4 Foresight methods for technology validation, roadmapping and development in the surface engineering area

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Abstract

Purpose: *The aim of this chapter is to present a set of methods for evaluating the strategic development perspectives of priority innovative technologies, backed by an example illustrating the practical application of a proposed solution with regard to the selected surface engineering methods.*

Design/methodology/approach: *The chapter describes a set of validation, roadmapping and technology development methods in the part pertaining to the dendrological matrix of technology value, the meteorological matrix of environment influence, the matrix of strategies for technologies, the setting of strategic development tracks and creating technology roadmaps.*

Findings: *The presented approach allows for organizing, enhancing and modernizing the process of testing as part of the technology foresight, with special consideration paid to material surface engineering.*

Research limitations/implications: *The proposed general analyses purposefully omit the materials science part of the methodology which will be thoroughly presented in the series of publications currently prepared for print, on selected surface engineering technologies. The carried out works are part of a bigger research project aimed at generating a set of most promising surface engineering technologies.*

Practical implications *The described methods will be used to set priority innovative technologies in the field of material surface engineering; however, their universal character indicates they may be successfully used during the realisation of any technology foresight and, after a slight adaptation - also an regional foresight.*

Originality/value: *The value of the chapter is an example-supported presentation of an original authority set of methods for validation, roadmapping and forecasting the development of technologies, with special consideration paid to the field of material surface engineering.*
Keywords: *Methodology of research; Analysis and modeling; Foresight; Technology value and development; Technology Roadmapping*

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1. Introduction

Sustainable development which provides societies or their present or future citizens equal access to the environment, as well as economic growth stimulated by economy based on knowledge require a statistical increase of the quality of technologies implemented in industry [1-3]. The analysed problem pertains not only to avant-garde technologies realised by model companies but, to a larger extent, to the absolute need to increase the average level of implementing technologies by the statistical majority of manufacturers. This has very large significance on the quality and durability of the statistical majority of products introduced to the market and significantly decides about the competitiveness of economy. Thus, it is justifiable to aim at a scientific forecasting and shaping of the future [4-13], thus deviating as far as possible from the ineffective and risky method of trials and errors which may quickly lead to wasting the accomplishments of previous generations. In this situation, it seems critical to direct scientific research to the most promising scientific fields and branches which may have a large influence on the quick civilisation-economic development, the development of the IT community and the creation of an economy based on knowledge, what is the goal of many actually realised and recently finished projects [3, 14-22]. Moreover, attention should be drawn to providing the possibility of a rational practical use of conducted studies and of creating budgetary references for them. Such defined aims and targets are realised through the implementation of foresight study results in real economy, pertaining to detailed, specialist and promising thematic fields. A generalisation of Europe's technology foresight results announced in reports from the realisation of projects The Future of Manufacturing in Europe (FutMan) [14] and Manufacturing Visions The Futures Project (ManVis) [15] is the anticipation of manufacturing engineering materials of qualities ordered by product users. New engineering materials, as well as the processes of their manufacturing and processing are subordinated to customer needs and the utility functions of products. Very often, utility functions of many products and their elements depend mainly on the structure and qualities of surface layers [1-2, 23-25]. As a result of a suitable selection of the element's material and the processes which shape its structure and qualities, as well as due to the type and technology of the surface layer which provide the required utility properties, it is possible to set the properties of the core and surface layer of the manufactured element in the most favourable way. Material surface engineering, involving surface treatment and surface covering is one of the most dynamically developing economy branches in many technologically advanced countries [15] and many detailed fields, what is the subject matter of scientific works, such as [26-42]. It is anticipated that material surface engineering, as a highly significant part of broadly understood material engineering and deserving a separate and thorough analysis, will in the nearest decades be placed among the most promising advanced material technologies [14-16, 20]. Thus, it is appropriate to conduct scientific studies pertaining to strategic development directions of material surface engineering, while the analysed problem has high social-economic significance [1-5]. The strategic development directions of material surface engineering may be set in an ordered, facilitated and modernised way based on the results of classic studies of the structure and properties of surfaced engineering materials and on computer-aided foresight studies intended for anticipating and shaping the future through acquiring knowledge from experts, organizing and spreading it according to the rules of the worked out strategy. This constitutes the subject of wide-spread individual foresight-materials science research [43-48] whose main aim is the identification and critical discussion on priority innovative technologies and strategic directions of developmental studies which qualify for using industrial methods of shaping the structure and properties of engineering material surfaces whose development will be critical during the next 20 years. Generally, an analysis was anticipated of a dozen or so thematic areas, constituting in total approx. 500 detailed technologies, out of which approx. 150 technologies were qualified for further analyses as part of three iterations of surveys addressed to high-quality experts selected from scientific, business and public administration circles, in total leading to obtaining over 600 expert opinions. The analysis of this problem leads to generating a set of priority innovative surface engineering technologies which contribute to the statistical quality increase of technologies applied in industrial companies, stimulating sustainable development and strengthening economy based on knowledge. The selected aims of the undertaken individual studies include also working out a methodology of the computer-aided integrated management of foresight studies. The assumptions of the newly-created author's e-foresight methodology pertaining to the Computer Aided Foresight Integrated Research Management (CA FIRM), together with creating an accompanying IT technology including especially: a Virtual Organisation for Foresight Integrated Research Management (VO FIRM), an Web Platform for Foresight Integrated Research Management (WP FIRM), with the use of Neuron Networks for Foresight Integrated Research Management (NN FIRM), were presented in an independent publication [43]. The worked out e-foresight methodology which uses IT technologies corresponds to already known and commonly used notions [49-51]: e-management, e-business, e-trade, e-banking, e-logistics, e-services, e-administration and e-education. Each of these terms means conducting specified activities with the use of computer networks, especially the internet. The e-foresight methodology allows for organizing, facilitating and modernizing the conducted foresight research [43]. The aim of this chapter is to present an authority methodology of specifying the values of the analysed set of selected technologies for shaping the structure and properties of the surface layer against the environment, together with the recommended strategies of acting, strategic development tracks taking into account the influence of each of the used technologies of processing engineering material surfaces on the quality, structure and properties of surface layers obtained as a result of these technologies, and creating a set of technology roadmaps of the analysed technology groups. The creation and use of these tools allows for presenting, in a uniform and clear format, various types of factors which directly and indirectly characterize given groups of technologies together with the forecast and perspectives of their development in different intervals of the adopted time horizon [52-54]. Technology roadmaps are a very comfortable and practical tool of comparative analysis which facilitates the selection of technologies according to the selected criterion, and when supplemented by operation sheets with precise technological details - they enable the implementation of a given technology in industrial practice. A very large significance of technology roadmaps is their flexibility which enables their supplementing and expanding by new sub-layers depending on the arising needs.

The methodological bases described in this chapter are used in a series of foresight-materials science research which constitute a fragment of broader individual actions [4, 5, 44] aimed at selecting, testing, characterizing and specifying strategic development perspectives of priority innovative material surface engineering technologies in the process of technological e-foresight and subsequently prepared publications, including especially the results of individual research corresponding to specific surfacing technologies. However, the created methodology has a broader significance and may be applied in all types of technology and regional foresights, as well as in other areas of knowledge and information management in which the use of modern IT systems constitutes a prospective, modern and effective approach aimed at using the currently available economic, system, technological, financial and social potential for the realisation of strategic developmental aims.

2. Outworked research methodology

The conducted studies are interdisciplinary and the used testing methodology pertains mainly to technology foresight [6] being an element of a field called organisation and management and to surface engineering included in a more broadly understood material engineering. At certain stages of the conducted studies, also methods were used which come from artificial intelligence, statistics, IT technology, construction and exploitation of machines, as well as strategic [55], operational [56] and quality [57] management.

According to the adopted methodology, the carried out research include: selecting technology groups for experimental-comparative research, collecting expert opinions, carrying out a multi-criteria analysis and marking its results on the dendrological and meteorological matrix, determining strategies for technologies preceded by rescaling and objectivising test results using formulated mathematical relations, setting strategic development tracks for technologies, carrying out a series of specialist materials science experiments in experienced team [33-42] using a specialist diagnostic-measuring apparatus and the creation of technology roadmaps.

In accordance with the applied methodology of foresight-materials science research, several possibilities of homogenous groups should be singled out from the analysed technologies in order to subject them to planned experimental-comparative nature research.

The division criterion may be, e.g.: the type of tested substrate, the type or number of coatings/surface layers applied to the tested material, the manner or type of the researching apparatus for applying coatings/surface layers to the tested material.

The determination of objectivised values of specific singled out technologies or their groups is done through the dendrological matrix of technology value, while the meteorological matrix of environment influence is used to specify the positive and negative force of the micro- and macroenvironment on given technologies. The methodological construction of both these matrices refers to portfolio methods commonly known in management sciences [57-61], serving as characterisation of the portfolio of products offered to the customer by the company, allowing for a graphic presentation of the results of comparative analysis conducted based on two criteria/factors placed on the horizontal and vertical axes of the matrix, respectively. The most famous matrix of this type – the Boston Consulting Group (BCG) matrix [62] – owes its extraordinary popularity to simple associations and intuitive concluding, which has become an inspiration during the creation of methodological assumptions of the dendrological and meteorological matrices. For the purpose of evaluating technology groups with regard to their values and environmental influence, a ten-point universal scale of relative states (Table 1) was adopted, in which the smallest value 1 corresponds to a minimum level, and the highest value 10 is the level of perfection.

Table 1. *Universal scale of relative states*

NUMBER	Class discriminant	LEVEL	
			perfection
10	0.95	EXCELLENT	
9	0.85	VERY HIGH	
8	0.75	HIGH	normality
7	0.65	QUITE HIGH	
6	0.55	MODERATE	
5	0.45	MEDIUM	
4	0.35	QUITE LOW	mediocrity
3	0.25	LOW	
2	0.15	VERY LOW	
1	0.05	MINIMAL	

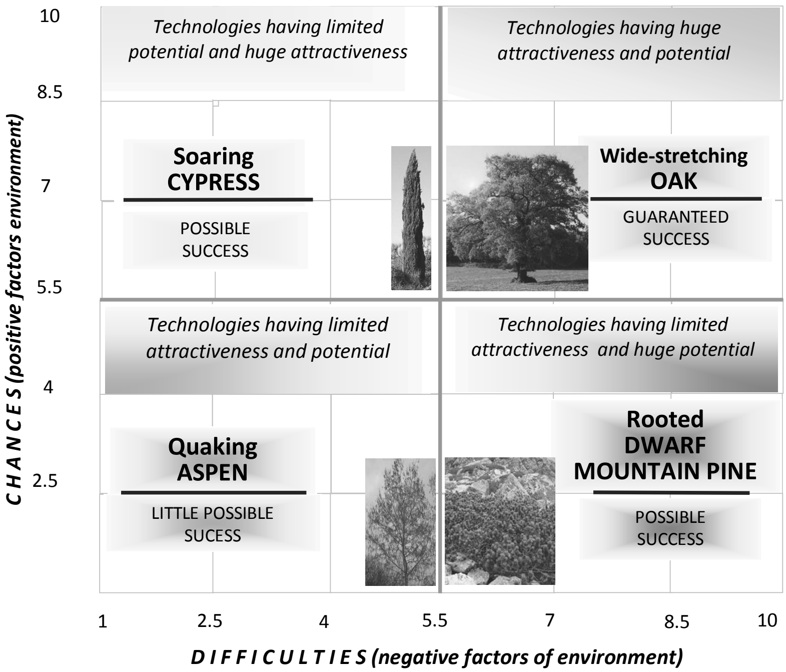


***Figure 1**. The dendrological matrix of technology value. The idea presentation*

The dendrological matrix of technology value (Fig. 1) presents graphic results of evaluating specific technology groups, with special attention paid to the potential constituting the real objective value of a given technology and to the attractiveness reflecting how a given technology is subjectively perceived among its potential users. The potential of a given technology group expressed through a ten-point universal scale of relative states, marked on the horizontal scale of the dendrological matrix is the result of a multi-criteria analysis carried out based on an expert opinions taking into account, in suitable proportions, the following types of potential: creational, application, qualitative, developmental and technical. On the vertical scale of the dendrological matrix the level of attractiveness was marked of a given technology group which is the mean weighed expert opinions based on detailed criteria corresponding to the business, economic, liberal, environmental and system attractiveness. Depending on the type of potential and level of attractiveness determined as part of the expert opinion, a given technology may be placed in one of the quarters of the matrix. The following quarters were distinguished in the dendrological matrix of technology value:

- **Quaking aspen** is a weak technology with limited potential, included within the range ⟨1, 5.5⟩ and with limited attractiveness within the range ⟨1, 5.5⟩, whose future success is unlikely;
- **Soaring cypress** corresponds to a technology with limited potential within the range ⟨1, 5.5⟩, but with huge attractiveness included in the range (5.5, 10⟩, which causes the success of a given technology to be possible;
- **Rooted dwarf mountain pine** is a technology with limited attractiveness within the range ⟨1, 5.5⟩, but with huge potential included in the range (5.5, 10⟩, thanks to which its future success is possible;
- **Wide-stretching oak** corresponds to the best possible situation in which the analysed technology is characterised by huge potential within the range (5.5, 10⟩, as well as huge attractiveness within the range (5.5, 10⟩, and this connection guarantees future success.

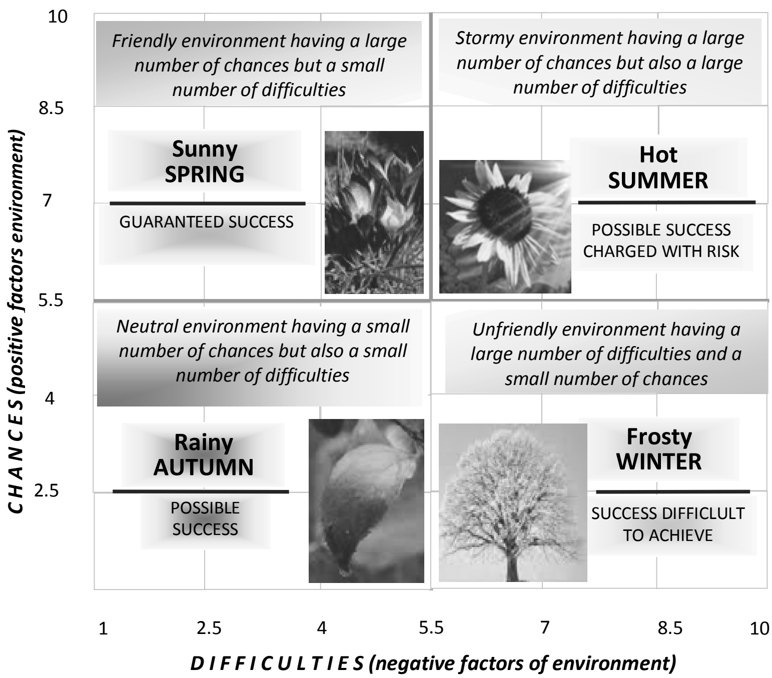


Figure 2. *The meteorological matrix of environment influence. The idea presentation*

The meteorological matrix of environment influence (Fig. 2) presents graphic results of evaluating the impact of external factors on specific groups of technologies which had been divided into difficulties with a negative impact and chances which positively influence the analysed technologies. The testing of expert opinions on the subject of positive and negative factors which influence specific technologies was carried out based on a survey comprising several dozens of questions pertaining to the micro- and macroenvironment in strictly defined proportions. 16% of the questions pertain to the competitive environment, while the remaining 84% are questions regarding specific constituents of the macroenvironment, and especially the following types of environment: technological (20%), economic (16%), social (12%), political-legal (12%), international (12%) and natural (12%). External difficulties expressed with the use of a ten-point universal scale of relative states, which are the result of a multi-criteria analysis conducted based on the expert opinions, have been placed on the horizontal scale of the meteorological matrix. On the other hand, chances, i.e. positive environment factors being a mean weighed expert opinions based on detailed criteria, were placed on the vertical scale. Depending on the level of influence of positive and negative environment factors on the analysed technology, determined as part of the expert opinions on a ten-point scale, it is placed in one of the matrix quarters. The following quarters were distinguished in the meteorological matrix of technology value:

- **Frosty winter** corresponds to the worst possible situation in which the environment carries a large number of difficulties included in the range (5.5, 10⟩ and a small number of chances within the range ⟨1, 5.5⟩, which causes the success in a given environment to be difficult or impossible to obtain;
- **Hot summer** corresponds to a situation in which the environment brings many chances included within the range (5.5, 10⟩, but which is also accompanied by many difficulties from the range (5.5, 10⟩; this causes the success of the technology under these conditions to be possible but charged with risk;
- **Rainy autumn** corresponds to a neutral situation in which there are no dangers awaiting for a given technology, which corresponds to the range ⟨1, 5.5⟩, but also the environment does not carry many chances which is reflected by the range ⟨1, 5.5⟩;
- **Sunny spring** is the best possible variant because it denotes a friendly environment with a large number of chances from the range ⟨5.5, 10⟩ and a small number of difficulties included within the range ⟨1, 5.5⟩, which will guarantee success of a given technology under such good conditions.

INFLUENCE OF ENVIRONMENT				
10 – 7.25	STRATEGY OF AN ASPEN IN SPRING TO TAKE ADVANTAGE OF PRESENCE ON AN ATTRACTIVE MARKET	STRATEGY OF A CYPRESS IN SPRING TO TAKE ADVANTAGE OF CHANCES, STRENGTHENING TECHNOLOGY POTENTIAL	STRATEGY OF A DWARF MOUNTAIN PINE IN SPRING TO TAKE ADVANTAGE OF CHANCES, STRENGTHENING TECHNOLOGY ATTRACTIVENESS	STRATEGY OF AN OAK IN SPRING SUCCEED
7.25 – 5.5	STRATEGY OF AN ASPEN IN SUMMER TO ANALIZE RISK	STRATEGY OF A CYPRESS IN SUMMER TO STRENGTHEN POTENTIAL AND ESTIMATE RISK	STRATEGY OF A DWARF MOUNTAIN PINE IN SUMMER TO STRENGTHEN ATTRACTIVENESS AND ADJUST PRODUCT TO CLIENT'S REQUIREMENTS	STRATEGY OF AN OAK IN SUMMER TO ANALIZE THE MARKET AND TAKE ADVANTAGE OF CHANCES
5.5 – 2.25	STRATEGY OF AN ASPEN IN AUTUMN TO SLOWLY LEAVE THE MARKET	STRATEGY OF A CYPRESS IN AUTUMN "TO MILK THE COW" AS LONG AS POSSIBLE STRENGTHENING TECHNOLOGY POTENTIAL	STRATEGY OF A DWARF MOUNTAIN PINE IN AUTUMN "TO MILK THE COW" AS LONG AS POSSIBLE STRENGTHENING TECHNOLOGY ATTRACTIVENESS	STRATEGY OF AN OAK IN AUTUMN "TO MILK THE COW" WHILE SEARCHING FOR A NEW RANGE OF TECHNOLOGY APPLICATIONS
2.25 – 1	STRATEGY OF AN ASPEN IN WINTER TO LEAVE THE MARKET	STRATEGY OF A CYPRESS IN WINTER TO SLOWLY LEAVE THE MARKET	STRATEGY OF A DWARF MOUNTAIN PINE IN WINTER TO RESIST DIFFICULTIES	STRATEGY OF AN OAK IN WINTER TO INTENSIVELY SEARCH FOR NEW TECHNOLOGY APPLICATIONS
	2.25	5.5	7.25	10

VALUE OF TECHOLOGY

LEGEND

Well-portending strategies

Badly-portending strategies

Uncertain strategies which can cause success or only minimalize losses depending on circumstances

Figure 3. *The general matrix of strategies for technologies*

INFLUENCE OF ENVIRONMENT				
10	To utilize, as much as possible, weak technology using a good economic situation and, utilizing insight into the attractive market, test, develop and introduce new technologies. TO TAKE ADVANTAGE OF PRESENCE ON AN ATTRACTIVE MARKET	To test, perfect, strengthen and fully invest in an attractive technology making use of a good economic situation on the market TO TAKE ADVANTAGE OF CHANCES, STRENGTHENING TECHNOLOGY POTENTIAL	To enhance, modernize, automate, computerize and promote technology of high potential, using good economic conditions on the market TO TAKE ADVANTAGE OF CHANCES, STRENGTHENING TECHNOLOGY ATTRACTIVENESS	To develop, strengthen, implement attractive technology of a large potential in industrial practice in order to achieve outstanding success. SUCCEED
7.25	To conduct risk analysis and, depending on its results, remain on the market or withdraw from it with weak technology TO ANALIZE RISK	To enhance the potential of an attractive technology in risky environment conditions, evaluate risk and, depending on the result, fight aggressively for the customer or slowly withdraw the technology TO STRENGTHEN POTENTIAL AND ESTIMATE RISK	To try to enhance and modernize the technology of high potential, carry out marketing studies and adjust the product to the customer's requirements TO STRENGTHEN ATTRACTIVENESS AND ADJUST PRODUCT TO CLIENT'S REQUIREMENTS	To use the attractiveness and potential of a technology in a risky environment, avoid difficulties, carry out marketing studies and adjust the product to the customer's requirements. TO ANALIZE THE MARKET AND TAKE ADVANTAGE OF CHANCES
5.5	To slowly withdraw a weak technology from the market which does not provide new possibilities. TO SLOWLY LEAVE THE MARKET	To utilize the stable, predictable environment to a maximum degree in order to implement production using an attractive technology, simultaneously strengthening its potential "TO MILK THE COW" AS LONG AS POSSIBLE STRENGTHENING TECHNOLOGY POTENTIAL	To profit from the realisation of production in a stable, predictable environment using solid technology which should be modernised and intensively promoted in order to strengthen its attractiveness "TO MILK THE COW" AS LONG AS POSSIBLE STRENGTHENING TECHNOLOGY ATTRACTIVENESS	Succeed with an attractive, stable technology on a predictable market while searching for new markets, customer groups and products possible to acquire using this technology. "TO MILK THE COW" WHILE SEARCHING FOR A NEW RANGE OF TECHNOLOGY APPLICATIONS
2.25 1	To withdraw a weak technology from the market in which difficulties predominate. TO LEAVE THE MARKET	Based on the technology's attractiveness, make use of the environment to a maximum degree and withdraw the technology of a small potential from the market in which difficulties predominate TO SLOWLY LEAVE THE MARKET	To resist piling up difficulties coming from the environment, at the same time trying to strengthen the attractiveness of a technology with a large potential TO RESIST DIFFICULTIES	To try and wait out the difficulties and remain on the market with a solid, attractive technology, while intensively searching for new markets, customers and products possible to manufacture using this technology. TO INTENSIVELY SEARCH FOR NEW TECHNOLOGY APPLICATIONS
	2.25	5.5	7.25	10

LEGEND

- Well-portending strategies
- Badly-portending strategies
- Uncertain strategies which can cause benefits or only minimalize losses depending on circumstances

Figure 4. *The detailed matrix of strategies of technology*

At the next stage of research works the results of research presented in graphic form using the dendrological matrix of technology value and the meteorological matrix of environment influence have been placed on the **matrix of strategies for technologies**. This matrix comprises sixteen fields corresponding to specific variants resulting from a combination set of four technology types and four environment types. The general matrix of strategies for technologies (Fig. 3) graphically presents the place of technologies, considering their value and environment influence and points to the strategy of conduct which should be adopted with regard to a given technology, taking into account the previously analysed factors. The detailed matrix of strategies for technologies presented in Figure 4 includes in its fields a short description of conduct recommended if a given technology with a specified value belonging to a given numeric range is applied in an environment with a value from the specified numeric range and a negative (difficulties) or positive (chances) return. To facilitate the transfer of specific numeric values from the dendrological matrix [2x2] and the meteorological matrix [2x2] to the matrix of strategies for technologies with the dimensions of [4x4], mathematical relations were formulated which enable the rescaling and objectivising of test results and, based on them, a short computer program was created to enable a quick calculation of the searched values and their placing on the chart. Thus, the following notions were introduced: the relative value of technology V_n and the relative value of environment influence E_n. With the use of mathematical relations expressed in a simplified way by the system of equations (1), it is possible to perform detailed calculations and to visualize them using the matrix of strategies for technologies.

$$\begin{cases} V_n' = c + \left(\dfrac{d-c}{b-a}\right)\left(V_n - a\right) \\ E_n' = c + \left(\dfrac{d-c}{b-a}\right)\left(E_n - a\right) \end{cases} \tag{1}$$

where:

a − the minimum value on a scale used in the dendrological and meteorological matrix;
b − the maximum value on a scale used in the dendrological and meteorological matrix;
c − the minimum value on a scale used in the matrix of strategies for technologies;
d − the maximum value on a scale used in the matrix of strategies for technologies;
V_n' − the relative value of technology on a scale used in the matrix of strategies for technologies;
V_n −the relative value of technology on a scale used in the dendrological and meteorological matrices;

E_n' − the relative value of the environment influence on a scale used in the matrix of strategies for technologies;

E_n − the relative value of environment influence on a scale used in the dendrological and meteorological matrices;

n − the alphanumeric symbol of a given technology/group of technologies, $n \in \{A, B, \ldots, Z.\}$.

The next stage of research involves specifying **strategic development tracks** for specific technologies / groups of technologies which constitute a forecast of their development in time intervals corresponding to the years 2015, 2020, 2025 and 2030 in three variants: optimistic, pessimistic and most probable, and then visualizing them against a matrix of strategies for technologies.

The results of the carried out experimental-comparative research constitute source data which serve for creating technology roadmaps. The heading of each **technology roadmap** contains a basic characteristic of the technology, including: the name of the technology, the represented research field and the given catalogue number. The layout of the technology roadmap created for the purpose of the realised research corresponds to the first quarter of the Cartesian coordinate system. Three time intervals were placed on the horizontal axis, pertaining to: the situation as of today (year 2010), in ten years' (in 2020) and in twenty years' time (in 2030). The time horizon of all the research placed on the technology roadmap equals 20 years and is adequate to the dynamics of changes occurring in the analysed thematic field − the surface engineering. On the vertical axis of the technology roadmap seven main layers were placed, characterised in short in Table 2, corresponding to a specific question pertaining to the analysed scope. Each of the main layers has been additionally divided into sub-layers with a higher level of detail. The main layers of the technology roadmap were organised in a hierarchical way. The upper part of the technology roadmap contains the most general layers specifying the premises, reasons and causes of realised research which influence the layers placed under them in the process of „pull". The middle part of the technology roadmap pertains to the essence of the analysed problem by characterizing the product and technology used for its manufacturing. The lowest layers of the technology roadmap contain various details of the technical-organisational nature which influence the higher-located layers in the process of „push". In addition, the technology roadmap presents relations between its specific layers and sub-layers, with a division into: cause-and-effect relations, capital relations, time correlations and two-way flows of data and/or resources, visualised using different types of arrows.

Table 2. *Characteristics of the main layers of the technology roadmap*

Item	Layer name	Range	Question	Description
1.	Time	Order	When?	Defines the adopted time intervals and time horizon of conducted research
2.	Conceptual	Purpose	Why?	Specifies social and economic perspectives of conducted actions and the suitable strategy for a given technology
3.	Product	Subject	What?	Characterizes the product created during a given technological process, taking into account its structure and properties
4.	Technological	Manner	How?	Characterizes a given technology in terms of the following detailed criteria: lifespan, type and form of production, machinery park, automation and robotisation, quality, ecology
5.	Spatial	Place	Where?	Specifies the type of organisation and represented industrial branches
6.	Staff	Contractor	Who?	Defines the structure of the staff and expected employee competences
7.	Quantitative	Cost	How much?	Specifies capital requirements and the estimated production volume

The technology roadmap is a universal tool which enables presenting, in a unified and clear format, different types of internal and external factors directly and indirectly characterizing a given technology, taking into account the ways of influence, interdependencies and the change of specific factors over time. Such created technology roadmaps are becoming a very comfortable and practical tool of comparative analysis, facilitating the selection of the best technology in terms of the specified selected criterion, and when supplemented by technological sheets with precise technological details – they enable the implementation of a given technology in industrial practice. It should also be noted that a very important feature of technology roadmaps is their flexibility. When needed, the technology roadmap may be supplemented and expanded by additional sub-layers, adapting it, e.g. to the specificity of the carried out scientific-research studies, the requirements of a given industrial field or the size of a company.

The inherent part of the worked out methodology are detailed materials science research of surface layers structures created with the use of various surfacing methods, research of mechanical and tribological properties, as well as research of utility functions under conditions of exploitation or similar ones. The results of these research relating to technologies selected through the described technology valuating methods constitute an important premise for working out and experimentally verifying the evaluations made using methods of working out matrices of strategies for these technologies and they are necessary for creating a technology roadmaps and operation sheets. A synergic impact of the materials science and foresight testing methods guarantees the accuracy and compatibility of evaluations made according to the methodology worked out and described in this work with regard to surface engineering. Each time, carrying out such research requires supporting the forecasts based on foresight research with detailed materials science research as integral elements of the created applied methodology, which gives basis for proper concluding as part of the technology foresight. It is obvious that there is no unity of the place and time of realizing such research because proper finishing of the technology foresight requires possessing detailed results of research pertaining to the analysed technology, which could have been carried out previously. If it is impossible, it is necessary to carry out such detailed research as part of the foresight.

3. Illustrative example

The procedure, whose aim is to evaluate strategic development perspectives of surface engineering technologies in accordance with the methodology described in sub-chapter 2 of this chapter, has been illustrated with an example that presents the recommended manner of conduct step by step using specific numeric values. Thus, the presented example includes: a dendrological matrix of technology value, a meteorological matrix of environment influence and a matrix of strategies for technologies together with points placed on them which correspond to specific technologies, three alternative strategic development tracks created for an exemplary technology and one from representative technology roadmaps created as part of the carried out works [3, 44]. The conducted general analyses purposefully omit a strictly materials science part of the methodology pertaining to specific research of surface layer structures created via different methods, research of mechanical and tribological properties and research of utility functions under exploitation or similar conditions. This aspect of the analysed theme will be properly presented in the series of publications currently prepared for print, pertaining to the application of the proposed methodology in a comparative analysis of specific technologies or their homogenous groups. These groups may be created based on a division in terms of the type of tested surface, type or number of coatings/ surface layers applied to the tested substrate, the manner or type of the apparatus for applying coatings/surface layers to the tested substrate or any other clearly defined, objectively verifiable criterion.

Adopting the method of material surfacing as the division criterion in the presented example, four detailed technologies were subjected to analysis:

(A) Laser remelting,

(B) Passivation,

(C) Detonation spraying,

(D) PVD multilayer coatings deposition.

Source data constituting a basis for the performed assessments are obtained from experts who, in a survey study, answer a series of detailed questions on the potential and attractiveness of a given technology, evaluating each of them using a ten-point universal scale of relative states. Depending on the advancement level of the carried out foresight works, at the earlier stages answers may be provided by a narrow group of key experts, while at the advanced stages – by a considerably bigger group of trade experts selected among scientific, business, and public administration circles, which is realizing this aim, eg, as part of the Delphi method [6, 8, 11]. The studies especially test the creational, application, qualitative, developmental and technical potential, as well as the business, economic, liberal, environmental and system attractiveness. Using a multi-criteria analysis, the mean weighed value is calculated from the analysed criteria (attractiveness and potential), and the result obtained for specific technologies is placed on the dendrological matrix of technology value (Fig. 5).

In the presented example, PVD multilayer coatings deposition D (8.11, 8.99) was placed in the most promising quarter – the wide-stretching oak – which includes technologies with large potential and attractiveness. Laser remelting A (2.23, 7.44) turned out to be a soaring cypress with large attractiveness and a relatively small potential. Detonation spraying C (9.30, 1.94) was placed in the quarter representing the rooted dwarf mountain pine with large potential and relatively small attractiveness, while the lowest result was obtained by passivation B (3.22, 4.39), placed in the quarter referred to as the quaking aspen with low attractiveness and small potential. The evaluation of the positive and negative impact of the environment on specific technologies has been carried out with the use of a meteorological matrix of environment influence. In accordance with the adopted methodology, the matrix includes results of a multi-criteria analysis which were subjected to expert assessments during surveying, presented in Figure 6. The form used for survey studies comprises several dozen questions relating to micro- and macroenvironment forces influencing technologies in strictly specified proportions. The research results presented in the example show that in accordance with the expert opinions, the friendliest environment called sunny spring, characterised by a large number of chances and small number of difficulties, currently includes the B (9.45, 8.02) technology – passivation. In accordance with the obtained results, risky hot summer with a large number of chances accompanied by numerous difficulties is the environment of technology D (9.14, 8.92) belonging to the group of PVD multilayer coatings deposition. Neutral rainy autumn with a small number of chances and difficulties is the environment of technology A (4.10, 3.78), i.e. laser remelting, while frosty winter with its numerous difficulties and lack of chances is the environment of technology C (8.22, 2.35), i.e. detonation spraying.

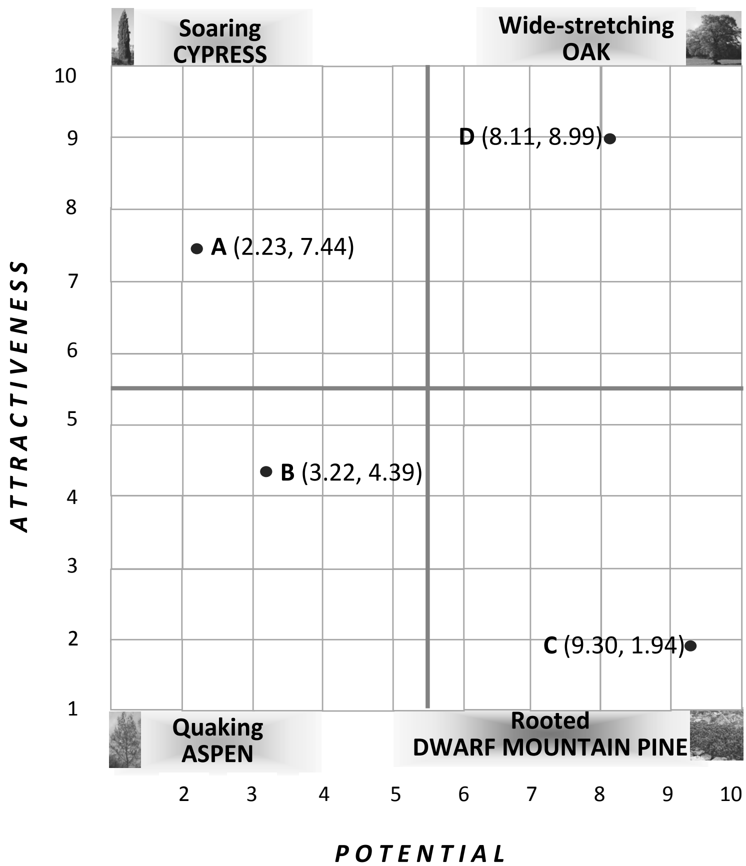


Figure 5. The dendrological matrix of technology value prepared for example technologies representing, as following: (A) Laser remelting, (B) Passivation, (C) Detonation spraying, (D) PVD multilayer coatings deposition

At the next stage of research works, the results of the multi-criteria analysis which uses source data obtained from experts in the process of surveying, presented in graphic form using a dendrological matrix of technology value and meteorological matrix of environment influence, were placed on the matrix of strategies for technologies (Fig. 7). In order to transfer specific numeric values from the dendrological and meteorological matrices onto the matrix of strategies for technologies of different dimensions, formulated mathematical relations were used which allow for rescaling and objectivising research results (1). The matrix of strategies for technologies illustrates a graphic place of specific technologies, taking into account their values and impact forces of the environment, indicating a suitable acting strategy.

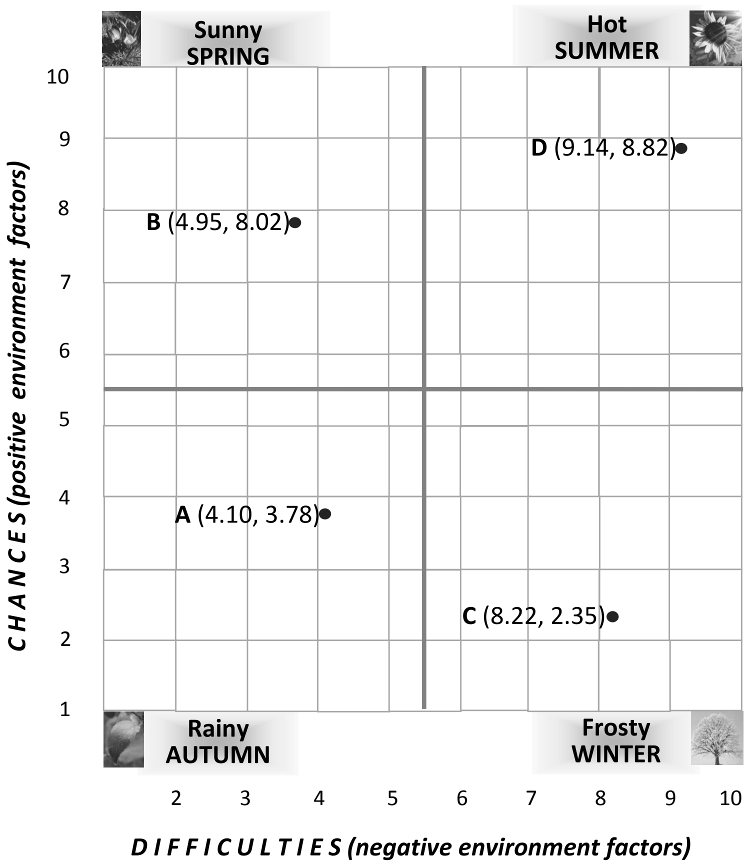


Figure 6. *The meteorological matrix of environment influence prepared for example technologies representing, as following: (A) Laser remelting, (B) Passivation, (C) Detonation spraying, (D) PVD multilayer coatings deposition*

The laser remelting technology – A (3.75, 3.87) – was placed in the matrix field corresponding to the strategy of a cypress in autumn, according to which the use of a stable, predictable environment is recommended for the realisation of production using an attractive technology with limited potential, and it should be accompanied by strengthening its potential. Passivation – B (2.01, 8.07) was placed in the matrix field corresponding to the strategy of an aspen in spring. For this strategy, it is recommended to exploit, as much as possible, a weak technology in times of good economic conditions and to test, develop and introduce new technologies relying on business contacts and insight into the attractive market. Technology C (6.07, 1.53), i.e. detonation spraying, was placed in the matrix field corresponding to the strategy of a dwarf mountain pine in winter which means that the actions recommended for it involve resisting the piling up difficulties coming from the environment, at the same time trying to strengthen the attractiveness of that technology with high potential. The last of the technologies – D (9.13, 6.33) – which represents PVD hard multilayer coatings deposition was placed in the matrix field corresponding to the strategy of an oak in summer, which involves using the attractiveness and potential of technology in a risky environment and avoiding difficulties; moreover, it is recommended to conduct insightful marketing studies and, based on them, to adjust a product manufactured using a given technology to the customer's requirements and expectations. It is necessary to emphasise that the evaluation in a scale of relative states are hypothetically presented for the use of this chapter and do not actually come from wide questionnaire surveys of experts, as well as environmental conditions for each of these discussed technologies are well established hypothetically. For example, the potential and attractiveness of passivation are low rated, what symbolizes an aspen. However, it is possible to imagine that for example in a plant equipped with technological equipment for the thermo-chemical treatment, taken over by the new owner with large capital resources, it is possible to use successfully such technology until new technological processes are worked out for new products, what is symbolised by the sunny spring in a matrix assessing environmental conditions. Mentioning these technologies is therefore an example to illustrate the mechanisms for the evaluation resulting from the newly developed methodology presented in this chapter. The presented examples, illustrating the manner of practical implementation of the proposed methodology with regard to specific technologies used in the industry, purposefully adopted various values of the analysed factors wanting to obtain the most diversified end results possible so that it will be possible to show a maximum broad spectrum of variants which may occur in the economic reality.

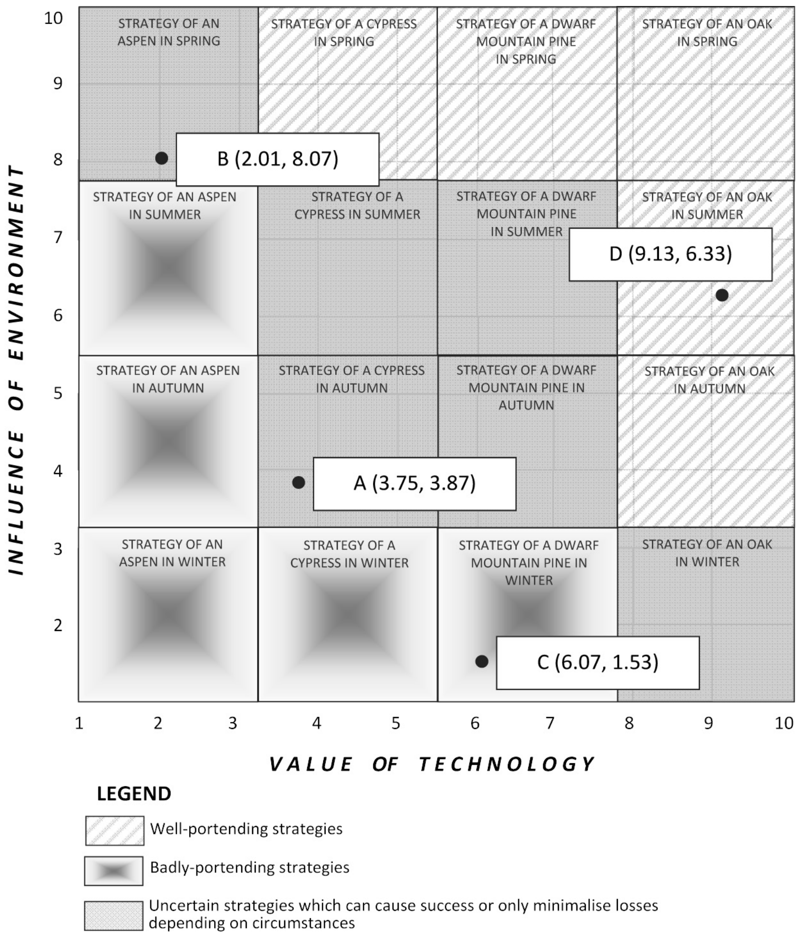


Figure 7. *The matrix of strategies for technologies prepared for example technologies representing, as following: (A) Laser remelting, (B) Passivation, (C) Detonation spraying, (D) PVD multilayer coatings deposition*

When the actual value of a given technology against the environment and the recommended strategy of conduct are known, the aim of the next step, in accordance with the proposed approach, is to specify how the technology itself and its environment will be changing in specific time horizon intervals of foresight studies. For this purpose, strategic development tracks are set in three variants: optimistic, pessimistic and most probable. For example, for the graphic delimitation of strategic development tracks being the forecast for their development in: 2015, 2020, 2025 and 2030 in three variants, another technology of gas nitriding marked as E (3.44, 3.62) was chosen.

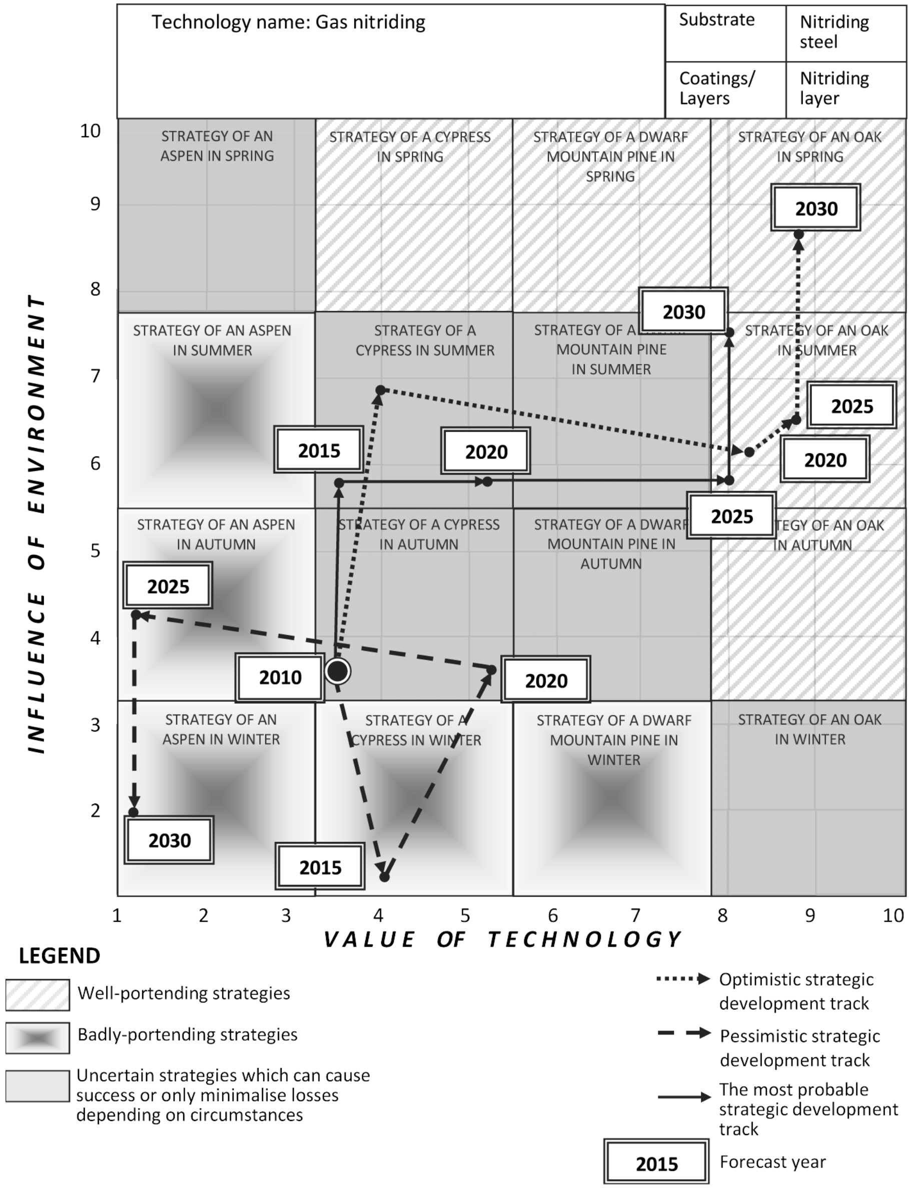
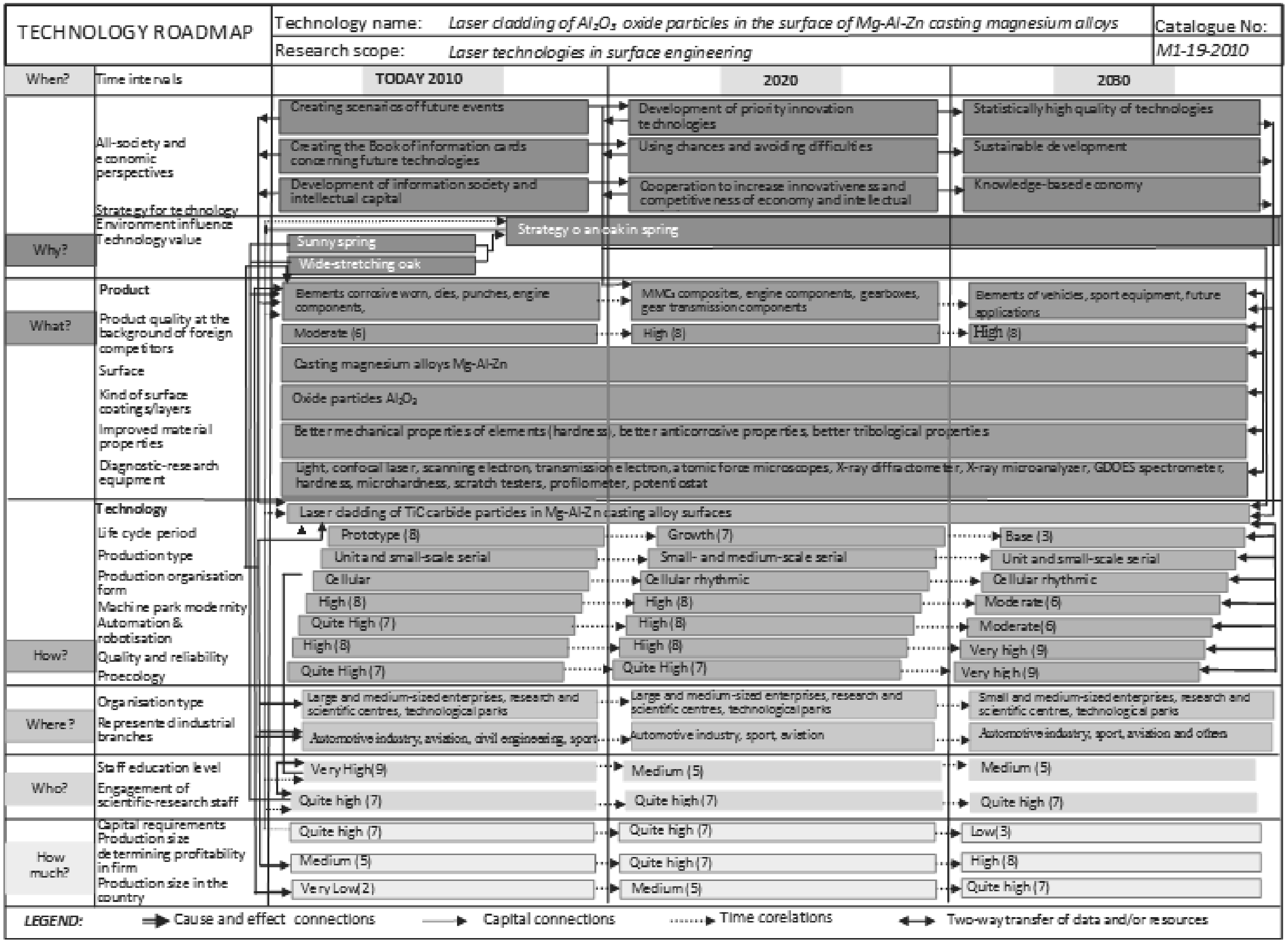


Figure 8. *Optimistic, pessimistic and the most probable strategic development tracks for example technology (E) - gas nitriding against the background of the matrix of strategies for technologies*

On the one hand the meaning of this technology becomes weak against the development of ionisation technology and in turn its development, even dynamic is possible, because of the development of hybrid technologies of conventional thermo-chemical treatment combined with

PVD coating deposition, or even laser surface treatment. Remembering of a still hypothetical meaning of presented examples to illustrate the newly developed methodology for the evaluation of future technological development, strategic development tracks, although, of course, because of the described example – still a hypothetical one were presented in Figure 8. The most probable strategic development track of this technology assumes the change of environment conditions from neutral autumn to risky summer (2015-2020) which, with simultaneous intensive strengthening of potential and maintaining high attractiveness characteristic for a soaring cypress, will allow the technology to shift to the field of the wide-stretching oak on 2025, which will be accompanied by an improvement of environment conditions (2030). The optimistic strategic development tracks of the gas nitriding assumes that the technology will be temporarily placed in a risky environment (2015); however, thanks to its high attractiveness and actions aiming at strengthening its potential it will be placed in the wide-stretching oak field already in 2020. Next, the technology potential will undergo further strengthening which, assuming its large attractiveness and increasingly favourable environment conditions, will in 2030 cause the technology to be placed in the most attractive matrix field corresponding to the position of an oak during spring. The pessimistic variant, expressed through the third set strategic development track of technology (E) assumes the exacerbation of the world crisis within a short period of time (2015) because of the unfavourably developing political and economic situation. Although actions will be undertaken aimed at strengthening the technology potential, crowned by partial success, and the environment situation will improve (year 2020), the technology will dramatically lose its attractiveness in 2025, shifting to the field of aspen during autumn. Subsequent years will lead to a further deterioration of the situation so that in 2030 technology (E) will find itself placed in the weakest matrix field corresponding to aspen during winter, which is related to withdrawing it from the market. In accordance with the adopted manner of conduct, based on the results of works carried out using matrix methods supported by materials science results of experimental research performed on a specialist diagnostic-measuring apparatus, technology roadmaps are created. The worked out technology roadmaps are universal tools which enable presenting, in a unified and clear format, different types of internal and external factors directly and indirectly characterizing given technologies, taking into account the ways of influence, interdependencies and the change of specific factors in time. An exemplary representative (F) technology roadmap prepared for a laser treatment of Al_2O_3 aluminium oxides into the substrate of Mg-Al-Zn casting magnesium alloys was presented in Table 3. The layout of the technology roadmap corresponds

Table 3. *An example (F) technology roadmap prepared for laser cladding Al_2O_3 oxide particles in the surface of Mg-Al-Zn casting magnesium alloys*



to the first quarter of the Cartesian coordinate system in which time intervals are presented on the x-axis, while seven hierarchically organised main layers are organised on the y-axis. Starting from the top, these are the following layers: time, conceptual, product, technological, spatial, staff, quantitative. This enables the setting, in one place, of data on the purpose, subject, manner, place, contractor and cost in relation to the analysed technology, taking into account the changes of these parameters in time. Upper layers placed in the top part of the technology roadmap, specifying general premises, causes and reasons of activity in the process of pulling, act on the fundamental middle layers pertaining to the product and technology. On the other hand, lower layers which specify the organisational-technical details act on the middle layers in an opposite direction, which is referred to in production management as pushing.

4. Conclusions

New engineering materials and the processes of their manufacturing and processing should be subordinated to the needs of the customer and to the products' utility functions, and very often the utility functions of products and their elements depend on the structure and property of surface layers. Material surface engineering is one of the most dynamically developing economy branches in many technologically advanced countries and it is anticipated that during the next decades it will be placed among the most promising advanced material technologies [14-16, 20] which justifies carrying out scientific studies pertaining to strategic developmental directions of this group of technologies. The strategic development directions of material surface engineering may be set in an ordered, facilitated and modernised way based on the results of computer-aided foresight studies intended for scientific anticipating and shaping the future through acquiring knowledge from experts, organizing it and spreading according to the rules of the worked out strategy and to classic studies on the structure and properties of surfaced engineering materials, which constitutes the subject of widespread individual studies [44]. A dozen or so thematic areas are subjected to analysis, in total with approx. 500 technologies, out of which approx. 150 technologies were qualified for further analyses as part of three iterations of surveys studies; at the basis of these studies lies the author's individual idea of e-foresight [43] meaning conducting foresight studies with the use of IT and internet technologies.

In this chapter, methodological grounds were created for material-foresight studies in order to specify the strategic development perspectives of priority innovative technologies of material surface engineering. The worked out methodology has big significance here and may be applied in all types of foresights for formulating strategic development aims of other technologies. In the analysed case it includes especially determining the value of the analysed set of selected technologies for shaping the structure and properties of the surface layer against the environment, working out recommended strategies of conduct, strategic development tracks and creating technology roadmaps of analysed groups of technologies and operation sheets which enable their industrial implementation, taking into account the influence of each of the implemented technology on the quality, structure and properties of surface layers obtained as a result of these technologies. In accordance with the worked out methodology, the subsequently performed research include selecting technology groups for experimental-comparative research, collecting expert opinions, carrying out a multi-criteria analysis and marking its results on the dendrological and meteorological matrices, determining strategies for technologies preceded by rescaling and objectivising test results using mathematical relations, setting strategic development tracks for technologies, carrying out a series of specialist materials science research using a specialist diagnostic-measuring apparatus and creating technology roadmaps and operation sheets.

In order to perform a full cycle of research included in the worked out methodology, several homogenous groups should be singled out among the analysed technologies; the groups are subjected to experimental-comparative research according to the adopted criteria.

Referring to commonly known matrix methods, including the most famous one - BCG (Boston Consulting Group) a dendrological matrix of technology value was created for objectivising the values of specific technologies or their groups, as well as a meteorological matrix of environment influence for specifying the impact force of the micro- and macroenvironment on these technologies. For the purpose of evaluating these groups of technologies, a ten-point universal scale of relative states was adopted, with values ranging from 1 as the minimum level to 10 - corresponding to the highest value perceived as perfection.

In the dendrological matrix of technology value the quaking aspen was differentiated which symbolizes a weak technology with a limited potential and limited attractiveness, whose future success is unlikely; the soaring cypress corresponds to a technology with limited potential but high attractiveness and possible success; the rooted dwarf mountain pine corresponds to a technology with limited attractiveness but with a large potential and possible future success; the wide-stretching oak refers to the best possible situation guaranteeing success, in which the technology has large potential and high attractiveness. The meteorological matrix of environment influence presents graphic results of assessing the influence of external factors on specific technology groups which were divided into negative difficulties and chances which positively influence the analysed technologies, determined based on expert opinions in response to several dozen questions included in an electronic survey. The technology values were illustrated as frosty winter corresponding to the worst possible situation when success is very hard or impossible to obtain; hot summer when the success of the technology under given conditions is possible but charged with risk; rainy autumn corresponding to a neutral situation; and sunny spring which is the best possible variant, in which the success of a given technology under such good conditions is guaranteed. The test results presented in graphic form using a dendrological matrix of technology value and meteorological matrix of environment influence should be placed on a matrix of strategies for technologies, consisting of sixteen fields corresponding to specific variants resulting from the set of combinations of four types of technologies and four types of environment. To facilitate the transfer of specific numeric values from the dendrological and meteorological matrices to the matrix of strategies for technologies, mathematical relations were formulated which enable the rescaling and objectivising of test results with the use of the notions of the relative value of technology V_n and the relative value of environment influence E_n. For specific technologies/groups of technologies the strategic development tracks are specified which constitute a forecast of their development in the years 2015, 2020, 2025 and 2030 in three variants: optimistic, pessimistic and most probable, and they are presented against a matrix of strategies for technologies. The results of carried out experimental-comparative research constitute source data for technology roadmapping for the purpose of a detailed forecasting of each technology's development starting from today, as well as in 10 and 20 years. The vertical axis of the technology roadmap contains seven main layers which include answers to the following questions: When? Why? What? How? Where? Who? How many?, which are additionally divided into sub-layers with a higher degree of detail. The main layers of the technology roadmap were organised hierarchically so that the upper parts contain the most general layers specifying the premises, reasons and causes of realised actions which influence, through „push", the layers placed under them containing technical-organisational details impacting, through „pull", the layers placed above. On the other hand, the middle part of the technology roadmap pertains to the essence of the analysed problem by characterizing the product and technology used for its manufacturing. The technology roadmap presents relations between its specific layers and sub-layers, with a division into: cause-and-effect relations, capital relations, time correlations and two-way flows of data and/or resources, visualised using differentiated arrows. Such created technology roadmaps function as a tool of comparative analysis, facilitating the selection of the best technology in terms of the specified selected criterion, and when supplemented by operation sheets with precise technological details – they enable the implementation of a selected technology in industrial practice.

A very important element of the worked out methodology is the inclusion of detailed materials science research whose description, because of objective reasons standing from a countless number and diversity of possible variants, is impossible to realise in only one chapter. One should underline the significance of materials science research of the surface layer structures created using various surfacing methods, research of mechanical and tribological properties, as well as research of utility functions under exploitation or similar conditions. The results of these research in relation to technologies selected through the previously described technology valuating methods constitute an important premise for working out and experimentally verifying the evaluations made using methods of working out matrices of strategies for these technologies and they are necessary for creating a technology roadmap and an operation sheet. A synergic impact of the materials science and foresight researching methods guarantees the accuracy and compatibility of evaluations made according to the worked out methodology. The unity of place and time is not necessary for these research realisation and does not in any way influence the correctness of the concluding process carried out as part of the technology foresight; however, in sure abandoning of these research has negative influence for foresight realisation correctness.

The worked out tools have broader significance and enable the forecasting of the development of various technologies pertaining not only to surface engineering, in different time intervals with the consideration of various factors which characterize the analysed technologies. It is possible to use them at the initial, general stage of the realised technology foresight when opinions of few key experts are used, as well as at the final stages of formulating results of foresight research for evaluating the results of survey studies carried out among a large group of trade experts. If it is anticipated to carry out studies using the Delphi method, the described method may also be useful. In accordance with the worked out e-foresight methodology, the performance of survey studies is expected through an original developed method which uses modern IT tools for obtaining the adopted aims: virtual organisation, internet platform and neuron networks. Attention must be paid also to an important practical feature of the proposed approach which enables the application of the worked out methodology with regard to each detailed technology of manufacturing a specific final product, as well as to different sizes of technology groups if their division is possible in terms of a clearly defined objectively verified criterion. As part of a broad scope of the currently realised individual studies, the working out of many groups of surfacing technologies was anticipated, using the mentioned newly-developed tools, which will certainly be the subject of further publications in which the methods described in this work will be applied.

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