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TECHNOLOGY MAPPING – PROPOSAL OF A METHOD OF TECHNOLOGY ANALYSIS IN FORESIGHT STUDIES

Alicja E. GUDANOWSKA

Faculty of Management, Bialystok University of Technology, Wiejska 45A, 15-351 Bialystok, Poland
E-mail: a.gudanowska@pb.edu.pl

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Abstract. The purpose of the article was to exhibit the technology mapping method as one of the methods which may be used in foresight research. Foresight studies was described in the context of technology as well as technology analysis. The main part of the article is the presentation of an original proposal of a technology mapping method enabling to diagnose the current state of technology. The execution of the method should allow to maximise the resources of knowledge on specific technologies. A list of technological knowledge base elements which might emerge as a result of the process was also described.

Keywords: foresight, technology analysis, technology mapping, proposal of a method, technological knowledge base.

JEL Classification: O32.

Introduction

Technology is not easy to analyze. This fact is caused by difficulty in defining technology unambiguously, high dynamics of technological development, and having to include numerous aspects which are under the influence of technology, as well as aspects which influence technology, in technology analysis. In accordance with the systematic approach to technology, the components of a technological system include: technoware (tools and artefacts), humanware (skills and talents), infoware (specifications and regulations) and orgaware (flows and procedures), as well as cysnetware (virtual environment). In keeping with this approach, it is humanware that is key; it comprises broadely defined skills (not only technical ones, but also creativity and decision-making skills) without which tools, machines and resources (components of technoware) are useless. A high skill level does not only allow for the use of the best tools but it also facilitates the acquisition of the most recent knowledge of production (infoware) as well as the utilisation and organization of the entire production process (orgaware). Like in all systems, the weakest link of any system determines its utility. Therefore, it is substantial that development of each of the enumerated elements be tended to, bearing in mind that only their dynamic interaction will generate a technological value added (Sharif 2012). Currently, technological innovations are not only the result of a spontaneous and deterministic phenomenon; methods and tools used for their evaluation should account for the achievements of non-technological disciplines. They should be included especially at the stage of identifying the needs stemming from the application of previous technological solutions (Kaźmierczak 2013). Decisions on technological development are made in uncertain conditions which require the knowledge of current research trends, intuition, and ability to use academic methods, including predictive ones. Foresight research may be a support tool in that area. Doing foresight research allows for creating visions of development coupled with an indication on how to reach them. In contrast to predicting, foresight is a process whose aim is to create the future through searching for a common vision which will be achieved by taking action now. The author believes the first phase of research methodology,

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which encompasses a diagnosis of the current state, to be especially important among the issues addressed in foresight research. It is in that first stage that information is delivered to technological development decision-makers, and validity of the decisions is mostly assesses. That stage, regardless of its subject, supports the creation of a justifiable picture of future changes.

In the light of the above observations, the aim of the article was to exhibit the technology mapping method as one of the methods which may be used in foresight research in the current state analysis stage. The author showed technology mapping as a diagnostic method of the current state of technology together with assumptions for the construction of the method. The main part of the article is the presentation of an original proposal of a technology mapping method with a list of technological knowledge base elements which might emerge as a result of the process.

1. Background research

1.1. Foresight and technology

The term foresight is sometimes identified with earlier terms like forecasting, predicting or planning. However, the term emerged due to the fact that those earlier notions did not capture the essence of the research procedure. The main difference between foresight and forecasting lies in the fact that the paramount role of foresight is not foreseeing the future, but understanding it. Moreover, unlike traditional planning, foresight uses systematic methods which cover a substantial period of time and involve the aspect of social participation (Piasecki, Rogut 2011). What distinguishes foresight from other long-term approaches to thinking about the future is the participation of interested stakeholders groups, orientation towards action (foresight is always an attempt at linking observations of change dynamics with current decision-making) and openness (the aim of undertaken activities is not indicating a future state beforehand, but its possible development schemes) (Warnke, Heimeriks 2008). When the substantial goal of foresight research is the development of certain technological solutions which imply development of the research area, then that research assumes a character of technological foresight (Nazarko 2013).

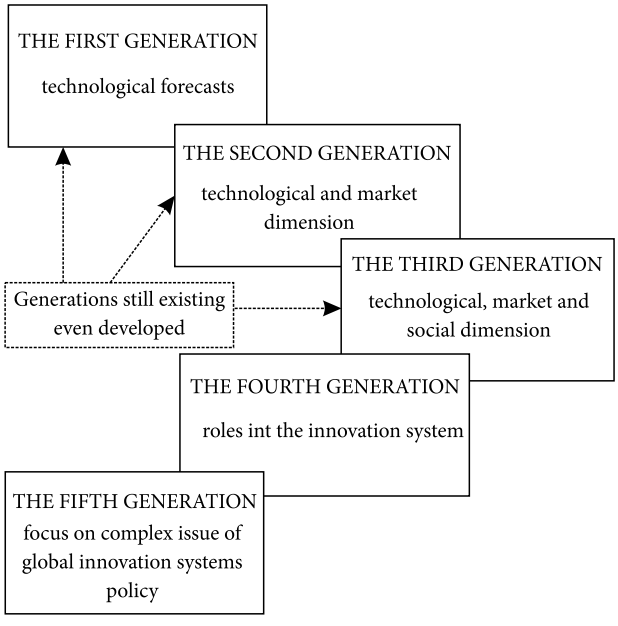

Fig. 1. Generations of technological foresight (source: Chan, Daim 2012)

Technological foresight development reflects changes analogous to those described in the evolution of foresight research by L. Georghiou (Georghiou 2007), but also changes in the perception of technologies: from the narrow to the systematic view. Initially, technological foresight initiatives were profiled narrowly towards evaluation of technological and scientific development in order to support decisions on setting priorities based on technologies. In the following years a wide socio-economic scope connected with technological development must be encompassed (Warnke, Heimeriks 2008). Generations of technological foresight have been illustrated by L. Chan i T. Daim (see Fig. 1). Currently, technological foresight incorporates significant activities in numerous countries which constitute assistance in directing technological development and in focusing countries' key resources on the key technologies (Chen *et al.* 2012).

In the process of searching for analogies between foresight research and technology, the work by S. Liao (Liao 2005) should be noticed. He makes three basic suggestions about technology management which can be applied to foresight research. The first one indicates that qualitative and quantitative methods of technology management methodology should be integrated, which is analogous to research methodology of foresight that accommodates a combination of qualitative and quantitative methods as well as intermediate ones (Popper 2008; Magruk 2011a). The second suggestion is that the interdisciplinary character of technology management should be noted, so the research scope in technology management methods should be widened. The third suggestion proposes seeing change as a source of development, which also corresponds with the idea of foresight research as systematic analysis of possible variants of the future. S. A. W. Drew suggests that there are five basic functions required for creating technology strategy, especially in uncertain and difficult market conditions. The first function he enumerates is foresight which is indispensable to set new development paths for technology and innovation while taking into account the uncertainty. The other functions, although the author does not relate them directly to foresight, seem to refer to it as well (Drew 2006).

A. Magruk also sees a link between technology management and foresight research through the applied methods. He shows that it is becoming more frequent to employ technological foresight and his research methods by organizations orientated towards technological development. When analyzing the reciprocity, he notes that foresight research uses methods of technological character, mostly those associated with the implementation of the functions of technology identification and selection (Magruk 2011b).

1.2. Foresight and technology analysis

There may be found numerous classifications in literature which organize the methods used in foresight research. One of the classifications is systemic foresight methodology (SFM) which sections the methods in terms of their potential of application in the phases of the foresight process (Smith, Saritas 2011):

- systemic understanding – the first phase of the foresight process; it provides entry data for the entire process;
- systems synthesis and modeling – the collected data are synthesized into conceptual models which form possible variants of the future;
- systemic analysis and selection – systematic analysis is conducted of possible variants of the future and the most desired variant is chosen;
- systemic transformation – analysis of relations between the future and the present aimed at planning changes and making strategic decisions on activities which must be undertaken;
- systemic action, creating an outline of informing the decision-makers of today about the structural and behavioral changes which must be made, so that the desired variant of the future would materialize.

The first phase, which encompasses the diagnosis of the current state, is especially worth noting. It provides entry data for the entire research, which in the author's opinion causes the fact that this stage mostly conditions the validity of the foresight process. This phase should commence with operations aiming at preparing the most complete portrayal of the situation, it being the understanding of the system and its surroundings (Smith, Saritas 2011). When a set of technologies is being analyzed, a diagnosis of their current state must be conducted. What determines the current state of technology? What knowledge sources should the diagnosis be based on and how? In the context of technology analysis, the trend of patent analysis is covered extensively in literature. Patent analysis is believed to provide unique knowledge of the advancement of work on a technology and is treated as a basis for determining the presence of mutual influence of technologies (e.g. Choi *et al.* 2007; Abercrombie *et al.* 2012). Also, publication analysis in the form of measuring academic publications on a given subject, provide knowledge of coming trends and on technological areas in which emphasis on development is the most intense (e.g. van Eck *et al.* 2010). It should be noted that the maximum potential of data organization and bibliometrics can be achieved only when they are combined with expert analysis of chosen parts of collected knowledge base (de Miranda Santo *et al.* 2006). Therefore, it is important that experts, both theoretical and practical, be involved in technology analysis.

Records of data on academic production or patents linked to a technology can be treated as the basis for technology diagnosis in the context of foresight research, together with general knowledge of a technology, aspects like essential financial inputs, benefits and barriers of development. What may confirm this observation is the conclusion drawn by V. Coates *et al.* who, referencing an analysis of six case studies, claim that innovations linked to technologies are not developed by organizations on their own and that technologies initiated in a company often develop in another (Coates *et al.* 2001). That observation also indicates the importance of organizations which deal with technological development and the significance of cooperation networks among them whose density might influence the rate of development of a technological solution. Therefore, the next important aspect of technology analysis is identifying both academic and research centers being the source of innovation, as well as producers expanding the innovation and moving it into the diffusion stage. Another issue worth noting in the process of determining the essence of technology analysis is the possibility of coexistence of different technological solutions. Technologies evolve and an emergence of a new solution might cause another one to die out (Adomavicius *et al.* 2008). In the author's opinion, collecting and organizing data on technologies which are thought of as development directions of a region, a country, an industry or a company during foresight research should, where legitimate, be completed with visualization of collected data. Using visualization definitely improves data analysis possibilities and allows for presentation of new knowledge while basing on the previously collected knowledge (Davies 2011). In literature it is sometimes indicated that technology analysis can be conducted with the use of two approaches. The first approach requires bibliometrics analyses conducted through, for instance, citation index or patent index analyses; the second approach involves focusing on analysis of data clusters from knowledge base about technologies. It is crucial that those two approaches be treated not as competitive approaches, but as complementary ones (Lee, Song 2007).

Another noteworthy analysis method of state of technology is identification of technology readiness level (TRL). The TRL scale, used by the American army as categorization of technology development, has been developed

by NASA. Initially, it was a scale from 1 to 7; since 1995 it has been a scale from 1 to 9. Creating the TRL scale was related to identification of technological immaturity as the cause of unforeseen development costs and delays in technology planning schedules. Those were supposed to be corrected thanks to the use of a cohesive system of technological maturity evaluation. The TRL scale is the basis of evaluation of risk and of the chance for successful passing a technology to the final user, which determines the value of prospective investment in the technology. On the 1 to 9 scale, 1 means the lowest level of technology maturity/readiness, and 9 means a mature technology. The described index is especially useful when a number of technologies are being dealt with, and it is key to understand that an improvement in a technology is possible, but whether the technology will be ready to use is uncertain. The TRL index allows for evaluation of the maturity stage of a technology and comparison of that technology and other ones (Graettinger *et al.* 2002; McGarvey *et al.* 2009; Mankins 1995; Gao *et al.* 2013).

When numerous definitions and approaches to foresight research are analyzed, a conclusion can be drawn that the goal of foresight is to connect current decisions and activities to a strategic perspective, where the requirement of the initiating stage is constituted by looking at what is happening now. It should be remembered that in order to estimate the direction of future development of a technology and make a decision on prospective investment, indicating the life cycle stage of the technology is crucial (Gao *et al.* 2013). Keeping in mind the broad context of approaches to technology analysis which covers many issues in addition to technical feasibility and economic aspects, the statement can be broadened by indicating that it is essential to determine the current state of technology development and elements related to that technology, in order to establish technological development trends. In the light of this, "evolution" of technological foresight in future-oriented technology analysis is worth noting (Cagnin *et al.* 2008). In the author's opinion, that change of foresight research direction from grounded firmly in analysis of the future to analysis still orientated towards the future, but focused on technology and to a greater extent based on observation of the current state, emphasizes the essence of the diagnostic activities. One of the methods in the scope of these activities is the technology mapping method whose application should enhance the process of technology identification and allow for the acquisition of the greatest possible knowledge about technologies, used in the technology selection process.

2. Technology mapping

2.1. Assumptions and methodology proposal

The preparations of the technology mapping method methodology were preceded by studying literature on understanding and applying methods of diagnosing a current state of technology in chosen research initiatives, mainly of foresight research nature. In many diagnosed works special attention was paid to issues like usability of bibliometrics analyses, particularly patent analyses, and the essence of referring to expert knowledge. Frequently, the works whose aim was to establish the starting point of technology development analysis were based on determining its current level of development according to an adopted scale. Also, what was accentuated was the need to pay attention to the environment connected with the technology, especially research and industrial centers related to the development and creation of the technology, as well as the aspect of current and potential cooperation of such centers. Another important issue was the need for broad knowledge to be delivered by analyses of technologies, so that the recipients of could select the importance of the received information themselves as well as interpret it. It also seems vital that the term "mapping" (not necessarily in the context of technology) was used to refer to monitoring ongoing activities, compiling knowledge and prospective classification of the research subject; mapping was often supported by tools of visual data presentation in order to facilitate the recipient's understanding of extensive results. The results of the literature studies have been shown in publications (see Gudanowska 2013, 2014).

There are numerous research methods used for activities related to technology identification. Those methods capture the subject matter of technologies from different angles. Therefore, it has been decided that the technology mapping methodology should be a comprehensive one, covering various aspects of technologies and their environment. It has been assumed that conducting all research tasks in the scope of the method should not require supplementing the knowledge on the current state of technology. It should allow for executing a chosen group of research tasks adjusted to the recipient's needs.

The proceedings adopted for the method should allow recipients to conduct a qualitative analysis of a technology and to examine analogies among technologies. According to A. T. Roper *et al.*, those analyses are as important as the structured approach to collecting information about the technology, supporting technologies, and technologies which compete during the creation of a justified image of current technologies and their future (Roper *et al.* 2011). Processing the data collected during method application and their interpretation must depend on the recipients' needs. However, in the course of the method it must be possible to conduct analytic work which expands the gathered knowledge and makes its interpretation easier, so that the method does not come down to a review and record of data on technologies. It has been assumed that

the technology mapping methodology should adopt a simplistic form of a clear, repeatable algorithm of research conduct. It is imposed by the necessity of updating maps, which is emphasized because of the usability of the results of the updates. Awareness is significant of the fact that links displayed on the maps are not stable and are subject to constant and often dynamic changes.

The author's technology mapping methodology has been presented in Figure 2.

The methodology consists of an array of research tasks conducted in four phases. Some of the tasks should be performed in a sequence; others in the scope of a phase might be conducted simultaneously. In Figure 2 the qualitative as well as the quantitative approaches have been recommended. The author believes that there is a need for an analysis of aspects (those which may be described quantitatively) of current technology evaluation. She is also of the opinion that aspects should be analyzed that emerge from intuition, knowledge and skills of people who develop given technologies. The essence of contemporary technology indicates that technology mustn't be perceived solely through machines or technical knowledge; what must be included as well are skills and experiences of experts who develop technologies. Those skills and experiences are often difficult or impossible to measure and present quantitatively. Moreover, patents and publications represent "products" of technology development while what is more important during determining development possibilities are ideas and notions which can be found mainly in the expert knowledge. The technology mapping method, when performed comprehensively, should encompass elements of the two approaches. Focusing on one of them is also possible and should be deemed correct method application. What it requires is only a suitable annotation for the recipients of the method's effects; the annotation will enable them to make adequate conclusions).

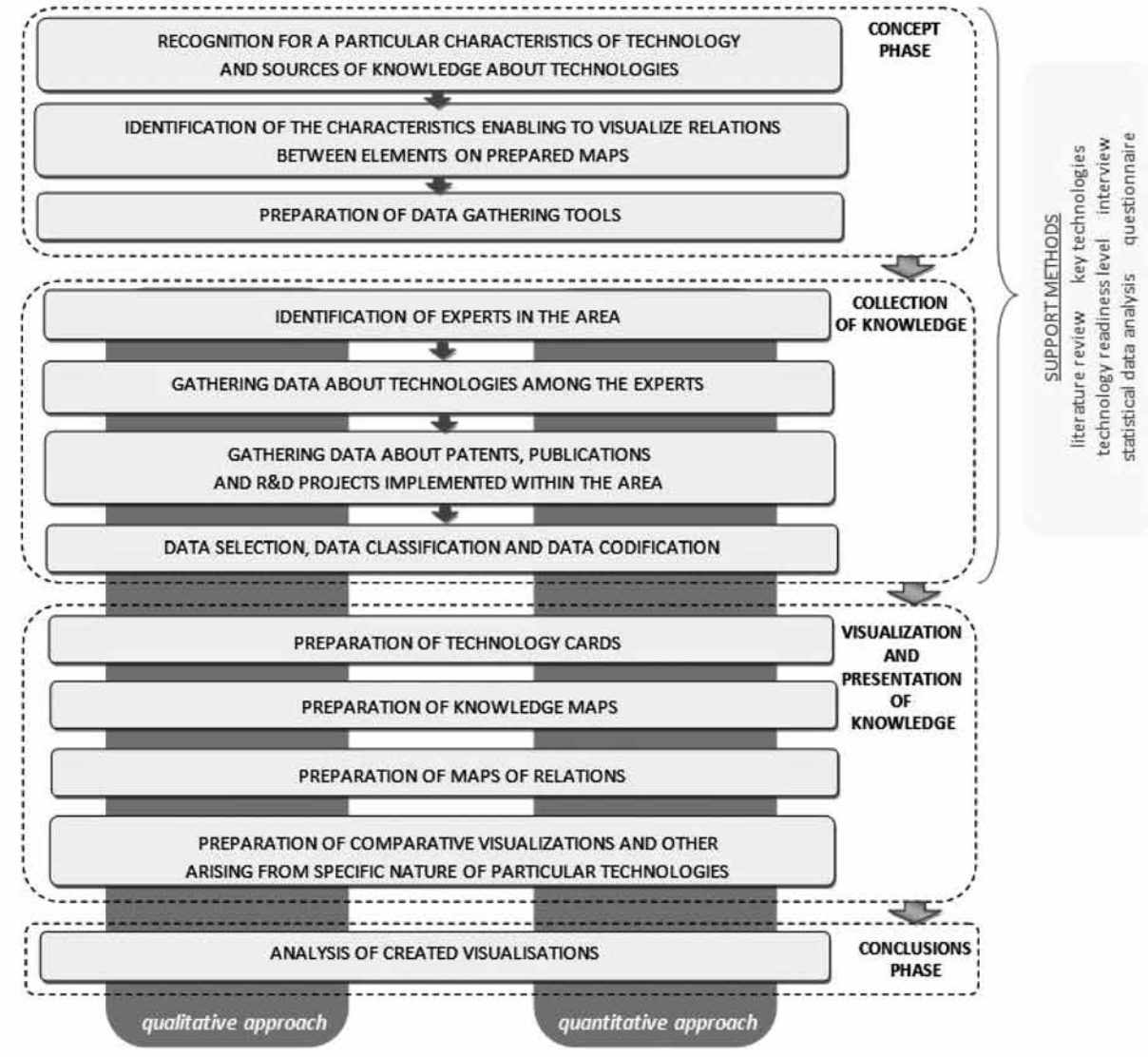

Fig. 2. Proposal of a technology mapping method

2.2. Knowledge base of technologies

A description of elements of a knowledge base which constitute the results of technology mapping are presented in Table 1 along with an indication of a proposed form and function (determined by reasoning possibilities) of the elements.

Other visualizations or presentations resulting from a particular character of a technology might constitute a possible complement of the enumerated elements, which may be called standard implementation effects, of a base of knowledge.

Table 1. Elements of a knowledge base which constitute the results of technology mapping

Technological knowledge base element		Form	Function (determined by reasoning possibilities)
Technology card		text, tables and graphs; it may contains maps with location of technology development centers	collect and systematize the basic knowledge about the analyzed technology (such aspects as, among others, technology development stage, advantages and obstructions of technology implementation, essential equipment of a laboratory which develops the technology, essential financial outlays, examples of current application, components of the technology, alternative technologies, technologies depending on the development of the considered one, legal regulations); identification of technology development centers in a geographical arrangement
Maps of relations	a map of key technologies relations	network – nodes assumed as analyzed technologies, lines defined as mutual influences of technologies – influences of diverse power; stimulating or inhibiting the development	identification of technologies, which the most affect other ones from the analyzed group, technologies most involved in relationships with others, an indication of technology clusters stimulating or inhibiting their development, the ability to comparision identified arrangement of technologies with a formal division of technologies (for example division according to areas of application)
	a map of relations among technologies development centers	network – nodes assumed as technology development centres, in order to establish connections among the elements, technology sets should be determined whose development is dealt with by the given center; if there is an intersection of the two sets, a connection is established; the more numerous the intersection is, the stronger the connection is	presentation of existing and potential cooperation networks in the area of technologies development centers, also between science-business
	a map of technology expert relations	network – nodes defined as experts developing analyzed technologies, lines assumed as interest in developing the same technologies	presentation of existing and potential cooperation networks in the area of experts developing analyzed technologies
Knowledge maps connected with technology development	knowledge map based on scientific publications	network – nodes assumed as key words from publications, lines defined as coexistence of words in the same publication	identification of the most common research topics (keywords and their compilations): (1) described in scientific publications (2) and/or analyzed in research projects (3) and/or topics that are reflected in patent descriptions from a given region or about analyzed technology/technologies group
	map of research topics developed in the R&D projects	network – nodes defined as key words from project description, lines assumed as coexistence of words in one project description	
	map of patented technological solutions	network – nodes assumed as key words from patent description, lines defined as coexistence of words in one patent description	
Examples of comparative visualizations	maps with location of technology development centers	geographical maps with the designation of location of technology development centres; it may be included as one of the elements of technology card	presentation of technology development centers in a geographical arrangement, identification of regions of the most intense research in the field of technology
	comparison of the technology development level	chart-marking technology on the technology readiness level scale or summary table	presentation of technologies in the research and development phase, technologies in the testing and demonstration phase and technologies in the implementation phase

Conclusions

The dynamics of technology development determines the need for defining its state and foreseeing its possible development paths. Development of technology analysis methodology became essential for inventing early warning systems of technological changes, even of the slightest ones which are already approaching. Estimating the value of technologies supports indicating which ones are the most promising and allows for identification of a technological niche. When analyzing available literature, what may be noticed is the lack of a methodical, uniform solution on which the process of conducting a diagnosis of the current technology state could be based. It is visible that the quantitative aspect is represented by topics developed, presented and supported by many documented examples in scientometric literature from the area of bibliometrics and patentometrics. The qualitative aspect of the current technology state evaluation is characterized by a higher level of disorder and numerous ambiguous proposals presented in literature.

If observations of academic research and technology development, not only in foresight research, is conducted methodically, it becomes useful to different innovation system recipient groups. The most significant groups, quoting K. Klincewicz, are: science-related government bodies, national academic-research centers, non-academic government institutions (patent offices, statistical offices, ministries), universities, research units and institutes, and technological companies. Recipients' needs in the area of technology development analysis are vast and sometimes unconscious, which may often stem from the lack of knowledge about available sources and methods (Klincewicz *et al.* 2012).

The author suggests that technology analysis in foresight research should be based on conducting technology mapping in accordance with the methodology proposed in this article. The methodology is an ordered procedure of academic conduct whose use allows for collecting the widest possible knowledge about a chosen group of technologies. It should be remembered that its application in specific foresight research may require the use of the entire methodology. Another option is choosing only a part of the tasks to perform, depending on preferences and recipients' needs. If available data do not undermine the validity of their employment, a full application is recommended. Data acquired for mapping should constitute a large collection of expert knowledge and/or quantitative data, as well as apply to the context of the area of the foresight research (the country, region, industry or company). The results of technology mapping can form the basis for the choice of technologies crucial for a given area, or supply initial knowledge to people planning to develop in that area.

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Alicja E. GUDANOWSKA, PhD. She is an employee at the Bialystok University of Technology in Poland. Her scientific interests concentrate on foresight studies, technology management and visualization of knowledge with the special emphasis on the methodological issues and tools applied within it. She is an author or a co-author of over thirty publications – both in Polish and English – which touch upon the problems of technology management, technology mapping, knowledge mapping, technology roadmapping, the evaluation of the Polish foresight studies and the general methodology of foresight research.