2 The state of the art analysis and methodological assumptions of evaluation and development prediction for materials surface technologies

A.D. Dobrzańska-Danikiewicz
Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
Corresponding author: E-mail address: anna.dobrzanska-danikiewicz@polsl.pl

Abstract

Purpose: *The purpose of the chapter is to present an analysis of the state of the art including the general development trends and most prospective areas of materials surface engineering and to describe the general methodological concept for the evaluation and prediction of materials surface technology development, with special consideration given to methods for generating a pool of critical materials surface technologies.*

Design/methodology/approach: *The chapter was prepared by reviewing the international literature devoted to the latest trends in materials surface engineering and discusses the general methodological assumptions for the research conducted under the technology foresight of materials surface engineering.*

Findings: *Presentation of the most important trends, directions and areas of materials surface engineering and of the general methodology for the evaluation and prediction of materials surface technology development.*

Research limitations/implications: *The state of the art analysis and the methodology presented form constituent part of the technology foresight of materials surface engineering.*

Practical implications: *One of the final effects of the technology foresight of materials surface engineering is to establish the Critical Technologies Book comprising technology roadmaps and technology information sheets. The Book is characterising, in a harmonised fashion, the critical materials surface technologies, which is a convenient tool of comparative analysis, especially for SMEs lacking the funds sufficient to pursue their own research in this field.*

Originality/value: *The chapter is presenting the general development trends and most prospective areas of materials surface engineering and an original, newly established customs, methodological concept for the evaluation and prediction of materials surface engineering development.*

Keywords: *Surface engineering, technology foresight, the state of the art, development trends, evaluation methodology*

1. Introduction

It is a common expectation these days that materials be manufactured possessing the properties ordered by product users [1, 2]. This is significantly influencing the development of the products material design methodology as it is expected that materials are delivered having the required structure and physiochemical properties, meeting functional requirements, matching customer demands and usable functions of a product, i.e. so-called materials on demand. The functional properties of products can often be enhanced by forming the structure and properties of engineering materials surface layers [3-7], as their structure and properties are often decisive for the applicational prospects of many products. The mere transmission of mechanical loads through the entire active section of a part or its physiochemical properties are frequently not of overriding importance only. Other requirements relevant for surface properties, i.e. notably their smoothness or texture and roughness, colour and coating aesthetics, transparency, reflectivity or the absorptivity of light radiation, heat or sound waves, ability to absorb or not to absorb liquid or air, wear resistance, tenacity, ability to imitate other materials, e.g. wood, leather or glass [8] − apart from investigations into the structure of materials and their basic mechanical properties − are to a large extent decisive for the selection of technological processes for both, structural parts, tools, and other products made of, respectively, all groups of engineering materials.

An exhaustive overview of the contemporary treatment technologies decisive for the formation of the structure and properties of engineering materials surface layers, including also those exhibiting a nanometric structure, together with a general view on the current state of the art on the basis of analyses into the basic literature data and prior own research [9-17] is presented in an own book publication [18]. The publication [6] presents, on the other hand, the evaluation of the relevant material surface treatment technologies. The monograph [19] presents, however, the applications of materials science-foresight methods for predicting the development of the selected engineering materials groups for which selected surface treatment methods have been used, carried out to some extent as part of own research [20]. The culmination of all such efforts is an own methodological monograph [21] pertaining to the computer integrated development prediction methodology in surface engineering area.

This chapter describes the state of the art in the field of surface engineering and discusses a method of evaluating the state of the art of the technology in order to develop basic information enabling to pursue foresight research.

2. General development trends and most prospective areas of materials surface engineering

Surface layers can be classified as surface layers limited with the area of the part treated and encompassing the area of the material, with their structure and properties differing from the properties of the core, or as coatings being a layer of a material differing most often in its phase and chemical composition and the structure from the core, deposited permanently onto a substrate surface. Six groups are differentiated between for the surface layers production technologies according to the surface formation method, i.e. [3, 4, 18]:

- mechanical methods connected with the cold reinforcement of a surface layer or production of a protective coating on a cold substrate;
- thermomechanical methods employing heat influence and pressure together;
- thermal methods connected with the change of material structure as a result of heat impact both, in the solid state as well as by changing the state of concentration from solid into liquid and inversely;
- thermochemical methods as a result of the aggregated impact of heat and a chemically active centre;
- chemical and electrochemical methods connected with the deposition of a metallic or non-metallic material onto part surface, removal of the damaged surface layers, thermal and chemical solidification of film formers or curing of chemically setting resins;

- physical methods, achieved through the adhesion deposition of coatings and with the presence of diffusion joints.

Surface layers may have varied intended uses, exhibiting the required physical, mechanical and tribological properties, electrical or heat conductivity and temperature resistance, anticorrosive properties, including such representing a diffusion barrier; decorative and protective-decorative properties and such providing an aesthetic appearance and the required surface texture of products. The most beneficial properties of the core and the surface layer of the part produced, ensuring its required functional properties, can be obtained by selecting such core material and technology that ensure the part's properties (e.g. heat treatment or heat and plastic treatment) and by choosing at the same time the surface layer technology decisive for the functional properties of many products and parts thereof.

The tailoring of properties of different items produced by means of different engineering material groups, including structural, tool, functional and biomedical materials, to operational requirements with surface engineering methods has been used more and more often in many industries [2, 22-31]. The industries include the machine and tool construction, mechatronic, automotive, power engineering, aviation, polymer material processing, construction, medical equipment, sanitary fittings, electrical engineering electronic and jewellery sector. The scientific institutions around the globe are expressing their on-going and intensifying interest in this field, e.g. [32-46]. The basic literature data concerning the state of the art for the formation of surface layers structure and properties was analysed, therefore. The state of the art of the classical surface layers structure and properties formation technologies for the relevant groups of engineering materials has been well known and described in the basic domestic [7, 47-53] and foreign [8, 54-59] handbooks on material engineering and surface engineering. Moreover, numerous monograph papers and reviews [60-73] have been published. Research projects and numerous publications [74-93] in this thematic domain discuss a great deal of details concerning the phenomena and mechanisms in different materials being an outcome of surface treatment and its impact on the properties of diverse products. The information available in the literature relates to over 500 specific surface treatment technologies and their numerous technological variants with respect to all the basic groups of engineering materials. This aspect is of major economic importance and does not only relate to the avant-garde technologies implemented in leading, large corporations, but requires first of all that the quality and durability of most market products is improved by applying a broad array of available surface engineering technologies by the majority of industrial manufacturers, and especially by small- and medium-sized enterprises. For this reason the technologies used are identified along with their desired direction of development and products are indicated for which they should be applied. In addition, the development trends of the priority innovative technologies of engineering materials surface structure and properties formation and the directions of strategic research in this regard is of fundamental importance for economic growth in the coming decades and is decisive for the competitiveness of the domestic economy. Surface layers, for technological considerations, can be grouped as given in Table 1 and Figure 1.

Table 1. *Classification of surface layers according to technological considerations [18]*

Possible types of surface layers and coatings or processes occurring in the substrate surface		
monolayer	multiphase	amorphous
multilayer	graded	nanocrystalline
multilayer (>100 layers)	composite	hybrid
phase transformations of substrate surface layers	change of chemical composition of substrate surface layers	physical processes on substrate surface

Whilst analysing, in the course of own works [9-17, 94-108], the current state of the art for the development of the surface engineering technologies described in the literature against the macro- and micro-environment, the technologies were classified according to several thematic areas defined in an arbitrary manner, according to the phase of their development within the technology life cycle. The technologies analysed were classified as: base, key, experimental or embryonic technologies. A ranking was established of potentially critical technologies evaluated in a ten-degree universal scale of relative states by their attractiveness and potential. The selected critical technologies meeting at the same time in at least 50% the requirements of attractiveness and potential were considered only in the further literature analyses, and some of them were chosen on such basis to conduct own, supplementary research in the field of materials science.

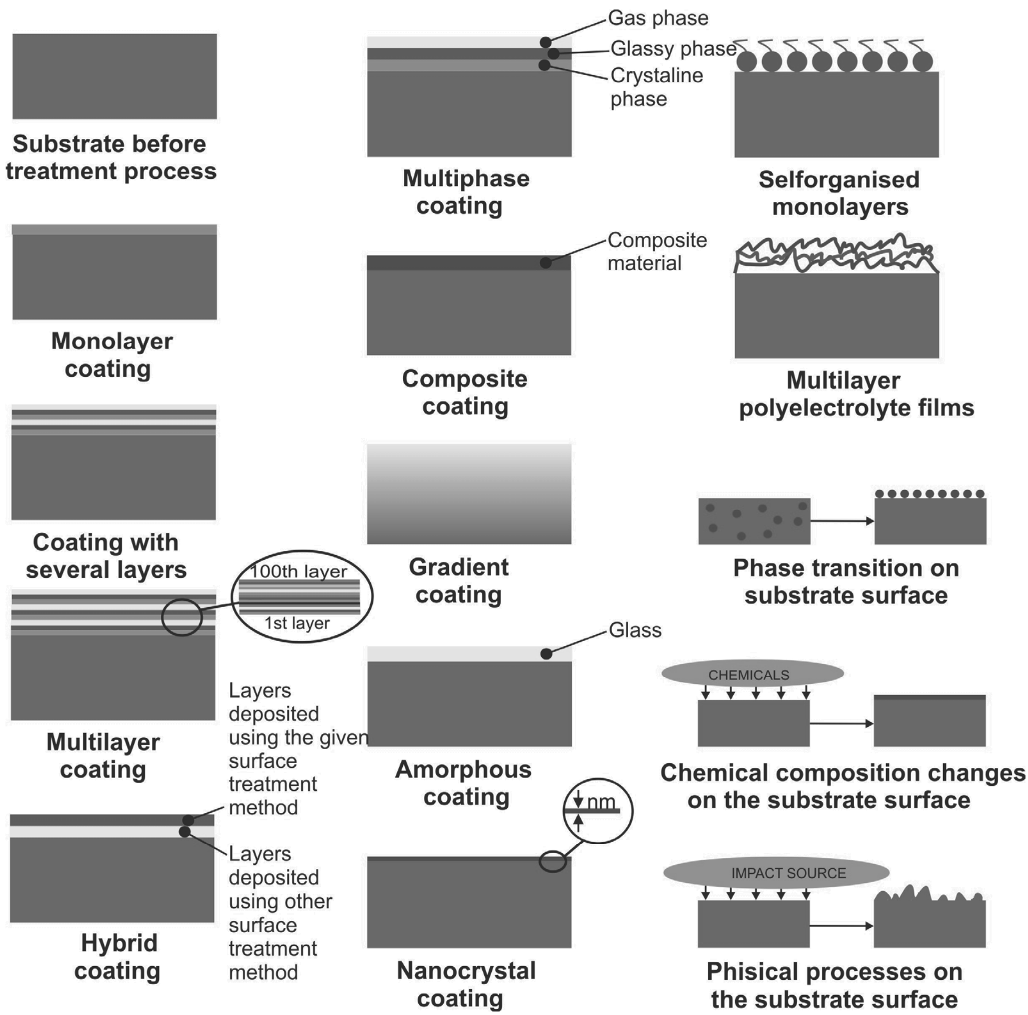

Figure 1. *Schematic examples of surface layers and processes occurring on the substrate surface according to technological conditions [21]*

Avant-garde technologies and such featuring extremely high development prospects are becoming especially vital in this context. This group includes a continuously developed concept of functionally graded materials (FGM) and tool graded materials (TGM) [15, 85-86, 109-115], new coating formation nanotechnologies for coatings several millimetres thick, sometimes composed of several dozens to several hundreds of layers, including multilayer and graded deposition with the PVD and CVD methods, but also composite coatings with a polymeric matrix reinforced with carbon or mineral nanotubes [116-120]. Extensive development prospects are also true for hybrid technologies ensuring the best possible properties of surface layers deposited subsequently on one another [121-124], as a result of combining some classical surface structure and properties formation methods (e.g. thermochemical treatment) with avant-garde technologies (e.g. laser alloying, remelting or cladding, powder injection moulding and physical vapour deposition- PVD). The fabrication of layer structures is also note-worthy, in particular with thermochemical treatment methods [74-77, 125], by producing composites [126-127] and through monolayer deposition with the PVD [128, 129] and CVD methods, and also cladding or sputtering the hard layers with the thermal sputtering method, laser surface treatment technologies (including alloying, remelting and cladding ensuring very high quality of the bond with the substrate and production of graded layers with high corrosive and wear resistance, high heat resistance and hardness and ductility, plasticity and fatigue strength) [35, 130, 131] as well as the laser texturisation of surface of parts of solar cells [14, 108, 132].

The permanent works conducted in foreign entities [109-110, 133-136] and developed also in Poland under the research projects [137-139] have laid the groundwork for the development of functional graded materials (FGM) with their properties changing in an abrupt way or continuously according to the position due to changes to chemical composition, phase composition, structure or due to harmonising atoms in a crystalline network. A lot of technologies were used for achieving the above structural outcomes, including powder metallurgy [86, 140-142], welding methods and laser treatment [34, 35, 87, 130]. An improvement in properties, by combining the very high resistance of tools surface to abrasive wear with large core ductility, is secured by tool graded materials (TGM). This group is becoming increasingly independent and more and more often considered as a separate group of engineering materials, developed to the same extent as functional graded materials (FGM), despite still being rarely used in the industrial practise [3, 4, 144]. The surface layers of graded tool materials with varying chemical or phase composition have the thickness of 10^{-3}-10^{-6} m, depending on the production technology.

One of the basic groups of technologies of producing graded tool materials is represented by the physical vapour deposition (PVD) of 3-5 μm thick graded coatings and changing constantly one or several of its components starting with the substrate up to the surface, onto the substrate made of conventional or sintered tool materials [33, 36, 142, 144, 145]. PVD coatings, sometimes only graded coatings, are used not only for depositing tool materials [146-150], but also in machine construction, automotive, aviation, space, construction, power and housing sector, optics, microelectronics and biomedicine [13, 26, 104, 151], to enhance durability, limit the rate of wear, improve resistance to high temperature, lower thermal conductivity and reduce corrosive processes [144, 152-154]. The PVD methods are also used as metal implants [155]. The following types of PVD coatings are distinguished:

- monolayer simple or complex coatings, including multicomponent coatings with a sublattice of one element partly filled with another element, usually as continuous solid solutions of carbides and nitrides;
- multilayer coatings produced by depositing the layers of different materials onto each other, usually simple coatings with different properties [156],
- multiphase coatings representing a mixture of different phases, characterised by high resistance to abrasive wear;
- graded coatings as a variant of multilayer coatings with their chemical composition and properties changing in a constant manner across the thickness [146, 147], including gradient wear-resistant coatings (GWRC) acting as gradient thermal barrier coatings (GTBC);
- composite coatings as a variant of multiphase coatings in which another phase is dispersed in one continuous phase, metastable with combined properties distinctive for materials featuring metallic and convalescence bonds as a result of solid solution strengthening of coatings.

High-temperature PVD techniques ensure the better quality of a coating's diffusion-adhesion joint to the substrate. PVD processes can be grouped into the techniques of classical deposition of pairs of metal in a vacuum or in the atmosphere of non-ionised gas on a clean and cold substrate, where the pairs of metal with low energy settle on the substrate, thus creating coatings with low density, considerable contamination and poor adherence as well as the techniques of ion vacuum deposition, most often reactive on a clean but cold or heated substrate, where the substrate is bombed with a stream of ions with their energy causing sputtering and the related shallow implantation, thus forming coatings with their high density, with no contaminants and with good adherence to the substrate. The very good adherence of PVD coatings to the substrate is caused by the adhesion and diffusion of the elements forming the coatings to the substrate in the direction of the substrate and of the elements contained in the substrate material (e.g. carbon and nitrogen) in an opposite direction, i.e. to the coating. As adhesion and diffusion occur at the same time, it is possible to produce a hybrid graded surface layer with the total thickness of up to 100 μm on the substrate made of, e.g. high-speed steels or tool alloy steels using the PVD technology with prior classical thermochemical treatment, e.g. ionising nitriding [3, 4].

Graded tool materials are also produced through chemical vapour deposition (CVD), when the coatings of carbides and nitrides of metals are formed on the surface of the treated product. They are made of the components of the gaseous atmosphere consisting of volatile halide of a diffusing element and of hydrocarbon, nitride, hydrogen or inert gas, e.g. argon, that are activated with heat or plasma, with the presence of substrate components, in a seal-tight reactor as a result of inhomogeneous, chemically and physically catalysed reactions on the substrate surface at the temperature of approx. 900-1100°C and at the pressure of $1 \cdot 10^5$-$1.35 \cdot 10^3$ Pa. The high temperature of a CVD process causes limitations to its applications to include the plates made of sintered carbides or sintered ceramic materials, which, historically, are deposited most early with single layers, then dual layers, and now usually multilayers [24, 157]. Sintered carbides deposited with multilayers are characterised by much higher wear resistance as compared to conventional grades with just slightly deteriorated ductility [148, 158, 159].

Graded materials, including tool materials, but also such with the substrate made of alloys of light metals, i.e. magnesium [9, 106, 107, 160] or aluminium, may be produced using appropriate laser remelting, cladding and alloying [143, 161-163]. The materials treated this way are reinforced by means of one or several mechanisms working in a synergy. One of the mechanisms is crystallisation and distribution of the structure of the surface layer remelted by laser and undergoing remelting hardening in the zone. The material, after hardening from the liquid state, is characterised by its dendritic morphology and the martensitic structure and the martensite laths are 1.5 to 2 times smaller than after conventional hardening [143]. Other mechanisms contributing to the reinforcement of materials as a result of laser treatment include: the dispersion hardening of the surface layer by melted or partially dissolved particles of the phases introduced; enriching the surface layers with alloy additions coming from the dissolving phases and precipitation hardening by the newly precipitated phases, e.g. carbides in case of tools steels and carbide steels [162].

This aspect is related to the new directions of laser formation of the structure and properties of light metals alloys surfaces, in particular multicomponent low density alloys of magnesium that different industries are interested in, among others, the aviation, automotive, power, electronic, chemical, nuclear, sports equipment, office devices and household appliances industry. The attractive technological options include the treatment of such alloys' surface ensuring the formation of an approx. 0.5 mm thick layer remelted by laser and next subjected to fast micro- or nanocrystallisation enabling to achieve the structure and properties the same as those achieved with the Rapid Solidification Processing (RSP) method. The laser treatment of such alloys' surface also enables to clad dispersive ceramic particles into the remelted surface layer, hence ensuring its properties corresponding to metal matrix composites (MMC) with a magnesium alloys matrix [106, 160, 164] and is considerably enhancing the durability of the products fabricated with such technology [107, 164].

Another promising laser technology requiring the use of low-power lasers is the texturisation of polycrystalline silicon used for producing solar cells. Laser texturisation is employed to develop the surface of polycrystalline silicon in the parallel or grid configuration. Texturised samples must undergo wet etching in alkali solutions to obtain the expected electrical properties of solar cells produced of silicon. The other methods of poly- and monocrystalline silicon surface treatment include: Reactive Ion Etching (RIE), Anti-reflective Coatings (ARC), including Plasma Enhanced Chemical Vapour Deposition (PECVD) and classical Chemical Vapour Deposition (CVD), thermal oxidisation [14, 108, 165, 166], sol-gel methods [167] and Atomic Layer Deposition (ALD). One of the more promising possibilities of fabricating photo-voltaic cells is a thin silicon layers technology, which is several millimetres thick, with trans-parent oxide ZnO layers dispersing light and conductive with the thickness of several hundred nanometers. The layers can be obtained with the chemical vapour deposition or physical vapour deposition method in the conditions of a lower pressure or with the aid of plasma, produced notably using the Hall accelerator being a source of low-temperature and thin plasma [168].

The welding methods of material surface layers formation include the deposition of a layer of the hardfaced metal onto the surface or edge of the substrate material with different chemical composition, using gas and arc technologies (MMA, GTA, SSA, GMA and PTA), energy of beam of electrons and arc thermal spraying or plasma spraying. The welding methods allow to produce − on a surface made of relatively cheap, readily available materials not subjected to structural changes or plastic deformation – coatings made of metal alloys, ceramic materials, materials based on intermetallic phases, cermets, carbides or polymer materials. Such coatings ensure anticorrosive protection, surface hardening, surface porosity, decorative effects, electrical conductivity, reflection of light and/or repair of surface recesses [3, 4, 18, 64]. The coatings sprayed thermally, containing Co, Ni, Cr, Al, Y, Si or Hf or phases containing some of such elements and thermal barrier coating (TBC) protect high-temperature nickel alloys by creating heat insulation [169]. Surface layers can also be deposited by detonation [5, 6, 18].

One can also use graded tool materials produced with the traditional powder metallurgy method. The method enables to, in particular, manufacture tool graded materials based on the high-speed steel matrix with the tungsten carbide reinforcing phase and carbide steels based on the cobalt matrix with the tungsten carbide phase. By using the powder metallurgy method, a surface layer can be provided with high abrasive wear resistance ensured by the hard carbide, nitride and/or oxygen phases or powders of higher-alloy high-speed steels whilst maintaining high core ductility typical for high-speed steels and traditional carbide steels at relatively low costs. Such material structure allows to formulate properties freely depending on the tool working conditions. A layer of hard material is used for example in those locations at the tool being exposed to wear while high ductility is ensured in those locations of the tool material that are susceptible to impact [15, 85, 114, 136, 170]. Considering the techniques of formulating the powder mixtures of functional graded material, classical pressing should be distinguished in a closed mould by filling moulds sequentially with the mixtures of powders, with the presence of hard ceramic phases rising towards the surface of the tool. The other techniques applied include: pressing in a uniaxial, one-sided mould, isostatic cold pressing, low-pressure moulding of polymer and powder slurry, vibration moulding and densing in a closed mould, sedimentation moulding and low-pressure moulding of polymer and powder slurry [171].

Composite surface alloy layers on the cast steel or cast iron parts of machines can be produced immediately in the process of flooding dies with the appropriate liquid cast steel or cast iron with a composite material situated in such moulds by matching the dimensions, sprigging or attaching it in the designated parts of the cavity interior. After filling a mould with liquid metal, the metal undergoes infiltration into a composite material that may occur as perforated inserts made of powders of the selected alloys or carbide or oxide reinforcing phases. Another possibility is to use a self-fusible composite with epoxy resin, organic limited solvent or water glass bond [172]. A composite can also be placed in a mould without the presence of bond by means of a magnetic field [173]. The casting surface composite alloy layers are used in the industry on casts resistant to abrasive wear, working in the conditions of dry abrasion caused by, e.g. hard coal, lignite and construction materials. A method combining the casting techniques (infiltration process) and powder metallurgy (preparation of porous sintered skeletons) is the pressure infiltration of porous sintered skeletons, being one of the fastest developing composite materials manufacturing methods [174, 175], enabling, in particular, to reinforce casts locally at their surface.

Surface treatment with polymer materials is especially significant. The treatment relates to the polymer coatings made of thermoplastics, hardening plastics and elastomers, deposited with various technologies on different other materials, e.g. on metal alloys and textile materials.

The treatment also concerns the formation of the structure and surface properties of different polymer materials, including the fabrication of layer composites, including polymer material laminates and polymer layer materials obtaining the desired usable properties of the surface [176]. Polymer coatings can be deposited by evaporating polymers dissolved in solvents, by sputtering polymer powders onto a hot substrate and through electrostatic spraying onto the substrate with a negative electrical potential. The other known methods include: electrolytic deposition from aqueous polymer solutions, deposition of immersion particles heated in steam in a fluid bed, flame spraying by depositing the powder of a polymer material melted by hot gases onto a heated substrate and plasma polymerisation. The following types of polymer layers with different properties can be distinguished: hydrophilic and hydrophobic layers preventing the deposition of sediments; adhesive or anti-adhesive layers; light protective layers; antidiffusive layers and layers resistant to scratches [67]. The formation of the structure of surface properties of polymer materials is most often preceded with pre-treatment, e.g. in case of polyolefin (e.g. polyethylene or polypropylene), polytetrafluoroethylene or polyacetals. In order to achieve the beneficial values of surface free energy, oxidisation with acids, flame activation or corona discharges with high-energy ions in a high voltage field under the atmospheric pressure of air is used prior to polymer bonding, painting, printing or metallisation. Activation in low-pressure plasma at the temperature of 60-100°C in reactors with the atmosphere of oxygen, nitride, fluorine or precious gases is used for thermoplastics and hardening plastics [67], with simultaneous ultraviolet radiation [177]. Ionising radiation, γ radiation of the C^{60} cobalt lamp or high-energy electron radiation is used [66], respectively, for the surface crosslinking of polyethylene for pipes, tapes, foils, for sterilising disposable polypropylene syringes, for polytetrafluoroethylene degradation, for changing the properties of insulation of polymer power cables and for improving the properties of rubber car tires. The surface properties of polymer materials in the electronic industry or in the manufacture of medical devices are formed through laser radiation [178]. Protective or decorative functions are fulfilled by painting the surface of polymer materials and by printing and decorating on printing machines, by electrostatic flocking, by metallisation or by rubbing antistatic agents, silicone oil or bactericides into polymer materials [67]. The mechanical properties of polymer surface layers can be improved by using carbon nanotubes, whereas the anisotropy in the arrangement of such nanotubes supports the improvement of such properties [179]. Composite polymer layers containing carbon nanotubes represent an active part of vacuum level and pressure nanosensors [180], in which changes to the material volume is directly impacting the electrical properties of an active element. Ultrathin surface films containing carbon nanotubes are developed in multiple applications, e.g. in gas sensors and biosensors [181, 182], differing in their thickness, the bonding material used and protecting nanotubes, and also in their structure (single-walled or multiwalled ones), in their purity and in the method of arrangement (random, ordered). Conductive or semi-conductive nanostructural coatings are produced as a result, applied in medicine, environmental protection, agriculture, automotive and food industry, and in industrial production [183]. The value of electrical conductivity is decisive for the application of a given composite as a component of surface layers with their insulation properties or properties allowing to evacuate an electrical charge safely. The value in some cases is higher than the electrical conductivity of the individual components of the composite, as e.g. in case of a polyaniline and multiwall carbon nanotubes of composite. Due to high thermal conductivity, surface layers made of polymer composites containing carbon nanotubes are used by the space and aviation industry as thermal shields. The conductive polymer coatings applied onto the wings of aeroplanes allow deicing during harsh weather conditions, and they replace traditional liquid heat evacuation systems on the external parts of cosmic crafts. Stresses can be determined by means of the Raman spectroscopy by introducing carbon nanotubes into a polymer matrix. It is because the shape of carbon nanotubes' spectrum (in particular the position of reflex equal to 2601 cm^{-1}) varies as a result of composite deformation [184, 185]. Polymer coatings containing carbon nanotubes with biocatalytic properties prevent foul odours, and are used for active elements of biosensors and as materials with higher biocompatibility [186-188]. Composite polymer layers containing carbon nanotubes can also be used for constructing solar cells [189]. As the conductivity of carbon nanotubes changes as a result of interacting with molecules of multiple chemical substances [190], they represent the elements of active sensors and electronic nanodevices in which sensitivity and selectivity of such detector increases as result of depositing the nanoparticles of precious metals, in particular Au, Pt, Pd, Rh onto the surface of carbon nanotubes [191-196]. A composite achieved as a result of coating the external surface of carbon nanotubes with a layer of conductive polymer can be used as a supercondenser [197]. The endeavours are also very promising in this field targeted at using polymer-matrix surface layers reinforced with mineral halloysite nanotubes as the substitutes of carbon nanotubes. As a result of depositing with conductive materials, they can also ensure a surface's thermal and electrical conductivity, and the general cost of such material can turn out to be much lower [198]. A prospective example of applying carbon nanotubes in surface engineering is also their use for producing ceramic nanotubes by depositing ZrO_2 onto their surface and then by oxidising in the temperature of above 800°C, as a result of which ceramic circles with the diameter of approx. 40-50 nm are developed on the surface of carbon nanotubes, with their walls approx. 6 nm thick [199]. The works carried out in this field are intended to establish the scope of such materials' application as most probably they can also be used as the composite reinforcement of polymer-matrix surface layers.

The surface engineering methods are also frequently used for filling recesses in such elements of machines and devices that are operated for a long time or in so-called remanufacturing processes for the formation of the structure and surface properties of re-processed structural components [200]. It is also noted that the surface properties of products and elements thereof during operation are subjected to considerable degradation, due to changes to the structure of engineering materials' surface, in particular as a result of corrosion of metals and alloys, tribological wear, wear and destruction of cutting tools and wear of hot-work tools. The mechanisms of wear should be taken into consideration already at the stage of products material and technological design by approaching them as factors the same as surface treatment, because, in fact, they form surface structure and properties, having, by the rule, usually an adverse impact and intensify over the time of product usage [3, 7, 18].

The state of the art of the highly extensive detailed knowledge in the field of surface engineering does not, paradoxically, support the making of correct managerial decisions on the optimised selection of the relevant technology in each case of producing a specific product. The reason for this is the lack of synthetic, collective elaborations that would take into account the cognitive, technical as well as economic aspects of the technologies mentioned and their importance in the industrial practise, according to harmonised, standardised criteria.

3. Analysed thematic areas and evaluation research methods

In the framework of the custom evaluation research [20, 21] concerning materials surface engineering two wide research areas were considered, respectively: *Manufacturing* (**M**) and *Product* (**P**). The first research field (M) reflects a manufacturer's point of view and encompasses the production processes determined by the state of the art and a machine park's manufacturing capacity. The *Manufacturing* (**M**) area is divided into narrower following research scopes:

M1: Laser technologies in surface engineering;

M2: PVD technologies;

M3: CVD technologies;

M4: Thermochemical technologies;

M5: Polymers surface layers;

M6: Nanostructural surface layers;

M7: Other surface engineering technologies.

The second research field (P) is determined by the expected functional and usable properties resulting from the client's demands and concentrates on the product and the material it is made of. The *Product* (P) area is divided into narrower following research scopes:

P1: Surface engineering of biomaterials;

P2: Surface engineering of structural metallic materials;

P3: Surface engineering of structural non-metallic materials;

P4: Surface engineering of tool materials;

P5: Surface engineering of steels used in automotive industry;

P6: Surface engineering of glass, micro- and optoelectronic and photovoltaic elements;

P7: Surface engineering of polymers.

The research tasks, intermediate goals and milestones in Table 2 are presented. The realisation scheme of methods used during the evaluation research taking into consideration, respectively: source data, monitoring spheres, current state, used foresight methods and final results in Fig. 2 is presented.

Table 2. *Research tasks, intermediate goals and milestones*

No.	Research task	Intermediate goal	Milestone
1.	Current situation analysis in the field of technology development and socioeconomic factors	Preparation of a report determining current situation in the field of technology development and socioeconomic factors in the scope of the foresight subject matter	Report *Current situation analysis*
2.	Research using a heuristic metho6d. e-Delphix method with experts participation	Achievement of research results using e-Delphix method and preparation of a report including results of three survey iterations	Report *e-Delphix method. Research results*
3.	Research using an artificial intelligence method, i.e. neural networks	Creation of artificial neural networks in order to determinate impacts between future trends and events	Neural networks

No.	Research task	Intermediate goal	Milestone
4.	Materials science- heuristic and foresight research	A series of materials science-heuristic and foresight research to verify development trends of the selected surface engineering technologies for selected engineering materials	Practical experimental verification of the computer integrated development prediction methodology developed
5.	Open public debate and social consultations	Open public debate and social consultations concerning research realisation and results	The International Conference
6	Generation and characterisation of priority leading technologies and strategic research directions in the scope of the foresight subject matter	Creation of technology roadmaps and technology information sheets for industrialists and three scenarios of possible future events: optimistic, neutral and pessimistic ones	The Critical Technologies Book Optimistic, neutral and pessimistic future events scenarios

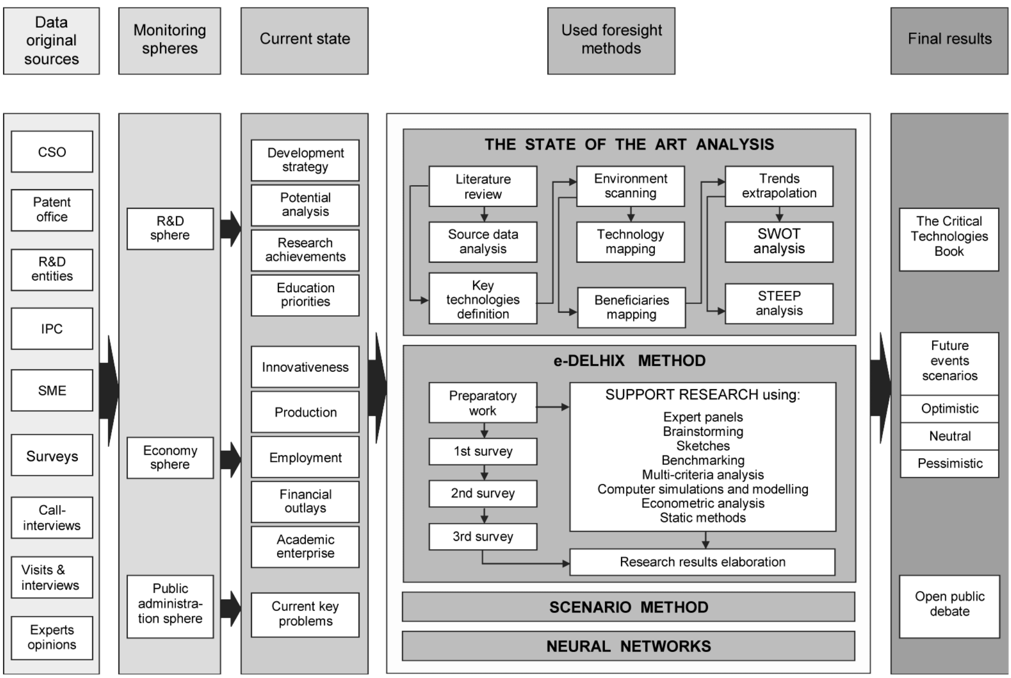

Figure 2. *The scheme of surface technologies evaluation methods [102]*

The following data from original sources during the evaluation research were used: Central Statistical Office (CSO), patent office, research and development (R&D) entities, Information

Processing Centre (IPC), small and medium enterprises (SME). The original data were gathered using survey questionnaires, call-interviews, visits and interviews in enterprises and institutions as well as expert opinions. The activity leaded within the framework of the research was concerned to three spheres: R&D, economy and public administration ones. In the R&D sphere development strategies, potential analysis, research achievements and education priorities are the most important. In the economy sphere especially innovativeness, production, employment, financial outlays and academic enterprise were considered. In the public administration sphere it is the most important to identify current key problems. Generally, the used evaluation research methods are typical for that kind of works and they are recommended as right and justifiable in foresight projects by National Foresight Programme "Poland 2020" [201], United Nations Industrial Development Organization and Polish Agency for Enterprise Development [202]. An exception is an innovative and experimental idea concerning the application one from artificial methods, i.e. neural networks into the analysis of impacts between future trends and events. All evaluation research were carried out parallel with reference to each one from the defined research scope pool.

4. The state of the art analysis for materials surface technologies

The research intermediate goal is to prepare a report characterising current situation in the field of technology development and socioeconomic factors in the materials surface engineering area. The state of the art analysis of surface technologies against a background of macro- and microenvironment realised by the key experts concerns each from the fourteen-element set of determined research scopes. Within the confines of the state of the art analysis the following works were carried out [102]:

- issue state assessment;
- technological review;
- strategic analysis using integrated methods.

Issue state assessment is a first part of the state of the art analysis. It is a set of elaborations connected with the consecutive research scopes. The following methods were recommended to key experts for the preparation of issue state assessment: literature review, source data analysis, environmental scanning, benchmarking (comparing to a leader), brainstorming, expert panels and trends extrapolation. Each elaboration concerning a given research scope includes the following elements: research scope general characteristics, statistical data, main trends and development directions as well as references. General characteristics concerning a given research scope includes main definitions, an outline of the knowledge development history and detail research fields included in the wide defined main research scope. Statistical data concerning issue state assessment in tables, graphs, charts and comparative tabulations were presented. Moreover, statistical data mainly shown within the confines issue state assessment are following [101]:

- domestic and/or European and/or world demand;
- domestic and/or European and/or world consumption;
- domestic and/or European and/or world production;
- the biggest domestic and/or European and/or world producers and sellers (amount produced/ sold by them);
- domestic and/or European and/or world export/import;
- domestic production capacity;
- production amount in given world countries;
- shares of given countries in European/world production;
- production amount changes in given years in a defined period.

The key experts in order to complete statistical data used many different source data. First of all the following raw data were utilised: Central Statistical Office (CSO), patent office, research and development (R&D) entities, Information Processing Centre (IPC), small and medium enterprises (SME). The raw data were gathered using survey questionnaires, call-interviews, expert opinions, visits and interviews in enterprises and institutions. Moreover, the key experts often in order to prepare the bibliographical as well as Internet review used the statistical comparisons. The next part of issue state assessment concerns main trends and development directions in the given research scope. The time horizon is strategic, it means a long-term one, i.e. the next 20 years. Especially, theories which are controversial, untypical as well as non thoroughly confirmed and investigated in that part of the elaboration were considered. The issue state assessment ends with references. The consecutive literature sources are arranged in an alphabetical order. The newest and English ones play the most important role between them.

The technological review is a second part of the state of the art analysis. It is a set of fourteen pieces from which every one is connected with a given research scope. The following methods were recommended to key experts for the preparation of technological review: critical technologies definition, technology mapping, literature review, environmental scanning, trends extrapolation, brainstorming, benchmarking and expert panels. Each part of a technological review concerning a given research scope includes the following elements: formulation of a technologies list included ones used in a given research scope; determination of the technology lifecycle phase in which are consecutive technologies from the previously defined technologies pool and identification of a preliminary critical technologies pool.

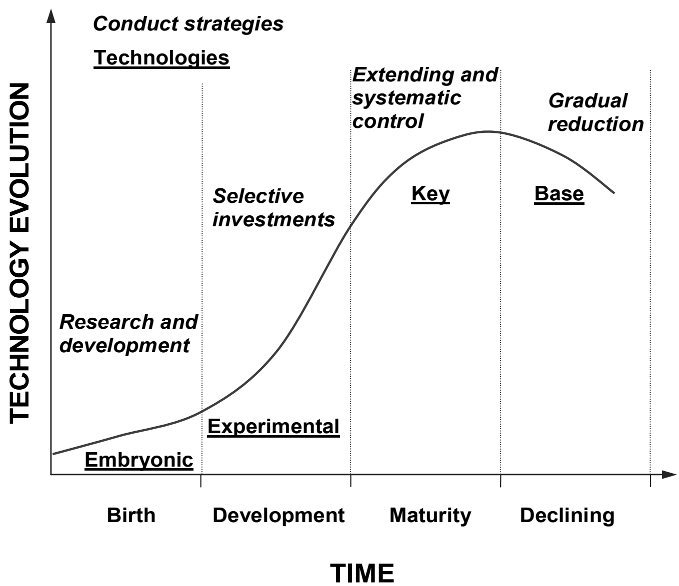

Figure 3. *Technology lifecycle [101]*

According to an issue called technology lifecycle all technologies were assigned to one from the following groups (Fig. 3) [101]:

- basic technologies; they are common available and used very often, their competitiveness decreases or is little yet; they are slowly falling into disuse;
- key technologies; they are the basis of the product competitiveness, their mastering is the key factor determining the enterprise success; the using perspective is ten years;

- experimental technologies; their application is not wide yet; their often are in testing or prototype building phase; a glorious future is predicted for them, because they should be key technologies in the future; they are very strong protect against competitors;
- embryonic technologies; they are in research development phase; works concerning outworking and implementation of prototypes are carried out, but prototypes do not exist yet; they are very strong protect against competitors the same like experimental technologies.

Into the next research step were qualified the key technologies which are not common used in the country as well as experimental and embryonic technologies. The assessment scale was five-steps, as follows: (1) really little, (2) little, (3) medium, (4) quite high and (5) high. There are two main criteria of technologies assessment which are defined in order to carried out research realisation, respectively: the (A) attractiveness and the (P) potential [101]. Moreover, the following six detailed criteria were outworked and used in carried out research:

- the (A1) economic attractiveness; significance of a given technology for the country and/or World economic development;
- the (A2) social attractiveness; significance and beneficial impact of a given technology for society;
- the (A3) ecological attractiveness; significance and beneficial impact of a given technology for natural environment state;
- the (P1) creative potential; the possibility of creation of new research and application directions;
- the (P2) applied potential; the possibility of a given technology application in implementation sphere;
- the (P3) research and development potential; the possibility of carried out of research and development works.

The $\overline{O_i}$ average mark concerning a given technology was determined using the (1) formula.

$$\overline{O_i} = \frac{\sum_{n=1}^{3} A_n + \sum_{m=1}^{3} P_m}{6} \quad (1)$$

where:

$\overline{O_i}$ – the average mark concerning the i-th technology; i=1,2,…,a; a – a number of analysed technologies;

A_n – an assessment of a given technology attractiveness according to defined criterion; n=1,2,3;

P_m – an assessment of a given technology potential according to defined criterion; m=1,2,3.

The set of possible critical technologies consists of the technologies with the highest average marks which fulfilled the (2) condition.

If $\overline{O_i} > 3$, then the *i-th* technology belongs to a possible critical technology pool. (2)

where:

$\overline{O_i}$ – the average mark concerning the i-th technology; i=1,2,…,a; a – a number of analysed technologies.

A technology ranking according to attractiveness and a potential parameters in Fig. 4 is presented. The next stage of that research part concerned to verification the preliminary critical technologies pool and generation the final pool of 10 critical technologies in each thematic area.

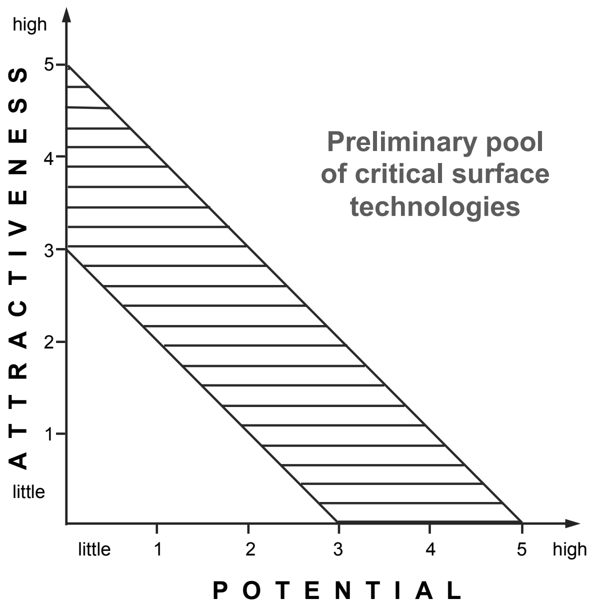

Figure 4. *A technology ranking according to attractiveness and potential parameters [101]*

Strategic analysis using integrated methods is a last part of the state of the art analysis. All from fourteen pieces connected with a given research scope fit together into a whole. Each part of strategic analysis concerning a given research scope includes the following elements:

STEEP analysis, SWOT analysis, conduct strategies choosing. The supporting role during preparation of strategic analysis by key experts played the following methods: multi-criteria analysis, trends extrapolation, beneficiaries mapping, environment scanning, brainstorming, expert panels.

According to the **STEEP analysis** assumptions consecutive outside remarks reflecting macroenvironment situation were considered [203, 204]. The macroenvironment characteristic feature is that it strong determines entities functioning conditions, but those entities can not directly influence on macroenvironment. Because of that, macroenvironment must be penetratingly observed. Particularly, arose opportunities should be used as well as shown weaknesses should be overcame. The outside positive and negative remarks according to the STEEP analysis are divided into the following remark groups (Table 3): (**S**): Social; (**T**): Technological; (**E**): Economic; (**E**): Ecological; (**P**): Political.

The STEEP analysis results were directly utilised into the research carried out using the **SWOT analysis** rules. SWOT analysis is a key analytic tool using in order to categorise significant inside and outside remarks which can influence in a positive or negative way on forecasted future events [202, 205]. SWOT analysis enables to determine strengths and weaknesses of future events as well as opportunities and threats coming from environment, which can help or interfere with some appearing events. The results of carried out SWOT analysis were used in followed e-Delphix method. The first stage in SWOT analysis concerns the remark list formulation. The given remark list is assigned to the given research scope. There is a clear division of presented remarks into four groups, as follows: (**S**): Strengths, inside positive remarks; **(W)**: Weaknesses, inside negative remarks; **(O)**: Opportunities, outside positive remarks; **(T)**: Threats, outside negative remarks. All analysed remark groups divided according to two criteria in Fig. 5 are presented. Within the confines of SWOT analysis realised for research needs the most important ten strengths and ten weaknesses of the given research scope were chosen. Similarly, also the most important ten opportunities and ten threats of the given research scope were completed. Next, each remark impact was defined. The sum of the impacts determined for each from four remark groups is equal 1. The consecutive remarks using the ten-steps universal relative scale was assessed. The best mark is (10) meaning very high level and the worst mark is (1) meaning very low level. The next stage requires weighted average calculation as a product of impact and assessment. The research results concerning each technology from the given research scope in four tables were presented. Each table correspond to each remark group.

Table 3. *Characteristics of different macroenvironment types*

Symbol	Macroenviron-ment type	Characteristics
S	Social environment	Social environment includes two remark groups: demographical and cultural ones. The demographical remarks are connected with the society size and people age structure, what in an important way determine profitability and development of some industry trades. However, the cultural remarks mainly include fashions, lifestyle and people tastes. They influence on some products and services popularity in certain social groups.
T	Technological environment	Technological environment signals increasing speed of technological changes, no limited innovations possibilities as well as high research and developments budgets. It pays attention also to little facilitates against huge inventions and the increasing number of legal articles concerning technological changes. Fast technological changes can contribute to decline some industry trades as well as to create another ones. Those events depended on entity activities profile can be an opportunity or a threat for the given entity.
E	Economic environment	Economic environment includes one of the most important and influenced group of remarks. It is determined by the domestic economy situation. The most important economic environment remarks are following: • the economic growth rate; high economic growth rate ensures the consumer expenses increase and from that arises higher development changes and lower competition on the market; • the interest rates; low level of the interest rates cause cheaper credits and ensure high demand level for the given products; • the exchange rates; they create competitiveness on the word markets; as an example: if given country exchange value is low comparing with other countries, then product import from that country is profitable and similarly if given country exchange value is high comparing with other countries, then product export to that country is profitable; • the inflation level; high inflation destabilises economy, limits growth rate, discourages investors from capital location and prevents from effective planning; the opposite of inflation is deflation; deflation causes reduction in goods and services prices and also in production and employment because of money flow limitation; too little money on the market generates stagnation what is unprofitable for domestic economy; the most profitable for domestic economy is little inflation reaching a few percent level; and also the consumption rate, unemployment level and public debt.
E	Ecological environment	Ecological environment is connected with natural factors and environment protection. The key issues concerning that environment are, as follows: raw materials deficiency, increasing energy costs and increasing environmental pollution level. The important factor concerns the increasing level of people ecological consciousness.
P	Political environment	Political-legal environment by the Government, binding legal acts and international situation is determined. Domestic government stability, transparent tax system and advantageous customs regulations encourage investors to investment of capital in the given country.

Next, overall statement including total weighted average of each remark group were shown. For each technology one of four possible conduct strategies were preliminary chosen. The strategy depends on inside and outside remark groups dominated with reference to the analysed research scope. Recommended conduct strategies in Fig. 6. is illustrated.

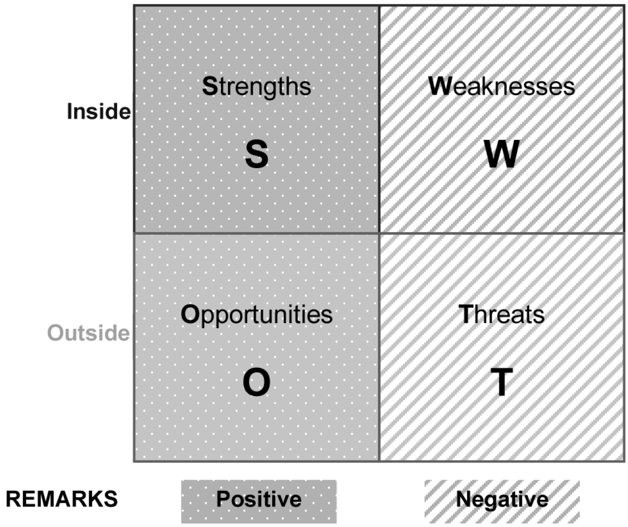

Figure 5. *Remark groups by SWOT analysis [101]*

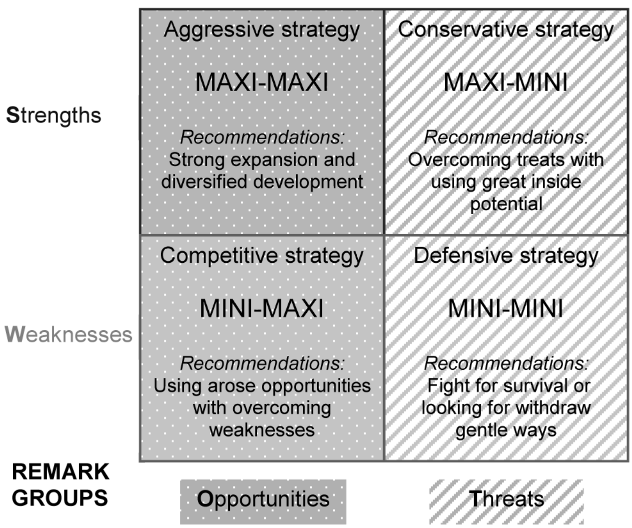

Figure 6. *Recommended conduct strategies [101]*

5. The computer integrated development prediction methods

The consecutive research intermediate goal is the achievement of research results using e-Delphix method and a preparation of a report including results of three survey iterations [20]. The results of carried out the state of the art analysis including, respectively: issue state assessment; technological review and strategic analysis using integrated methods is the pool of critical surface technologies. A collection of 140 critical technologies, 10 for each thematic group, was selected for the above 14 thematic groups from the initially inventoried approx. 500 specific technology groups.

The critical technologies generated as a result of the state of the art analysis next underwent expert studies performed with three iterations of the e-Delphi method according to the e-foresight concept. The e-Delphix method is a modified version of the classical Delphi method [206, 207], differing from the original method mainly in that experts are surveyed electronically and in that the level of generality for the questions asked to the experts is growing along with the subsequent iterations of the research. The relationships between the state of the art analysis and the e-Delphix method are given in Fig. 7. Over 300 independent experts from many countries representing scientific, business and public administration circles have taken part in the technology foresight [20]. The experts have completed approx. 650 multi-question surveys and held thematic discussions during 10 expert panels. Moreover, the scientific and research methods supporting main expert research realised by the e-Delphix method were parallel used, including: brainstorming, sketches, benchmarking, multi-criteria analysis, computer simulations and modelling, econometric and static analysis.

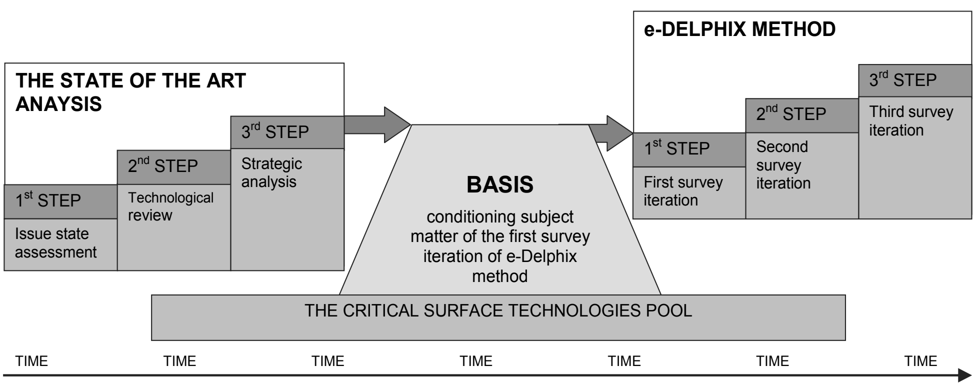

Figure 7. *The state of the art analysis versus e-Delphix method [101]*

The results of the expert studies laid the groundwork for further research targeted at identifying the position of the relevant critical technologies using contextual matrices, for preparing alternative scenarios of future events for materials surface engineering and for creating the Book of Critical Technologies of materials surface engineering consisting of technology roadmaps and technology information sheets. A very important element constituting a basis of the newly developed research methodology concerning the prediction of development of the relevant critical technologies is to perform a series of materials science and heuristic and foresight research to verify the development trends of the selected surface engineering technologies for the selected engineering materials described in a series of own works [9-17, 94-108] and in the next chapters of this book. The verification of the established methodology's correctness according to materials science criteria, made for the selected specific technologies of materials surface engineering, is necessary to ascertain that the reasoning used is correct and that the approach proposed is universal. The outcomes of the materials science research coupled with the results of heuristic research of strategic management of knowledge, show a full picture of the issue, allowing to characterise the analysed groups of technologies in terms of harmonising materials science, technological and economic criteria setting a basis of a comparative analysis of such technologies. The same place and time is not indispensable with reference to the implementation of materials science and heuristic research and does not affect the correctness of the reasoning conducted. The synergic influence of the materials science and heuristic research methods guarantees, therefore, that the evaluations made according to the methodology of computer-aided prediction of development of materials surface engineering is correct and adequate. The research was made using a customs e-foresight method detailed in the following papers [21, 94-97] and in one of the chapters of this book that follow.

The research main goal realisation should lead to achieve the following **final results**:

- The Critical Technologies Book preparation;
- Three alternative future events macroscenarios formulation and description,
- Open public debate on the foresight subject matter animation.

The Critical Technologies Book including technology roadmaps [208-210] and technology information sheets on the basis of the results of the materials science-heuristic research concerning critical technologies were prepared (Fig. 8).

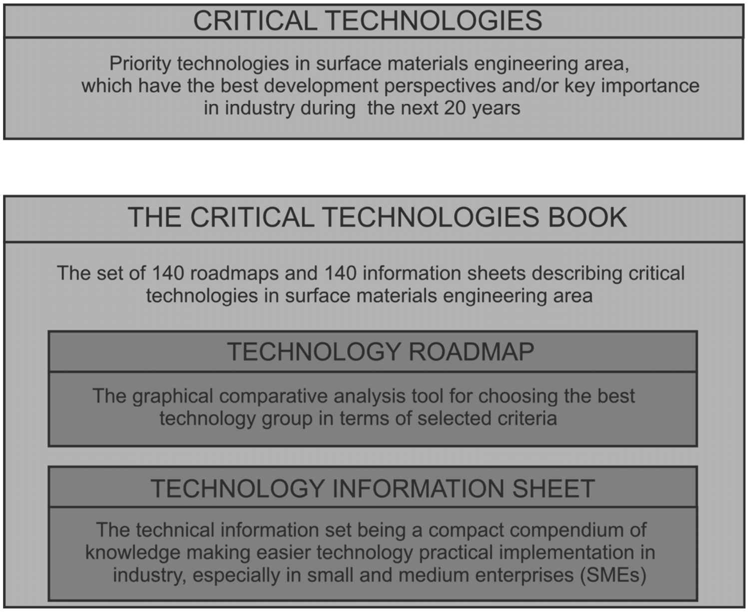

Figure 8. *The Critical Technologies Book content [13]*

The framework of the custom **technology roadmap** corresponds to the first quarter of the Cartesian system of coordinates. Three time intervals for the years: 2010-11, 2020 and 2030 are provided on the axis of abscissa, and the time horizon for all the results of the research applied onto the roadmap is 20 years. Seven main layers were applied onto the axis of coordinates of the technology roadmap: time layer, concept layer, product layer, technology layer, spatial layer, staff layer and quantitative layer, made up of more detailed sub-layers. The main technology roadmap layers divided into more detailed sub-layers were hierarchised starting with the top, most general layers determining all-social and economic reasons and causes of the actions taken, through the middle layers characterising a product and its manufacturing technology, to the bottom layers detailing organisational and technical matters concerning the place, contractor and costs. The middle layers of the technology roadmap are subject to two types of influence – pull from the top layers and push from the bottom layers. The relationships between the individual layers and sub-layers of the technology roadmap are presented with the different types of arrows representing, respectively, cause and effect relationships, capital ties, time correlations and two-directional data and/or resources flow [12, 13].

Technology information sheets, containing technical information very helpful in implementing a specific technology in the industrial practice, especially in SMEs are detailing and supplementing the technology roadmaps. The technology information sheets provide, in particular, a description of the technological process progress and a characteristic of a physiochemical phenomenon accompanying the technological processes, the advantages and disadvantages of the relevant technology, the most prospective detailed technologies and substitute / alternative technologies. They also contains the types of a coating / surface layer that may be deposited or the processes occurring at the substrate surface, as well as the specific properties of coatings / surface layers / substrate surfaces as a result of technological processes. A special heed was paid also to the general physiochemical conditions of technological process implementation, substrate material preparation methods, research instrument type / kind and possible specific accessories. Besides, the research results acquired with an expert research method have allowed to provide the following details in the developed sheets determined with a universal scale of relative states: the impact of technology application on the predicted and expected material properties, the efficiency of preventing the consequences of wear, industry section acc. to the PKD classification having the highest technology applicability, the applicability of computer modelling and steering methods and the development prospects of the individual analysed technologies. In addition, each technology information sheet provides a general or example diagram of the considered production process and a three-part list of the recommended references [12].

Three alternative future events macroscenarios, respectively: optimistic, neutral and pessimistic ones were formulated and described. The references [211-215] indicate that there is no one correct and generally accepted method of creating the scenarios of future events or a management algorithm recommended for implementation in the scenario creation process. In fact, the algorithm is created each time from the scratch by the practicians implementing a specific project [216]. The same refers to building the scenarios presenting the forecast future of materials surface engineering where a methodological challenge exists of combining skilfully the presentation and description of the phenomena characterised by varied generality and to capture the cause and effects relationships existing between them. In order to solve the so formulated research task, all the analysed phenomena are divided into the three groups: macro-, meso- and micro- ones. Three scenarios of future events are considered at the macrolevel. The mesolevel is grouping 16 key factors influencing the development of materials surface engineering and 14 thematic areas analysed under the foresight research. The microlevel is represented by 140 groups of critical technologies. Specific technologies with an unknown *n* number can be distinguished between for them, often differing only in details determining their applicability in the industrial practise. In a novel and experimental manner to impacts analysis between future events and development trends **neural networks** were used [16, 96]. The analysis serves to identify how the key mesofactors of surface engineering development (e.g. collaboration between science and industry, number of specialised laboratories and R&D institutions, continuous improvement and high quality of technology, transparent and friendly legislation, international co-operation and EU funds) and the relevant thematic areas analysed (M1-M7, P1-P7) may influence the occurrence of each of the macroscenarios. Nine models were created altogether using artificial neural networks by adopting, as dependent (input) variables, the probabilities of the occurrence of a growth trend, stabilised trend and/or declining trend determined for the key mesofactors conditioning the development of materials surface engineering and for the individual thematic areas for the research domain of M (Manufacturing) and P (Product). The experts were evaluating the occurrence probability of the relevant scenarios by dividing the total value of probability (of 100%) by the three possible variants of future events. The (output) dependent variables represent a probability that each of the three macroscenarios considered, i.e. optimistic, neutral and pessimistic, occurs [16].

Open public debate on the foresight subject matter is also the expected project result. Domestic and foreign representatives of science, economy, public administration and society are the main groups invited to join the debate. Open public debate initiated and animated in groups interested in a foresight subject matter should contribute to better cooperation between R&D and economy spheres and facilitate labour flow between them. The utility consequence of that is better competitiveness of Polish economy and science at the background of other European and world countries. The realisation of the research concerning the technologies of surface structure and properties formation of products and their elements should contribute significantly to predicted development. The best technological solutions taking into considerations the enterprises competitiveness increasing and improvement of product utility properties, stability and reliability should be founded. The expected practical project results are long-term ones. Identified and probably applied leading technologies and connected with them strategic research directions should be important minimum during the next ten or fifteen years. That is an average period of the amortisation of technological equipment in manufacturing sectors using those technologies. The introduction level of technological news in the field of selection of a material element and processes determining its structure and properties as well as selection of surface layer kind and technology ensuring expected utility properties currently is not satisfying. Special consideration should be given to small- and medium-sized enterprises encompassing

99.8% of all domestic companies and generating 68% of GDP in which the level of the priority innovative technologies introduction is insufficient. Because of that, an absolute need for increase average level of technologies realisation by producers' statistic majority takes place. It is very important for quality and stability of products on the market and it decides about Polish economy competitiveness. Thus, presented issues have great economic significance. The trade of surface properties formation of engineering materials and biomaterials is one from the most dynamic [3]. It requires the continual introduction of technological news into industrial entities working in almost all divisions of industries. Generally, SMEs have not considerable financial outlays allotted for development. It forces necessity of their activity directions determination. The research results will create good conditions for making objective decisions concerning innovativeness development and research financing. The additional effect will be knowledge propagation in scientific and industrial group of people interested in the foresight subject matter and activation of open public debate on the considered theme.

6. Conclusion

In order to diagnose the crucial scientific, technological, economic and ecological aspects of material surface engineering and to identify the directions of their strategic development and decision-taking, the appropriate instruments of forecasting and identifying the priority innovative technologies must be used. It is purposeful, therefore, to undertake systematic scientific research, notably using foresight methods, for predicting and formulating the directions of desired development of leading surface layers structure and properties formation technologies for products and their elements produced of different engineering materials. The directions of strategic research, classified in the most avant-garde thematic areas, should also be set to create several alternative feasible development scenarios aimed at the improvement of functional properties, durability and reliability of products and at selecting the most effective technologies that must be popularised in the industry which – in terms of their modernity and price to quality ratio – are most suitable for effective implementation in the industry. Foresight research in the field of material engineering allow, in particular, to identify the priority innovative technologies of materials surface engineering and to determine their strategic development directions. The dissemination of such research and the related public debate and the broadening awareness of entrepreneurs within the scope considered is tangibly translating into statistic growth in the quality of the technologies implemented industrially, into sustainable development and into the strengthening of a knowledge- and innovation-based economy. The development directions of the most advantageous technological solutions of surface layers structure and properties formation of products and their elements produced using materials surface engineering technologies considered as critical were indicated as part of own materials science-heuristic and foresight research [20] pursued together with top-notch, internationally recognised experts. The selected critical technologies of materials surface engineering understood as the priority technologies with the best development prospects and/or of key significance in the industry over the assumed time horizon were subjected to own research [6, 18, 20] in order to evaluate their value according to objectivised criteria against the micro- and macroenvironment and to identify their development prospects over the nearest 20 years. In this chapter the state of the art as well as evaluation and development prediction methodological assumptions for materials surface technologies is presented. The next chapters of this book present the detailed results of materials science and foresight investigations in relation to the selected groups of specific technologies [9-17] forming part of the practical verification of correctness of the established computer integrated development prediction methodology in surface engineering area, presented in general in the monograph publication [21].

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