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Main Concepts of Technology Analysis in the Light of the Literature on the Subject

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Abstract

The main aim of this article is to identify and present the relevant concepts and methods of technology analysis. On the basis of the bibliometric analysis of scientific articles, research subareas related to the technology analysis were selected. Relationships between earlier executed researches in this field were determined. Taking into account the obtained map of relationships, the possibility of the use of technology analysis was indicated. Also, methods used to analyse the current state of technology and concepts used for the prospective technology analysis were identified. Then, the concepts of predicting the technology development were discussed and compared. The conclusions from the conducted study can be used as the basis for determining the critical directions for the development of research areas related to the technology analysis.

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Keywords: technology analysis; forecasting; foresight; technology assessment; Future-oriented Technology Analysis

1. Introduction

Innovative technologies increasingly determine the competitive advantage of enterprises. They are also the basis of the modern manufacturing processes, making meeting the needs of the society possible. Awareness of the need to develop the technology became widespread, as evidenced by international and national programs supporting the development of technology, research institutes and R&D. In the situation of an increasing demand for innovative technologies and broad technologies' trading market, the use of specific methods allowing the effective technology analysis seems necessary.

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In both the domestic and foreign literature, no clear definition of technology analysis was given. It was noted that most commonly the technology analysis is understood as a study/examination of technologies, taking into account economic, technical, social and environmental factors. Both single technology and technology groups can be analysed. The purpose of the technology analysis, among other things, is to characterize and examine the used technologies, design their potential and determine their direction of development [1]. The technology analysis enables the identification of the strengths and weaknesses of the enterprise technological activities, designation of capabilities to increase competitive advantage by enterprises through the appropriate utilization of the used technologies, as well as identification of the available technologies that the company could employ, in order to improve their products and processes.

2. Identification of the research subareas related to the technology analysis

In order to identify the subareas and to establish relationships between the hitherto conducted studies on the technology analysis, an extensive bibliometric analysis was carried out. Initially, the dynamics of change of the number of publications in the studied period was evaluated. Then, to identify areas of research for the analysis of the technology the co-word analysis and cluster analysis method was used. A review of publications in the Scopus base was made. The choice of the bibliographic database was dictated by its extensiveness and availability. The database search was performed using the term "technology analysis" contained in the keywords, titles and summaries.

Over the last thirty years (from 1985 to 2015) 954 publications indexed in the Scopus were created, including 494 articles, 455 conference publications (conference paper) and 5 books containing the phrase "technology analysis" in the searched fields. The number of publications in the Scopus database related to the technology analysis is illustrated in Fig. 1. Analysing the figure, it can be observed that initially – for the first twenty years – interest in this issue was not significant. Until 2005, annually no more than 20 articles in this field were published. Only since 2005 the interest in the issues connected to the technology analysis clearly rises, which is reflected in the number of publications in the Scopus base.

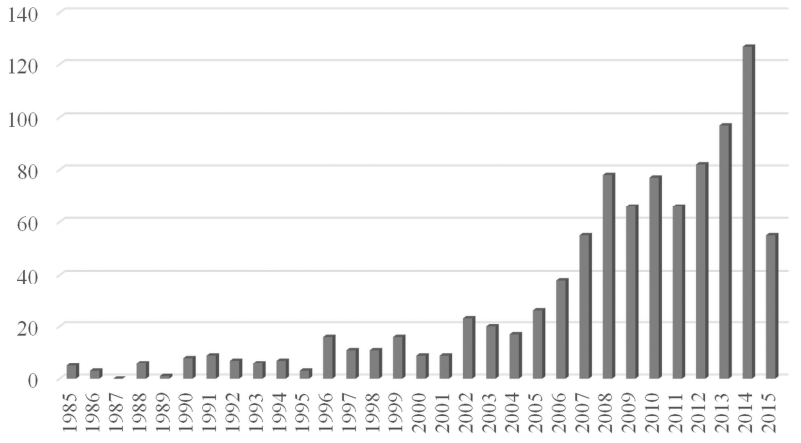

Fig. 1. The number of publications on the analysis technology in the Scopus database in the years 1985-2015.

The largest number of publications on the technology analysis has been published in such magazines as "Advanced Materials Research" (35 articles), "Applied Mechanics and Materials" (34 articles), "Proceedings of SPIE the International Society for Optical Engineering" (18 articles) and "Technological Forecasting and Social Change" (16 articles) and "Technology Analysis and Strategic Management" (11 articles).

The identified publications were analysed in terms of subject area (Fig. 2). More than half of the identified publications relates to the field of engineering. Often they mention the problem of identification, modification and maintenance of the enterprise core – profitable – technologies. Other articles related to such disciplines as medicine, biochemistry, genetics and biology, physics and astronomy, mathematics.

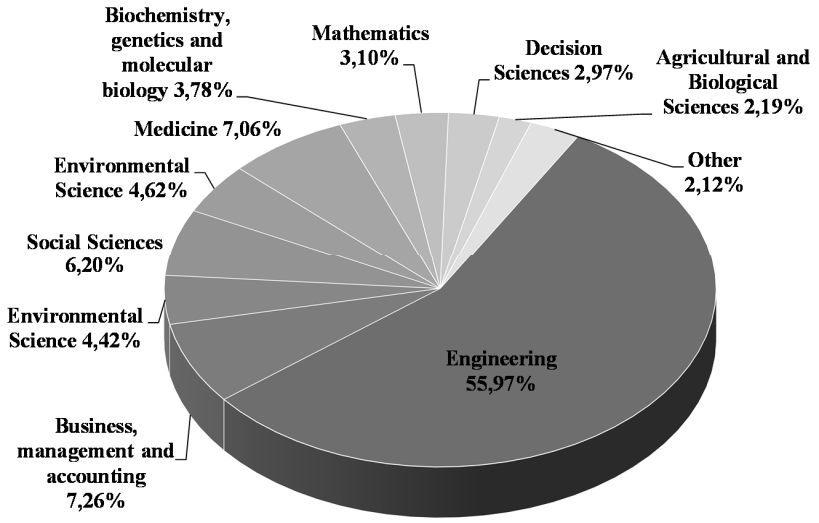

Fig. 2. The division of publications in relation to the topics covered in the identified articles.

The final stage of the conducted bibliometric analysis was the assessment of the coexistence of words and their co-classification. The word coexistence analysis method was used, which is based on counting of the number of the occurrences of the sequence of words in the analysed text. According to this approach, coexistence of words may indicate, among other things, the existence of research sub-areas. It also enables identification of the reasons determining the directions of further development of the research area. Using the VoSViewer software the bibliometric map was prepared, which is a visualization of the results of the co-occurrence of words analysis. The number of the word occurrences is reflected in the size of the circles, and the distance between the circles is dependent on the number of co-occurrence. The results of the analysis of the articles from the Scopus database were shown in Fig. 3.

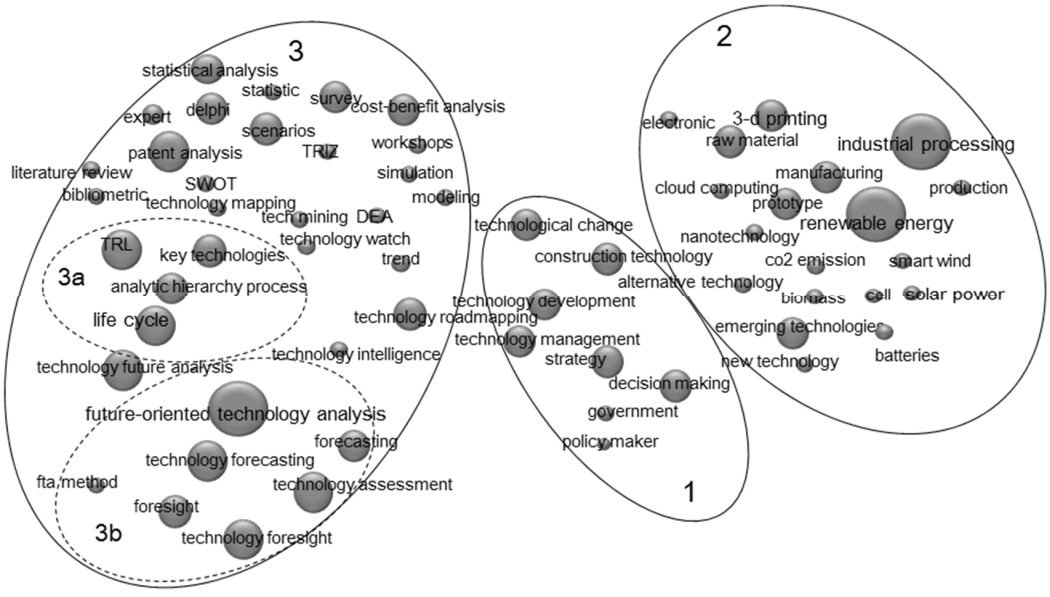

Fig. 3. The map of the research sub-areas related to the technology analysis.

The carried out analysis of the coexistence of words allowed for the emergence of three clusters – sub-areas of research relating to the issue of technology analysis. When analyzing individual clusters, the following naming scheme was proposed: (1) potential, (2) nature, (3) and methodology. The first two sub-areas concern the possibilities, as well as the type of the analysed technologies, and the third refers to the methods used in the analysis thereof. When analyzing the first cluster, it can be seen that the analyses of technologies are used for technology management, technology development, strategy, decision making, in the construction technology, as well as technological change. Another sub-area of research is related to the types of the analyzed technologies. When analyzing this cluster, it can be seen that the most frequently analyzed technologies are the ones related to the areas of nanotechnology, production, manufacturing, and renewable energy (cell, batteries, CO_2 emission, solar power, smart elevators), as well as industrial processing, and 3D printing technology. The objects of the analyses are: new technology, prototype, emerging technology, and alternative technology. The third sub-area concerns the methods and concepts of technology analysis.

Technology can be viewed in different time perspectives. It is possible to analyse both the current state, as well as the future possible states [2]. This observation is also confirmed by the conclusions resulting from the analysis of Cluster 3 (Fig. 3). During its analysis it is possible to distinguish three groups of methods and concepts used to analyze technologies. The first group – marked as 3a in Fig. 3 – represents the methods used to analyze the current state of technology (TRL, analytic hierarchy process, life cycle, key technologies). It is also possible to distinguish the concepts (in the figure marked 3b) used to predict technology development, such as: technology assessment, forecasting, technology, foresight, technology foresight, as well as future-oriented technology analysis (FTA). These concepts are very popular among researchers (markers depicting these concepts are larger than the markers reflecting other tools). Other methods – the largest group – represent the auxiliary methods, and they are used both to predict the development of technology and analysis of its current state. These methods include, among others, literature review, Bibliometrics, patent analysis, SWOT analysis, tech mining, statistical analyses, as well as data envelopment analysis (DEA), [3], data mining, as well as modeling and simulation. The selected concepts and methods of technology analysis are shown in Table 1.

Table 1. Selected methods and concepts of technology analysis.

Type of analysis	Main methods and concepts	Selected auxiliary methods
Current state of technology	technology readiness level; life cycle technology, technology S-curves; key technologies; analytic hierarchy process AHP	bibliometric; patent analysis; statistical analysis; SWOT; cost-benefit analysis; survey; Delphi; technology mapping; technology roadmapping; DEA; modeling; technology watch; expert panels; literature review; scenarios; simulation; tech mininig; TRIZ; workshops
Future state of technology (predicting technology development)	technology assessment; forecasting, technology; technology foresight; future-oriented technology analysis	

The methods and concepts allowing for the analysis of technology, mentioned in Table 1, often show a certain inconsistency in the methodology. However, these methods are not identical, and each one of them frequently fulfils a separate function, and complements the other ones. Presenting all the identified methods and concepts of technology analysis goes far beyond the scope of this article. The further part of this article will present the concepts – enjoying great interest among researchers – allowing us to predict the future state of technologies.

3. Concepts of technology development forecasting

One of the first methods used for technology analysis is technology forecasting. The origins of this method date back to the thirties of the twentieth century, and the increase in the use of this method occurred after World War II. In the opinion of E. Jantsch, technology forecasting can be defined as an assessment of the likelihood of transfer of a future technology at a relatively high confidence level [4]. According to M. Cetron, technology forecasting entails predicting, at an appropriate level of confidence, a technological achievement, within an established period of time, at a certain level of support [5]. In the opinion of A.T. Roper and others, technology forecasting is a type of technology development predicting, allowing – using scientific means – to study changes in technology, shows the path of its development or its functional capabilities [6]. Technological Forecasting refers to all the deliberate and systematic

attempts at predicting, as well as the potential direction and course of technological changes, especially in the case of innovative inventions, their introduction, and use. Technological Forecasting is primarily based on information from the past and usually refers to the near future (time horizon – up to several years). Prognostic knowledge helps in the better use of the available opportunities and more effective risk avoidance [7]. It also makes it possible to determine the market potential for given products, which are based on modern technologies. Technological forecasts are present in the process of making all significant business decisions. They help the company respond more quickly to changes taking place in the environment. Basic difficulties associated with technology forecasting – especially long term – are primarily associated with the selection of an appropriate model, and the costs associated with data collection. There is also a risk of interaction between technologies, the occurrence of unexpected social needs, or fundamental scientific discoveries disrupting a specific trend. Inadequate assessment of the speed of dissemination of technology, and the lack of acceptance of manufactured products are also possible.

The main reason for these difficulties is the fact that technological forecast, like any other type of forecast, is a single picture of reality, a point in the area of uncertainty, and is applied to phenomena which are less sensitive to disturbing events. According to P. Wack, the status quo of factors affecting the studied phenomenon is most commonly assumed for forecasting purposes [8]. The concept allowing studying the behavior, and the interaction between trends in a large area of uncertainty is called foresight [9].

The aim of foresight is not predicting, but "determining specific (desired) development visions and shaping the future". Through the use of scenarios, it allows to study the behavior, and the interaction between trends in a large area of uncertainty [10]. First of all, it allows for a broader look at the investigated phenomenon, and consideration from a perspective longer (usually 5-30 years) than the forecasts. Unlike forecasting, foresight takes into account the discontinuity of events through the identification of unprecedented events, the so-called wild cards, and weak signals [11, 12]. This method allows for a more comprehensive examination of the future.

Based on a review of literature, it may be noted that the main purpose of technology foresight is primarily: the identification of leading technologies; assessment of opportunities and threats facing technologies; thinking about the future of technology, i.e. analysis of the situations and trends in technology development; discussing the future of technology (taking into account the views of different environments); determination of the key factors affecting the development of technologies (e.g. political, economic, social, cultural, environmental, technical); determining the direction of technological development; preparation of a vision of future technological trends (technology development scenario building); consulting – analyzing the many possible "futures"; shaping the future, including, inter alia, the identification of actions to be taken in order to develop the desired technologies [13].

The critical review of the literature, analysis of foresight initiatives, and our own research experience indicate the existence of a number of weaknesses or limitations of technology foresight [14]. Based on a review of the conducted foresight studies it was noted that these initiatives did not include the bilateral interaction between technology and the environment, and the impact of innovative technologies and products on the environment, as well as the technologies' mutual impact on each other were not taken into account. The concept allowing to analyze technologies while eliminating a part of the above-mentioned limits is technology assessment (TA).

Technology assessment in the literature on the subject is often referred to as the measurement of technology, its evaluation or the analysis of the impact. It enables a public debate related to technology, as well as the combination of the opinions of stakeholders with expert knowledge. It also makes it possible to identify the risks associated with the introduction of technology. The main task of technology assessment is to study the social impact of innovative technologies and products [15]. It is a form of technology research, which analyzes the short- and long-term consequences of implementation, expansion and modification of a given technology [16]. The main element of this approach is the identification of the risk of introduction of a technology early enough to make it possible to precisely examine the extent of the possible real social, economic, political, ecological and cultural effects. This tool supports the processes of valuation of an enterprise, decision-making regarding the continuation or possibly the termination of the project and negotiations with suppliers, customers and intermediaries of technology [17, 18].

The systematic use of forecasting, foresight, and technology assessment will allow, among other things, the determination of the likely impact of technology on the society, economy, politics, ecology, and culture. It will also allow for the identification of the potential development possibilities of a given technology, as well as the reduction of the risk resulting from its use. Each of the approaches mentioned in the chapter, used for the analysis of technology,

has certain important advantages, but also limitations [19]. The approach integrating the tools for technology analysis and its development, mentioned above, is the Future-Oriented Technology Analysis.

The prospective analysis of technologies allows – according to O. Saritas and S. Burmaogs – to take action in the long term perspective, enabling the development of new future technologies [20]. According to the author, the FTA is a kind of a natural path of evolution of technology foresight. It is a process, whose primary objective is to predict the future of technology through detailed analysis (scanning) and assessment of its current state and the identification of the strategic factors of its development in the future [21].

The concepts of forecasting the development of technologies are shown in Table 2. Each of these projects fulfils a separate role and often complements the remaining ones. It is also difficult clearly determine which of the above-mentioned concepts fulfills a superior role.

Table 2. Selected methods and concepts of technology analysis.

Criterion for comparison	Forecasting	Foresight	Technology assessment	Future-Oriented Technology Analysis
Object	existing technologies	existing and new technologies	existing and new technologies	existing, new and emerging technologies
Objective	predicting changes in technology (properties, importance, functional capacity)	creation of the vision and determination of trends in technology development	forecasting and assessment of the impact of technology on the environment	forecasting the development of technologies, taking into account its current state, possibilities, and the factors influencing its development
Reference to the future	passive descriptive (without participation) future prediction	shaping, creation of the future	passive descriptive forecasting and shaping the future	forecasting the future, taking into account the factors influencing the future
Type of analysis	scientific process	social process	scientific and social process	scientific process taking into account the social, technical, economic changes
Reference to uncertainty	assumes a status quo of factors affecting the studied phenomenon	acceptance of the occurrence of uncertainty	acceptance of the occurrence of uncertainty	acceptance of the occurrence of uncertainty
Horizon	short-term perspective; several years	long-term perspective; several years	current state of technology; measuring the impact of technology on the environment in the short and long term	high variability/ multidimensional nature of time

Forecasting may be used to analyze existing, implemented technologies, whereas, both the foresight research and technology assessment apply to the existing, as well as newly implemented technologies. Forecasting is used mainly to predict the changes in the already implemented technologies. Foresight enables the identification of factors that influence the development of technology, as well as creation of the vision of technology development. The assessment of technologies is mainly used to study the effect of the implemented technologies on the environment. Both the foresight studies and the technology assessment take into account the presence of uncertainty. Technological Forecasting assumes a status quo of the factors affecting the issue under investigation and – in contrast to foresight – generally relates to a near future (up to several years). The time horizon of foresight research is longer than in the case of technological forecasting and concerns a period from five to thirty years. In turn, technology assessment allows the study of technologies in both the short and the long term. In turn, FTA allows assessing the current state of technologies, identifying the factors conducive to their development, examining both the impact of technology on the environment, and the impact of the environment on technologies, as well as enables to predict the future development of the implemented and emerging technologies. A significant advantage of this concept is the examination of technologies in different time horizons. The most commonly taken into account are the following time horizons: up to 5 years, 5-10, and above 10.

4. Conclusion

The analysis of technology requires having adequate resources of knowledge, which is distributed, and simultaneously applies to many aspects of technological development. The analysis of technology uses tools and skills enabling carrying out the substantive assessment of the technical characteristics and properties of its current status. The knowledge about the current trends in technology development is also necessary. Currently – in an era characterized by significant dynamics of the environment – careful consideration or even planning the future development of technology is gaining importance. The concepts that allow the prediction of the future state of technology development are technology assessment, technology forecasting, technology foresight, and Future-oriented Technology Analysis. The concept worth underscoring, enabling the presentation of the broad approach to the future of a chosen technology, developed taking into account the knowledge and experience in a given area is the prospective analysis of technology. This process facilitates the integration of science and technology with business practice, and to identify opportunities in the field of development of new technologies. It also allows for the coordination of the development of technological potential with the scenarios of market or sector development. With the prospective analysis of technology, it is possible to identify, examine in detail, assess the current state, as well as predict the priority futures – those with the greatest potential of technology development. Future-oriented Technology Analysis also makes it possible to distinguish factors conducive to the development of these technologies, examine the impact of technologies on the environment, and also allows predicting the future of development of these technologies. A significant advantage of this concept is considering technologies in different time perspectives: up to 5 years, from 5 to 10 years and above 10 years.

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References

[1] Carlson L. Using technology foresight to create business value. *Research Technology Management* 2004;47(5):51–60.
[2] Gudanowska AE. *Technology mapping as a tool for technology analysis in foresight studies*. Technology Management Conference: ITMC 2014: IEEE International 2014;1–4.
[3] Nazarko J, Saparauskas J. Application of DEA method in efficiency evaluation of public higher education institutions. *Technological and Economic Development of Economy* 2014;20(1);25–44.
[4] Jantsch E. *Technological forecasting in perspective. A Framework for Technological Forecasting. Techniques and Organisation*. OECD; 1967.
[5] Cetron MJ, Bartoch B. *Technological forecasting*. New York: Gordon and Breach Scence Publisher; 1969.
[6] Roper AT, et. al. *Forecasting and Management of Technology*. New York: John Wiley & Sons; 2011.
[7] Firat AK, Woon WL, Madnick S. *Technology Forecasting – A Review*. Composite Information Systems Laboratory Sloan School of Management. Cambridge: Massachusetts Institute of Technology; 2008.
[8] Wack P. *Scenarios: Uncharted Waters Ahead*. Harvard Business Review; 1985.
[9] Ejdys J. Ustinovicius L, Stankevičienė J. Innovative application of contemporary management methods in a knowledge-based economy – interdisciplinarity in science. *Journal of Business Economics and Management* 2015;16(1):261–274.
[10] Nazarko J, Kononiuk A. The critical analysis of scenario construction in the Polish foresight initiatives. *Technological and Economic Development of Economy* 2013;19(3):510–532.
[11] Magruk A. The Most Important Aspects of Uncertainty in the Internet of Things Field – Context of Smart Buildings. *Procedia Engineering* 2015;122:220–227.

[12] Magruk A. Analiza niepewności w złożonych, dynamicznych systemach – przypadek Internetu Rzeczy [Analysis of uncertainty in complex, dynamic systems: Internet of Things case study]. *Przegląd Organizacji* 2016;1:53–59.
[13] Ejdys J. Future oriented strategy for SMEs. *Procedia – Social and Behavioral Sciences* 2014;156:8–12.
[14] Nazarko J, Glinska U, Kononiuk A, Nazarko L. Sectoral foresight in Poland: thematic and methodological analysis. *International Journal of Foresight and Innovation Policy* 2013;9(1):19–38.
[15] Nazarko Ł. Responsible research and innovation – new paradigm of technology management. *The 9th International Scientific Conference "Business and Management" 2016: Conference Proceedings*; 2016.
[16] Nazarko Ł. Technology Assessment in Construction Sector as a Strategy towards Sustainability. *Procedia Engineering* 2015;122:290–295.
[17] Mazurkiewicz A, Belina B, Poteralska B, Giesko T, Karsznia W. Universal methodology for the innovative technologies assessment. *Proceedings of the 10th European Conference on Innovation and Entrepreneurship* 2015;458–467.
[18] Mazurkiewicz A, Poteralska B. Barriers to Technology Transfer at R&D Organisations. *Proceedings of the European Conference on Entrepreneurship and Innovation* 2015:449–457.
[19] Halicka K. Innovative Classification of Methods of The Future-Oriented Technology Analysis. *Technological and Economic Development of Economy* 2016;22(4):574–597.
[20] Saritas O, Burmaoglu S. The evolution of the use of Foresight methods: a scientometric analysis of global FTA research output. *Scientometrics* 2015;105(1):497–508.
[21] Halicka K, Lombardi PA, Styczyński Z. Future-oriented analysis of battery technologies. *Proceedings of the IEEE International Conference on Industrial Technology* 2015;1019–1024.