosis and 3) recommendations [Cagnin, 2009]. Building scientific and technological roadmap (BP approach) involves the following steps: 1) research planning, 2) technology planning, 3) product planning, 4) marketing Planning and roadmap visualization [Fenwick et al, 2009]. Consequently, the task of selecting the most appropriate approach for developing a specific roadmap remains intractable. The diversity of roadmapping approaches is also evident in the widespread use of the tool among Russian companies. Recently roadmaps are becoming more and more popular in the Russia as well. The motivation for developing roadmaps varies between industries and companies. Russian companies follow different ambitions in preparing roadmaps which is shown in the their motivation and aims (Table 2).

Tab. 2. Motivation and aims of roadmapping in different industries

Industry	Motivation / aim
Air transport	– Monitoring and control of the implementation of measures necessary for the implementation of innovative development programs of companies
Aviation	– Development and implementation of portfolios required for the development of the Russian aircraft industry advanced R&D – Identification of key technologies for the implementation of the development of aviation technology – Identification of development priorities – Identification of "gaps" between the goals and capabilities of technology development as scheduled
Space industry	– Identify the commercial market for space services, such as satellite signal – Identify possible areas of development commercial systems and methods for their construction
Refining and Petrochemicals, Energy	– Identifying priority technologies needed to achieve company's development objectives (sector) – Assessment promising market segments – Determining ways to interact with the external environment of innovative organizations
Medicine	– Identify assistive technology devices that have significant socio-orientation – Identify commercially promising high-tech assistive technology and devices – Form a strategy of commercialization of high-tech assistive technologies and devices

Source: HSE

However, it showed that the key obstacles towards the use of tool “roadmap” were marked by the high complexity of the roadmap development and confusion of selection criteria relevant for roadmap information. The recent trends towards increasing complexity of social relations, e.g. globalization, the enhancing the role of transnational companies, the variety of business forms and the variety of markets, improved technological systems, growth of research and development of "horizontal" cross-cutting technologies, underpins the growing importance of a systematic approach in all sciences. Hence the roadmapping methods constantly expand and become more complex — from roadmaps for products and technology to roadmaps for product and technology groups and entire industries [Phaal et al., 2011]. In a number of papers mentioned systemic component of the technology roadmaps (TRM), a more detailed examination of this can be one of the most promising directions for improving the development process of roadmap:

– R. Phaal and T. A. Kappel’s TRM is considered as one of the tools to support the process of management, ensuring the identification of dynamic relationships between resources, organizational goals and the changing environment [Phaal et al., 2004; Kappel, 2001].

– A number of publications TRM are classified as methods of technology foresight, which, in turn, aim to study complex systems by systematically, identify areas of technology development, and their potential impact on different aspects of the environment [Porter et al 2004].

– TRM positioned as a tool to identify and provide the right balance between the development of new technologies, business models and political processes by identifying complex system of relations of production, distribution and introduction of technologies [Ahlqvist et al 2012].

Furthermore all approaches include a graphical representation (visualization) of the results in a structured form which is one of the strengths of the roadmaps turning them into a decision-support tool (evaluation of the key conditions required for the development of the company or industry). This is because visualization allows to finding solutions to cross-sectoral and cross-cutting issues, making it possible to visually reflect the different facets of the study area, takes into account the entire life cycle of innovation and has multipurpose use, is used to solve problems of different levels of decision-making and can be integrated into the planning and forecasting process.

A number of parallels between system analysis and the construction of roadmaps from the perspective of the opportunities they provide when used in a certain area can be identified. Systems analysis is used to resolve a problematic situation that challenges a country, company, and team. Technology roadmaps (as one of the types of roadmaps) are also designed to identify the most perspective technologies and products, to identify new competitive markets in order to ensure the competitiveness of the company (industry, country), to solve social and environmental problems. Visual graphical representation of roadmaps is a way of formalization the object of study. A similar formalization is one of the key moments in systems analysis (modeling).

In the authors' opinion, the use of a systematic roadmapping approach will significantly improve the quality of their development, results and positive effects of their use (including the production of products demanded by the market, the development of technologies that provide a competitive advantage to companies and others.). The presence of complex systems with large numbers of interacting elements requires the developer to change the trajectory of the roadmap prediction of the most significant elements and environmental factors. Accounting for such important characteristics as the system elements and their properties, the direction of movement (change), the external macro and micro environment can more accurately reflect the basic parameters of the field, to determine ways and means to achieve the desired result.

The understanding of each element in the systems composition in the roadmapping development process helps to realize, what is important, what is interconnected, where and why the system moves, and, finally, it would be possible to develop such kind of roadmap, where would be taken into account all the main aspects of the studied area (Fig.1).

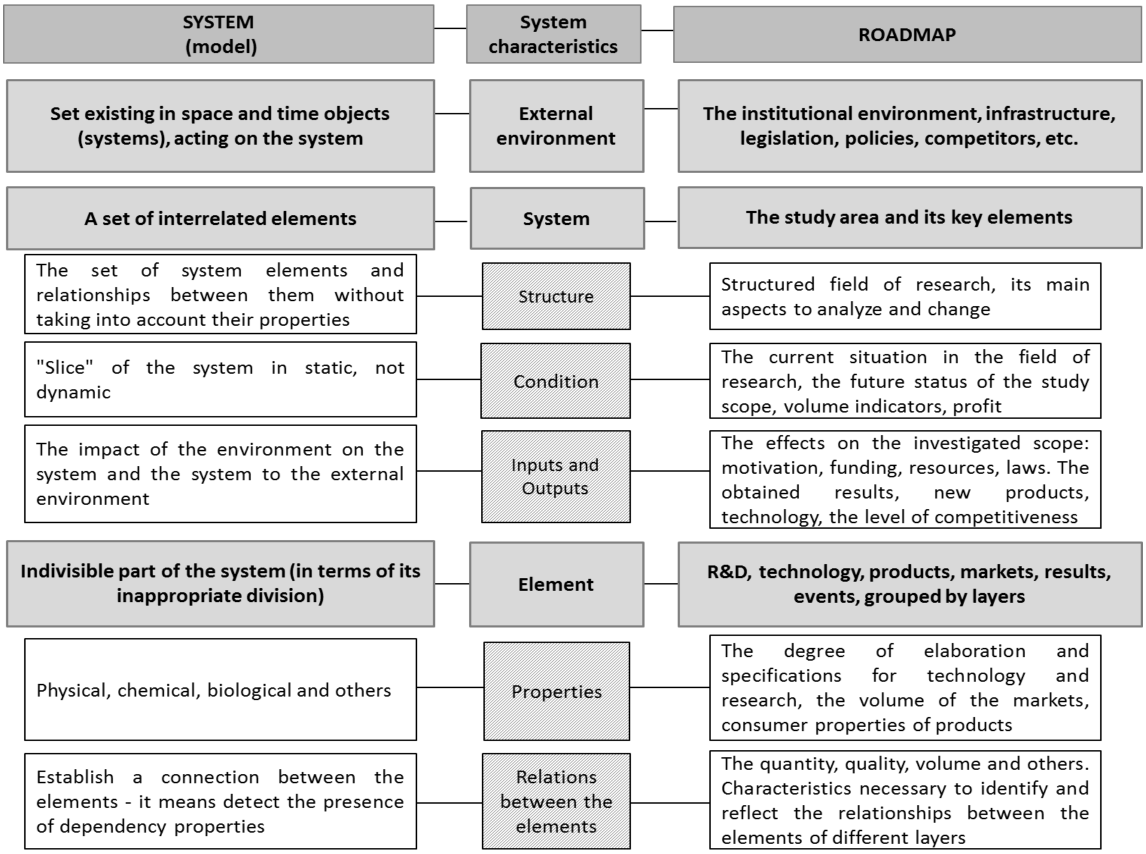


Fig.1. The terminology of system analysis from the perspective of tool "roadmap".
Source: compiled by the author.

The criterion of classification systems “degree of difficulty” [Magee, Weck, 2004] allows to submitting the study area as a group of sub-systems. With respect to roadmaps, this means an increase of their operationality as a complex system can be divided into subsystems and study each of them separately (depending on the level of decision-making and research purposes). As a result, a series of roadmaps, describing different levels of the system (from complex systems to large, from global to local) can be formed. As a consequence, each element of roadmaps can refer either to the system under study, or play the role of environmental factors, being a part of another system (Fig. 2).

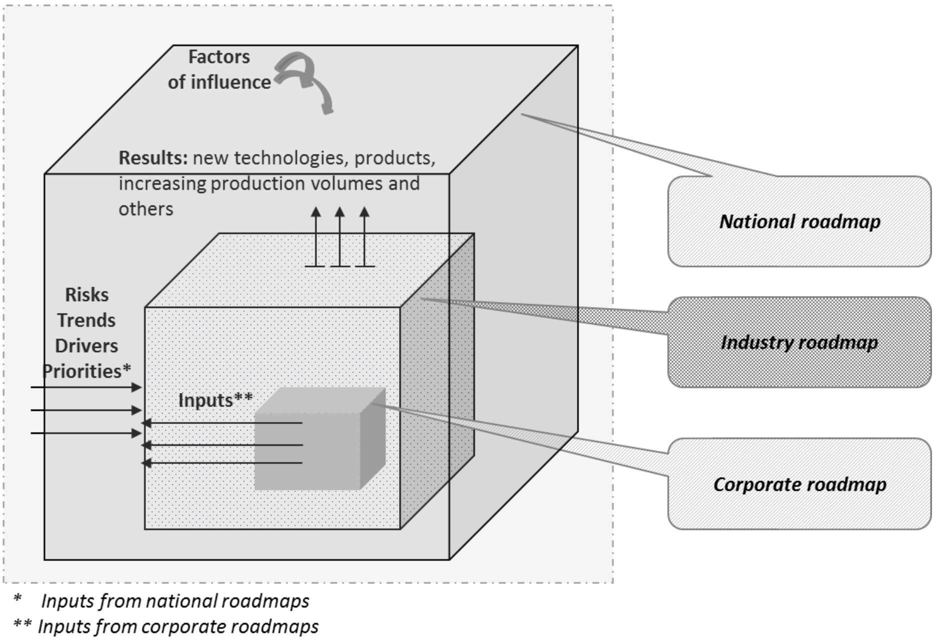


Fig.2. The system embedded roadmaps.

Note: when building a roadmap identifies 1) the most significant elements of the environment (“inputs” — risks, trends, drivers, etc.), 2) The results of operation of the system (“outputs” — results in the form of new technologies, products, etc.).

Source: National Research University Higher School of Economics.

In this case, the roadmap of a higher level (national) will become strategic, and will form the institutional environment and priorities in which companies can develop their own corporate roadmap lower level. As a result of this "nesting" it is possible to form a more coordinated approach to problem solving.

Roadmap development as a process of detailed system model

The graphical representation of the results of the construction of a roadmaps can be considered a way of formalizing the research object, handy for quick reference, a systematic exposition of the scope of research and decision-making. In applied research model system performs a similar function. Simulation is one of the methods of studying complex systems that allow them to describe the most complex and functional, including through the choice of the key elements of their relationship, evaluating the properties in statics and dynamics.

Visual representation of the model is similar to the TRM and contains the most important elements, their relationships and properties of the study area. Accordingly, the main stages of the roadmaps development can be described in terms of the development of models of varying degrees of detail. Accordingly, the basic steps of constructing road maps can be described from the perspective of different modeling granularity: *the black box model*, a model of the structure and the *composition model* (Fig.3).

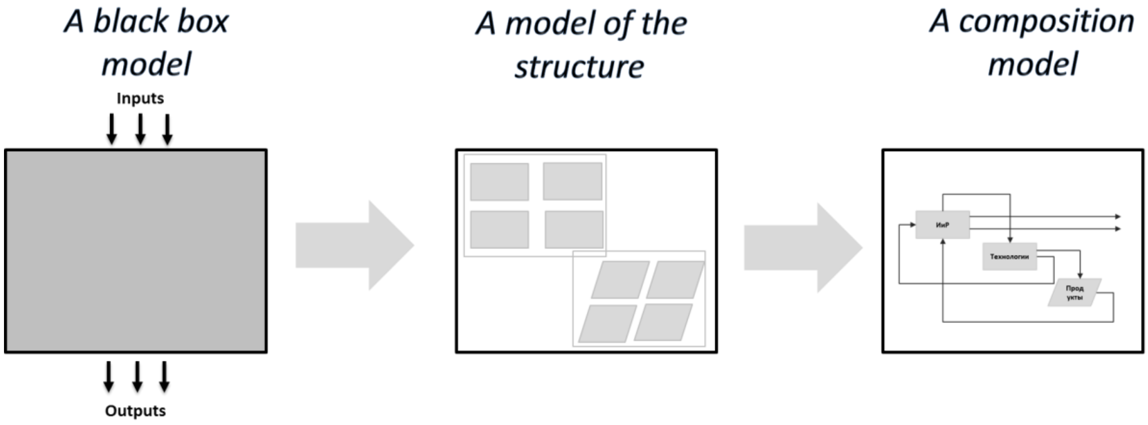


Fig.3. The development roadmap — development of models of varying degrees of detail system. Source: according to sources, dedicated to systems analysis and systems theory [Mesarovic, 1973; Chernishev et al, 2008; Bolshakov et al, 2012, etc].

The simplest model with the maximum degree of generalization is *the black box model*. This means that the main task of roadmapping in this stage is to identify the boundaries of the system, analysis of the near and distant surroundings, namely competitors, potential partners, and other factors influence; identification of the inputs and outputs of the system (the most important factors of influence, economic actors, the expected results, and others).

Next, it is appropriate to analyze in more detail the system itself by developing *a model of the structure*. Depending on the objectives, level of detail and interesting ways to impact on the system, the list of selected items for further work can vary considerably. Their selection, as well as the formation of the optimal structure depends on many factors: the purpose of the roadmap, the extent of the study area, the breadth and complexity of problems, visualization options [Martin, Daim, 2012]. As a rule, in the technology roadmaps (where technology development is seen as a key condition for the solution of existing problems and creating future opportunities (for example, a high level of import dependence, exit barriers to promising markets, low competitiveness)) elements are promising technological solutions, research research and development, innovative products. Elements are grouped into layers, which can be any number of [Probert et al 2003], but usually does not exceed five or six [Gerdsri, Assakul, 2007]. Resources, activities, tasks, organizational units are more characteristic of the management roadmaps.

In the transition to the next stage and construction of the *composition model* that best reflects the final version of the recreation center, a determination content of the relationship between the elements. It becomes important to the absence of a) a logical contradiction (through the use of technologies derived products, a set of products that can satisfy the same type of demand is one market (or a segment thereof) and b) temporary contradictions (the product can not be obtained before the development of technology, if technology developed independently and not purchased from outside).

Since no one model can fully describe and formalize the system under study, it can be formed many variations of relations between its elements. At the stage of system simulation key task is to choose the most important elements and the most "influential" relationships. The significance of this problem is also referred to in many sources about roadmaps. On implementation of interlinkages right technologies and products targeted various methods and technology roadmapping. For example, a number of methods for the development of technology roadmaps can be used to associate elements of scientific and technological proposals with elements of demand [Kostoff, 2001]. M. Dodgson, D.M. Gann, A.J. Salter have noted that the combination of these two approaches («technology push» and «market pull») allows you to develop a common strategy [Dodgson et al 2008]. Other researchers have suggested as one way to most fully reflect all the important relationships to develop an interconnected roadmap, which is based in the account three aspects — technology, marketing, and decision-making process [Fenwick et al 2009].

During the development of the system model (roadmap) a significant place takes into account the dynamics. Directed change of model parameters in a relatively stable part of it is necessary to achieve the objective of bringing the system to the right and a pre-selected state (or at least an approximation to it). Models describing the dynamics are functional. Methodology of development of technological roadmaps has found a way of convenient visual display of the model by defining the temporal characteristics of the elements of TRM as one of their essential properties (visual display of the timeline). The process of identifying the projected timing of the emergence of technology and products based on the extensive methodology, borrowed from various scientific disciplines (method of scenarios, essays, interviews, Delphi and others).

Functional types of roadmaps. Models can be classified into cognitive, pragmatic, and conceptual information. As a consequence, a roadmap as a model of the systems can also be assigned to any of these types, depending on the purposes of the study. For example, if the roadmap is designed for the formation and implementation of the strategy, it can be attributed to the "pragmatic type", as primarily a means of decision support and guide the implementation of practical actions [Anderson, 2008]; to the category of "information type" — if the key objective of roadmap — structuring and description of the study area to get acquainted with all interested parties. It can also be a "conceptual type", the basis of which is to identify and reflect causal relationships, for example, between the possibility of the release of products demanded by the market, and the implementation of the necessary applied research.

Six stages roadmapping: a systematic approach

Long-term practice of construction of roadmaps and records of practical experience allows to developing a systematic approach of development roadmaps (Fig.4), consisting of six stages.

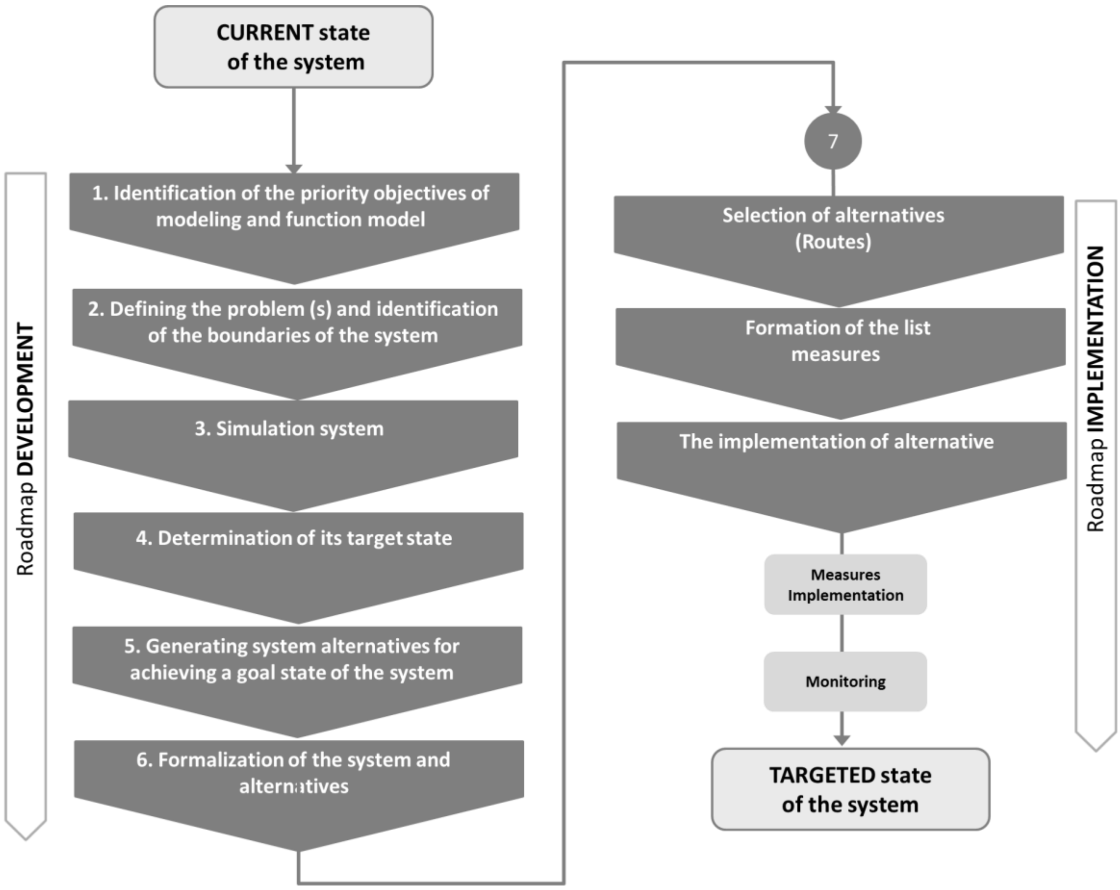


Fig.4. Six-stage for roadmap development.

Source: compiled by the author.

Identification of the priority objectives of modeling and function model (stage 1). At the beginning of roadmap development it is important to define the purpose of the simulation (the goal of roadmap) and function model (roadmap). Practice shows that in roadmapping to simulate the most common is the "optimization", implying the search for and establishment of such combinations of parameters of the model, its elements and their properties, that will ensure the best performance efficiency of the system as a whole (to achieve the desired results of the system). Other modeling purposes (evaluation, comparison prediction sensitivity analysis) are usually optional and may serve to reach the highest priority target. The forecast allows us to estimate the future state of the system at a certain combination of conditions (factors).

The next step is to identify the function that must fulfill roadmap — model of the study area. The results of the analysis of practices in the development of roadmaps allows you to make two key conclusions: on the one hand, one and the same roadmap may be characterized by several features simultaneously. On the other hand, the underestimation priority function early in the process of their construction leads to high complexity roadmap, difficulty understanding and further disuse. Therefore, in order to improve the effectiveness of all subsequent stages it is preferable to prioritize the modeling functions and choose the most important. Typically, the roadmap with the information and cognitive function are not intended as a primary objective changes in the existing system and serve as a means of informing, training stakeholders. Corporate roadmaps, by contrast, are designed to carry a pragmatic function.

Defining the problem (s) and identification of the boundaries of the system (stage 2). Here, the main task is to define the object of research, the identification of the system and its boundaries, which depend on the model and the problems identified goals. The problem may be referred to the customer research, but in some cases it is necessary to conduct a detailed analysis of its detection. In the literature and practice dealing with roadmapping, described a range of different methods for solving such problems (bibliometric analysis, benchmarking, literature review, interviews, statistical methods). After identifying the problems can be defined system boundary, and environmental factors are classified depending on their effects on the solution: they can either be assigned to the elements of the system, either to the far or near environment. Identification of external factors at this stage (trends, threats, opportunities, windows, barriers, wild cards, etc.) Is crucial, since none of the studied areas (systems) is not functioning independently and apart, and its change can not be predicted and planned excluding such factors. The boundaries of the system are determined based on the principle of functionality, ie it and its elements must be consistent with the study, the level of decision-making and planned activities for its amendment.

Simulation system (stage 3) and determination of its target state (stage 4). Performing these stages usually requires a considerable amount of time and resources. In the process of simulation developed three kinds of models with increasing degree of detail (the model of "black box", "structure" and "structure") (this stage has been described in more detail in the previous section). In the modeling stage play a significant role bibliometric analysis, literature review, an audit of the object of research, extrapolation, expert interviews, and others.

After the system has been modeled, it is determined by the desired (target) condition, which may be reflected in the roadmap in a single-layer model (results), or specific values of the properties of elements. The method used to carry out the stage in question may be a patent and bibliometric analysis, research fronts, certification, survey.

Generating system alternatives for achieving a goal state (stage 5) and the formalization of the system (stage 6). The need to generate alternatives due to the scale and complexity of the roadmap that reflects the most important characteristics of the system. In many cases, the customer and other stakeholders, is the implementation of the roadmap in whose area of responsibility, are not able to fully implement it because of objective constraints (timing, resources, ethical issues, long life cycle). In connection with this action developed by several groups (routes alternatives, scripts) that take into account various embodiments environmental changes. Factors that influence the choice of alternatives, may be: the need for quick results, minimization of resources and efforts, the maximum matching environmental conditions, etc. After the formation of alternatives carried out formalization of the model, developed a visual representation of the roadmap and, if necessary, the explanatory note to her.

Implementation roadmap: Choosing alternatives (routes), the formation of the list of activities for the implementation of alternatives and implementation of alternatives (in the introduction). These stages involve the selection and fulfillment of control actions on the system. Developed action plans, formed the program, projects, searches for sources of funding, human resources involved.

Case studies: technology roadmapping through a systematic approach

An approach based on gradual detail models of systems, used for by NRU Higher School the development of technological and management roadmaps Russian companies and industries. Below, in two cases the results of each of the stages in the article under consideration systematic approach.

Case 1: Technology Roadmap development of oil refining and petrochemical industry (the TRM).

The TRM was developed in 2014 at the initiative of The Ministry of education and science of the Russian Federation by NRU Higher School of Economics. At the first stage in the framework of close interaction of the team of the roadmapping with the Ministry identified the *key purpose* of the development and subsequent use of the TRM. It was in the possibility of using the TRM for the selection of applications for research and development. In the medium term the TRM should facilitate the optimization of the study area — to promote import substitution of oil refining technologies and increase of volume of export of oil and petrochemical high value added.

Taking into account key objectives the development and use of the TRM, it was determined that the TRM must fulfil, as a minimum, *two basic functions: a conceptual and pragmatic:*

– The *conceptual function* of the TRM is performed in the case of the presence of clearly defined and consistent relationships. With the features of this study are important causal connections was set the priorities of development of Russian oil refining and the necessary for its decision tasks. Also it was important to define and demonstrate the relationship between tasks and necessary technology. Each technology had to be associated also with promising products and the relevant markets. Thus lined up in two logically interrelated lines: "priorities - task-technologies" and "markets-products-technology", where technologies were the central element of the TRM.

– The *pragmatic function* of the TRM was seen as potentially possible, since the ongoing project is not provided for the establishment and use of mechanisms of implementation of the developed roadmap. Meanwhile, the information was planned to include in the TRM, could be used for the purpose of obtaining pragmatic results — improving the efficiency of selection R&D projects, the development of the Russian advanced technologies and, subsequently, achievement of targets on volumes of export of oil and petrochemical high value added.

As for the *key problems* existing in the study area, it was determined that it is primarily the lack of information in the strategic and planning documents of what technologies are needed to achieve the objectives of development of Russian oil refining and petrochemistry. According to this, the *boundaries of the system* (field of study) were restricted by priorities, tasks, technologies and products for oil refining and petrochemistry in Russia.

In the framework of the stage of "simulation model" were formed the black box model, a model of the structure and the composition model:

– *The black box model:* based on research of Russian and foreign strategic and program-planning documents have identified nearly 120 factors influencing the Russian oil refining and petrochemical production ("inputs"). During experts procedures, the number of these factors and problems decreased significantly up to 20 — were excluded irrelevant and insignificant. The factors were grouped into drivers and barriers for development of Russian oil refining, as well as the "window of opportunity", as influencing positively or negatively in the study area, depending on what is happening in the study area. Only, the most important eleven factors have been made subsequently to the visual representation of the TRM on the stage "formalization of the system". The "outputs" were the level of production and export products, target values of which were identified by the analysis of strategic industry documents.

– *The model of the structure* (Fig. 5): describes the key layers of the roadmap, identified the following (in the roadmap are arranged from left to right) — tasks, priorities, technologies, products/markets and factors of influence. in the study, were formed certain rules for the selection information for each of the layers. For example, in the layer "tasks" included only the most relevant tasks, which are not taken active measures and the solution of which depends on the creation and use of certain technologies. In the layer "products" should be included only those for oil and petrochemical products, which are highly significant for the Russian market and have a high export potential.

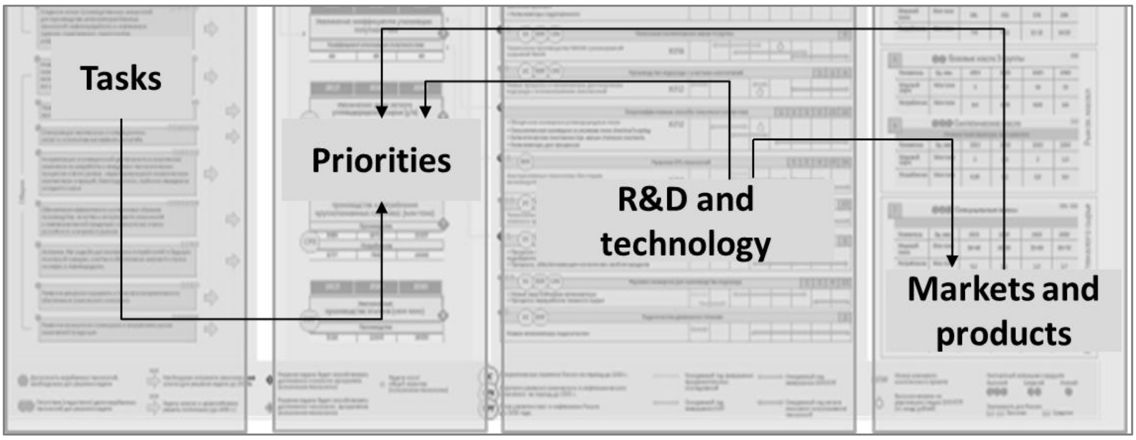


Fig. 5. The structure of Technological roadmap of development of oil refining and petrochemistry.

Source: HSE

– *The composition model* (Fig.6): includes specific lists of tasks, priorities, technologies, etc. and the relationships between them.

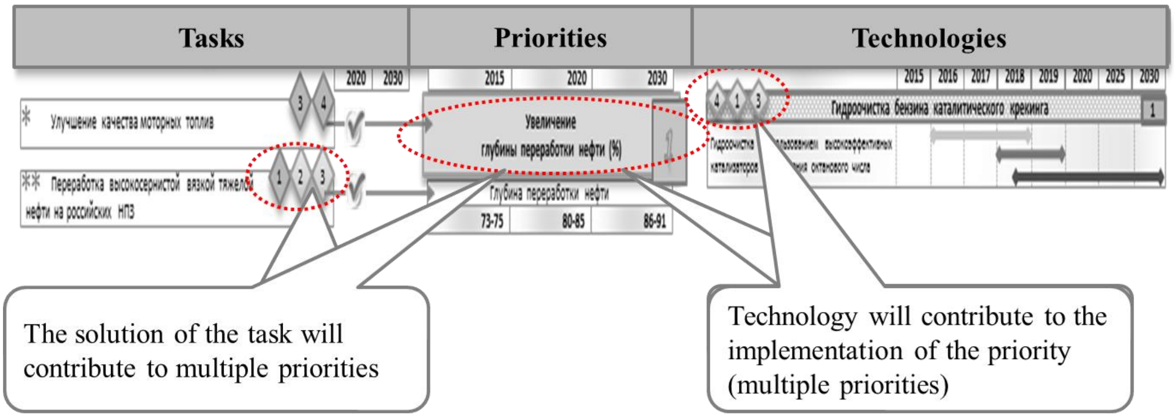


Fig. 6. The example of information including in the composition model of Technological roadmap of development of oil refining and petrochemistry.

Source: HSE

Alternative path of development in the study area are defined by a set of technologies and corresponding products, tasks, and priorities. Meanwhile, there are two key alternatives, including the development of oil refining and the achievement of relevant priorities (increasing the depth of refining, increasing exports of light oil products, etc.), or the development of petrochemistry and the production of a given alternative products with high export potential (propylene, benzene, styrene, polymers, etc.)

Case 2: *Management Roadmap for interaction with organizations engaged in research and development*

The management roadmap was developed in 2014 at the initiative of one of the largest Russian oil companies by NRU Higher School of Economics. The roadmap was supposed to cover only the process of interaction with external partners involved in the implementation of research and development. A *key goal* of the company with the management roadmap was to increase the efficiency and effectiveness of R&D external developers and third-party organizations — companies and universities. The management roadmap was to perform a *pragmatic function* only and do not include redundant causation, but only to describe the key implementation stages of R&D and decision-making about the continuation or termination of R&D.

As for the *key problems* existing in the study area, it was the ignorance of all the key stages of implementing R&D projects, control points and targets achieved at these points, and, as a consequence, the inefficient implementation of R&D projects — the expenditure of time, financial and other resources without obtaining the significant results. According to this, the *boundaries of the system* (field of study) were restricted by the process of implementing R&D projects by involving external organizations for one particular company.

In the framework of the stage of "simulation model" were formed the black box model, a model of the structure and the composition model:

– *The black box model:* "Inputs" in this study was the results of another study — and was a list of important for company R&D projects and organizations that can implement these projects. For this list it was necessary to develop the management roadmap of interactions with organizations in order to company will be able achieve important "outputs" — R&D results, such as technologies with the planned characteristics.

– *The model of the structure:* describes the key layers of the roadmap, identified the following: the key stage in the implementation process of R & d projects, key decision points, possible solutions, intermediate results of the projects (they are characteristics of emerging technologies). In the roadmap some layers were located in a top-down, others are logically interrelated with each other (e.g., intermediate results of the projects near to certain stages of project implementation)

– *The composition model* (Fig.7): includes specific stages for projects and intermediate results of the project that characterize the technical, economic and other targets of the developed technologies. Such targets value of the technologies are intended for use by management and employees to evaluate the activities of external organizations and decision-making on further continuation or termination of R&D project jointly with this organization. The composition model also include interrelated processes (for example, if the simultaneous creation of two technologies for their further integration.

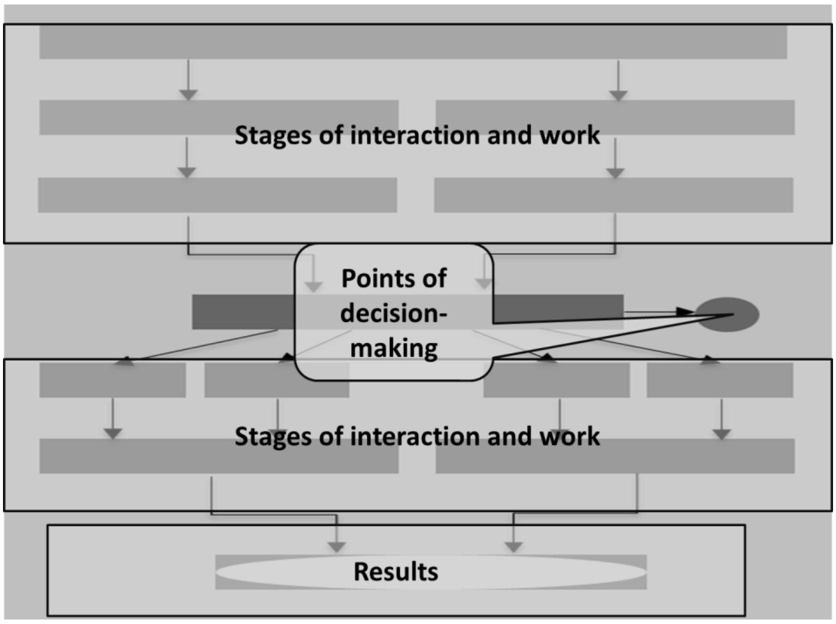


Fig.7. The structure of Management Roadmap for interaction with organizations engaged in research and development).

Note: because of the confidentiality of the information used by the typical structure of the management roadmap.

Source: HSE

Alternative path of development in the study area are defined by a various the results of the R&D project and is depended on the achievement of intermediate targets value of the technologies. For example, can be decided on choosing one of the following alternatives:

– continue the implementation of R&D project together *with the same organization;*

– continue the implementation of R&D project together *with another organization;*

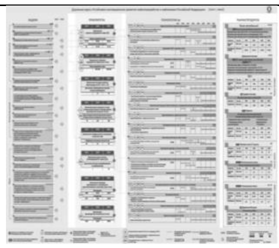
– termination of R&D project due to the inability to reach the target targets value of the technologies (intermediate results of the project);

Another group of alternatives relates to the possibility of commercialization and protection of intermediate results: the company can patent the resulting in the course of the R&D project technology; to sell the technology or to engage in the licensing.

Two of the case described above, demonstrate that the implementation of the same stages of systematic approach, proposed by the author, provides to develop a roadmap, which differ according to the type (technological, management). The approach can be used for roadmaps of different levels — from the national to the enterprise. At the same time saved and reflected in the layers and elements of the roadmaps specificity study areas and focus on problem solving (Table 2).

Tab. 2. The results of each stage of roadmap development in accordance with the proposed of systematic approach

№ stage (according Fig. 4)	**Stage results**	**CASE 1** Technology Roadmap development of oil refining and petrochemical industry	**CASE 2** Management Roadmap for interaction with organizations engaged in research and development
1.	The purpose of the simulation	Optimization	Optimization
	Model function (descending importance)	· Conceptual · Potentially pragmatic	· Pragmatic · Cognitive
2	Key problem	The lack of understanding of what technologies are needed to achieve the objectives set forth in the strategic documents	The complex control process partners – R&D developers
	System boundary	Russian oil refining and petrochemistry	R&D management system of the company in terms of interaction with external artists
3	System Simulation: *a black box model*	· Inputs — global trends (drivers and barriers to the development of Russian oil refining) · Outputs — the volume of oil refining and petrochemical production	· Inputs — scientific and technological priorities and performers · Outputs — the direction of commercialization of R&D
	System Simulation: *a model of the structure*	· The problems solved with the help of technology · Priorities expressed in quantitative terms · Technologies developed in Russia · Promising products and markets	· Key processes in the R&D stage · Key decision points
	System Simulation: a *composition model*	It identifies the key properties of the TRM: · Tasks - urgency solutions · Priorities - key performance indicators and their values by year · Technology - the power's contribution to the achievement of priorities and the issue of future products · Products - export potential and importance for Russia	· Forks (alternatives) · Options for action · Key work carried out as part of the process interaction
4	The target state of the system (priority elements, qualitative and quantitative parameters of the system)	· Tasks scheduled · Achieving the target volume production	· Production planned research and create results · Maximizing profits from R&D

5	Generate alternatives (scenarios, technological routes, the development strategy)	Alternatives are formed on the basis of decision-making on the implementation of conservative or progressive politics - encouraging the development of petroleum and petrochemical.	Alternatives are formed through the adoption of alternative solutions
6	The formalization of the system and alternatives (visual presentation)		No data
7	Roadmap implementation		
	The choice of alternatives	No data	No data
	Activities for implementation alternatives and their implementation (target state of the system)	Expected actions: · The selection of R & D proposals on topics that correspond to the elements of the layers of roadmap "technology" and "products" Adjustment forecasting and strategic documents	Expected actions: Implementation of the decision-making process of the company

Source: HSE

Conclusion and discussion

Results of the study indicate that currently there is no single methodology for roadmaps but each roadmap needs to be adjusted to the specific. Approaches, formed mainly on the basis of international practice TRM development, targeted at achieving various objectives, including reducing the time TRM development; building consensus among key stakeholder groups; ensure compliance TRM strategic goals, objectives and the company's capabilities.

The increasing complexity of social and economic relations (the study of objects in roadmapping), and as a consequence of the structure and content of the roadmaps, increases the importance of the formation of theoretically based approach to the methodology of the roadmapping. In this context, strengthening the system component of roadmaps (including elements, their relationships and the dynamics of change) is one of the key directions of development of the considered methodology. In this regard, the development of roadmaps by the author proposed to use an approach based on the construction and analysis of three types of system models: the black box, the structure and composition. This approach, unlike the existing ones, can be used to develop various types of roadmaps (technological, managerial, grocery, etc.), different level of detail and scope (national, sectoral, enterprise-level).

For further directions of approach can be offered a more detailed account of the achievements of the system analysis and allied disciplines, as well as the assessment of the possibilities of application of software tools of systems analysis, including analysis of approaches to modeling systems and quantitative study their applicability to the process of constructing roadmaps.

References

1. Ahlqvist, T., Valovirta, V., Liokkanen, T. (2012) Innovation policy roadmapping as a systemic instrument for forward-looking policy design. Science and Public Policy, Volume 39, pp. 178-190.

2. Albright, R. E. (2003) Roadmapping Convergence. Albright Strategy Group, 31 October.

3. Anderson, R.B., Hendrix, M. (2008) Air Force Materiel Command roadmapping assessmen. US Air Force Test & Evaluation Days Conference, Los Angeles, 5–7 February.

4. Bray, O. H., Garcia, M. L. (1997) Technology Roadmapping: the Integration of Strategic and Technology Planning for Competitiveness. Innovation in Technology Management-The Key to Global Leadership. PICMET'97: Portland International Conference on Management and Technology, pp. 25-28.

5. Cagnin C. (2009) Scenarios Snapshots and IMS2020 Vision. Deliverable D2.2. of IMS2020 Project Number 233469.

6. Dodgson, M., Gann, D.M., Salter, A.J. (2008) The management of technological innovation: strategy and practice. New York, NY: Oxford university press.

7. Fenwick, D., Daim, T.U., Gerdsri, N. (2009) Value Driven Technology Road Mapping (VTRM) process integrating decision making and marketing tools: Case of Internet security technologies. Technological Forecasting & Social Change, Volume 76, pp. 1055-1077.

8. Gerdsri, N., Assakul, P. (2007) Key success factors for initiating technology roadmapping (TRM) process: A case study of a leading Thai firm. ASIA Pacific Academy of Management and Business Conference (APAMB), 5-8 March, Singapore.

9. Gerdsri, N., Kocaoglu, D.F. (2007) Applying the Analytic Hierarchy Process (AHP) to build a strategic framework for technology roadmapping. Mathematical and Computer Modelling, Volume 46 (7-8): 1071-1080.

10. Gerdsri, N., Kocaoglu, D.F. (2007) Applying the Analytic Hierarchy Process (AHP) to build a strategic framework for technology roadmapping. Mathematical and Computer Modelling, Volume 46 (7-8), pp. 1071-1080.

11. Kappel, T.A. (2001) Perspectives on roadmaps: How organizations talk about the future. Journal of Product Innovation Management, Vol. 18 (1): 39-50.

12. Kostof, R.N., Schaller, R.R. (2001) Science and technology roadmaps. IEEE

Transactions on Engineering Management, Volume 38 (2): 132-143.

13. Lee, S., Kang, S., Park, E., Park, Y. (2007) Technology roadmapping for R&D planning: The case of the Korean parts and materials industry. Technovation, Volume 27, pp. 433-445.

14. Lee, S., Park, Y. (2005) Customization of technology roadmaps according to roadmapping purposes: overall process and detailed modules. Technology Forecasting & Social Change,Volume 72, pp. 267-583.

15. Magee, C.L., Weck, de O.L. (2004) Complex System Classification. Fourteenth annual International Symposium of the International Council On Systems Engineering (INCOSE), 20 June – 24 June.

16. Martin, H., Daim, T.U. (2012) Technology roadmap development process (TRDP) for the service sector: A conceptual framework. Technology in Society, Volume 34, pp. 94-105.

17. Misuraca, G., Broster, D., Centeno, C. (2010) Envisioning Digital Europe 2030: Scenarios for ICT in Future Governance and Policy Modelling. Joint Research Centre Institute for Prospective Technological Studies, P.1-84.

18. NASA (2015) Technology Roadmaps Introduction, Crosscutting Technologies, and Index.

19. NASA Langley Aeronautics Roadmap. National Aeronautics and Space Administration.

20. Park, B. (2007) Technology roadmapping as a foresight instrument. Technology Foresight Center, Korea Institute S&T Evaluation and Planning, the 3rd NISTEP International conference on foresight.

21. Phaal, R., Farrukh, C.J.P., David, R., Probert D.R. (2004) Technology roadmapping - A planning framework for evolution and revolution. Technological Forecasting & Social Change, Volume 71, pp. 5-26.

22. Phaal, R., Farrukh, C.J.P., Probert, D.R. (2001) T-Plan: the fast-start to technology roadmapping: planning your route to success. Institute for Manufacturing. Institute for Manufacturing, University of Cambridge.

23. Phaal, R., O'Sullivan, E., Routley, M., Ford, S., Probert, D. (2010) A framework for mapping industrial emergence. Technological Forecasting & Social Change, Volume 78, pp. 217-230.

24. Porter, A.L., Ashton, W.B., Clar, G. (2004) Technology futures analysis: Toward integration of the field and new methods. Technological Forecasting and Social Change, Volume 71 (3).

25. Probert, D.R., Farrukh, C.J.P., Phaal, R. (2003) Technology roadmapping – developing a practical approach for linking resources to strategic goals. Proceedings of the Institute of Mechanical Engineers, Volume 217, Part B: J.Engineering Manufacture.

26. Vishnevskiy, K., Karasev, O., Meissner, D. (2016) Integrated roadmaps for strategic management and planning. Technological Forecasting and Social Change, Volume 110, pp. 153-166.

27. Vojak, B. A., Chambers, F. A. (2004) Roadmapping disruptive technical threats and opportunities in complex, technology-based subsystems: The SAILS methodology. Technological Forecasting & Social Change, Volume 71, pp. 121-139.

28. Bol'shakov, B.E., SHamaeva, E.F. (2012) Sistemnyj analiz metodov proektirovaniya i upravleniya ustojchivym razvitiem. Naukovedenie, № 4 (13), pp. 1-13.

29. Mesarovich, M. (1973) Teoriya ierarhicheskih mnogourovnevyh sistem / M. Mesarovich, D. Mako, I. Takahara. – M.: Mir, 1973.

30. CHernyshev, V.N, CHernyshev, A.V. (2008) Teoriya sistem i sistemnyj analiz, Tambov, Izdatel'stvo TGTU.

Lyubov Y. Matich
National Research University Higher School of Economics, lmatich@hse.ru