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The methodological fundaments of development state analysis of surface engineering technologies

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Education and research trends

ABSTRACT

Purpose: The goal of this paper is to present the authority methodological fundaments of development state analysis of surface engineering technologies against a background of macro- and microenvironment. That analysis is carried out as a part of the project entitled "The foresight of surface properties formation leading technologies of engineering materials and biomaterials". The research project called FORSURF is co-founded by European Regional Development Fund.
Design/methodology/approach: The foresight is the whole activity focused on choosing the best future vision and showing ways of that vision realisation using the right methods. However, the approach called technology foresight is the process concentrating scientists, engineers, industrialists, Government officials and others in order to identify areas of strategic research and the leading technologies, which in long term will contribute to the greatest economic and social benefits and sustain industrial competitiveness. The considered FORSURF project belongs to the set of technology foresights.
Findings: The set of the crucial technologies in each considered research scope is an expected result of the carried out development state analysis of surface engineering technology against a background of macro- and microenvironment. There are fourteen research scopes in the FORSURF project.
Research limitations/implications: The results of the development state analysis of surface engineering technologies are the basis conditioning subject matter of the first research iteration of Delphi method carried out within the framework of the FORSURF project. The main research implication of the whole FORSURF project is an identification of strategic research directions crucial in the next 20 years in the field of surface engineering.
Practical implications: The practical implication of the definition of the methodological fundaments of development state analysis of surface engineering technology is to show the way of the crucial technologies selection. The consequence of that is a creation of the basic conditioning subject matter of the first research iteration of Delphi method.
Originality/value: That paper is the publication concerning the authority methodological fundaments of development state analysis of surface engineering technology against a background of macro- and microenvironment within the framework of the FORSURF project. Particularly, the way of the selection of crucial technologies being the basis conditioning a subject matter of the first research iteration of Delphi method is presented.
Keywords: Development in the field of materials; Manufacturing and mechanical engineering; Foresight

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1. Introduction

The presentation of the authority methodological fundaments of development state analysis of surface engineering technologies against a background of macro- and microenvironment is the goal of that paper. The shown issues concern the research project entitled "The foresight of surface properties formation leading technologies of engineering materials and biomaterials". That project called FORSURF was started last year and should be realised during three calendar years. It is co-founded by the European Regional Development Fund and the Polish Ministry of Science and Higher Education. The FORSURF project is realised with the participation of high-class experts from Poland and foreign countries.

The importance to industry issues concerning surface properties formation of engineering materials and biomaterials is great. That knowledge area belongs to one of the most dynamic one in all European countries and is met in almost all divisions of industries, such as [1,2]: automotive, machine-building and tools, mechatronics, metallurgical, electrical engineering, electronics, plastics, aircraft, medical equipment, sanitary equipment, jewellery, precision, building and others. The FORSURF project makes an effort to meet market needs, because there is an absolute need to increase an average level of technologies realisation by producers' statistic majority. It is very important for quality and stability of product statistic majority on the market and it decides about domestic economy competitiveness. Currently, one of the most important industrial problems is a right selection of material element and processes determining its structure and properties as well as right selection of surface layer kind and technology ensuring expected utility properties [3,4]. In that scope a level of the technological news implementation certainly in contemporary enterprises, especially small and medium ones (SME), is not satisfying [5]. Moreover, it is very important to adjust a subject matter of research work to meet current and real production enterprises needs. Thus, it is necessary to increase domestic enterprises involvement in proinnovative activity. It causes a high absorption level of innovations and financial resources allotted for proinnovative activity in economy. In the light of presented remarks the considered problem has great economic significance.

2. About the FORSURF project

The main goal of the research project entitled "The foresight of surface properties formation leading technologies of engineering materials and biomaterials" is to identify priority innovative technologies and strategic research directions which development will be crucial during the next 20 years in the field of surface properties formation leading technologies of engineering materials and biomaterials. The achievement of project main goal is tantamount to the achievement of common goal. The project common goal is to increase Polish economy innovativeness and competitiveness by closer co-operation between economy and sphere of research and development (R&D). The achievement of the project main goal comes down to achieve the set of intermediate goals. The achievement of each intermediate goal is tantamount to the realisation of a specific task planned within the confines of the considered project. The finishing of each task causes a result being a milestone which moves significantly executors closer to finalise the whole planned works. There are the following intermediate goals in the considered project [6]:

- The creation of project executors net as well as creation and initiation of the Internet platform;
- Preparation of a report determining current situation in the field of technology development and socioeconomic factors in the scope of the foresight subject matter;
- Preparation of database concerning the experts participating in the project;
- Achievement of research results using Delphi method and preparation of a report including results of three survey iterations;
- Creation of a neural network (one from artificial intelligence method) in order to determinate cross impacts between trends and events;
- Organisation of the International Conference in order to initiate open public debate and social consultations concerning project realisation and results;
- Creation of database with information cards for industrialists and three scenarios of possible future events: optimistic, neutral and pessimistic;
- Competent project management, project flexibility enabling to adjust carried out activities to meet fast changing environmental conditions and effective project promotion, such as: conferences, workshops and seminars.

All shown goals of the FORSURF project are compatible with the main goal of Innovative Economy Operational Programme (IE OP) 2007–2013. The main goal of IE OP is Polish economy development in the basis of innovative enterprises. Particularly, the goals and assumptions of the FORSURF project meet Priority Axis 1. Research and development of new technologies, Action 1.1. Scientific research supporting for building knowledge-based economy, Subaction 1.1.1. Research projects using foresight method. The FORSURF project activities also meet the detailed goals of IE OP. Therefore, the project realisation directly and indirectly will contribute to: the increase of enterprise innovativeness, the increase of Polish academic research competitiveness and significance in economic development, the greater importance of innovative Polish products on international market, the create of many new permanent workplaces connected with building of knowledge-based economy and greater utilisation of information and communication technologies in Polish economy. The project realisation will contribute to scientific research orientation at fields which building knowledge-based economy and can have great influence on fast country economic development. Another effect of the project finalisation should be rational implementation of research results in industry. Moreover, it will create for the selected research fields and disciplines preferential conditions during the division of financial resources from a state budget.

In the framework of the FORSURF project two wide research areas has been distinguished. Those research areas are following: *Manufacturing* (**M**) and *Product* (**P**). The first research area called *Manufacturing* is determined by knowledge state and machines production possibilities. The *Manufacturing* (**M**) area has been divided into narrower following research scopes:

M1: Laser technologies in surface engineering;
M2: PVD/CVD technologies;
M3: Thermochemical technologies;
M4: Other technologies in surface engineering;
M5: Polymers surface treatment;
M6: Modelling and computer adding in surface engineering;
M7: The impact of wear conditions on engineering materials surface properties.

The second research area called *Product* (**P**) concerns manufactured product and materials out of which that product is made. That area is determined by expected functional and practical properties arising from costumer needs. The *Product* area has been 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 functional materials;
P6: Surface engineering of nanomaterials;
P7: Surface engineering of polymeric materials.

All project works concerning development state analysis have been carried out parallel with reference to each defined research scope.

3. Development state analysis

The authority methodological fundaments of development state analysis of surface engineering technology against a background of macro- and microenvironment in the FORSURF project in that chapter has been presented. Particularly, there is the exact description of the consecutive steps of development state analysis realised as a part of the FORSURF project. The realisation of the consecutive steps of development state analysis leads to create the basis conditioning subject matter of the first research iteration of Delphi method carried out within the framework of the FORSURF project. From presented statements appear that the considered methodological fundaments enable the selection of crucial technologies being the basis conditioning a subject matter of the first survey iteration of Delphi method (Fig.1). It is planned that Delphi method will consist of three survey iterations being the basis of the next project researches. The survey questionnaires will be filled-in by high-class experts mainly from the country and also from abroad. According to Delphi method assumptions consecutive surveys are constructed on the basis of the results of preceded surveys [7,8]. The detail level of consecutive surveys increases [9]. During the researches the gradual transition from common level of issues included in a first survey iteration, by more detailed questions in the second research step to the whole process conclusion in the third survey iteration takes place [10,11]. Parallel to basic researches using Delphi method other support researches of lower standing using the recommended methods will run, such as [12,13]: expert panels, brainstorming, sketches, benchmarking, multi-criteria analysis, computational simulations and modelling, econometric analyses, statistical methods, e.g.: game theory. All works made during the FORSURF project serve to achieve the following expected final results: technology information cards, scenarios of possible future events [14], open public debate on the foresight subject matter.

Development state analysis made as a part of the FORSURF project concerns each from the fourteen-element set of determined research scopes. Within the confines of development state analysis the following project works has been carried out:

- issue state assessment;
- technological review;
- strategic analysis.

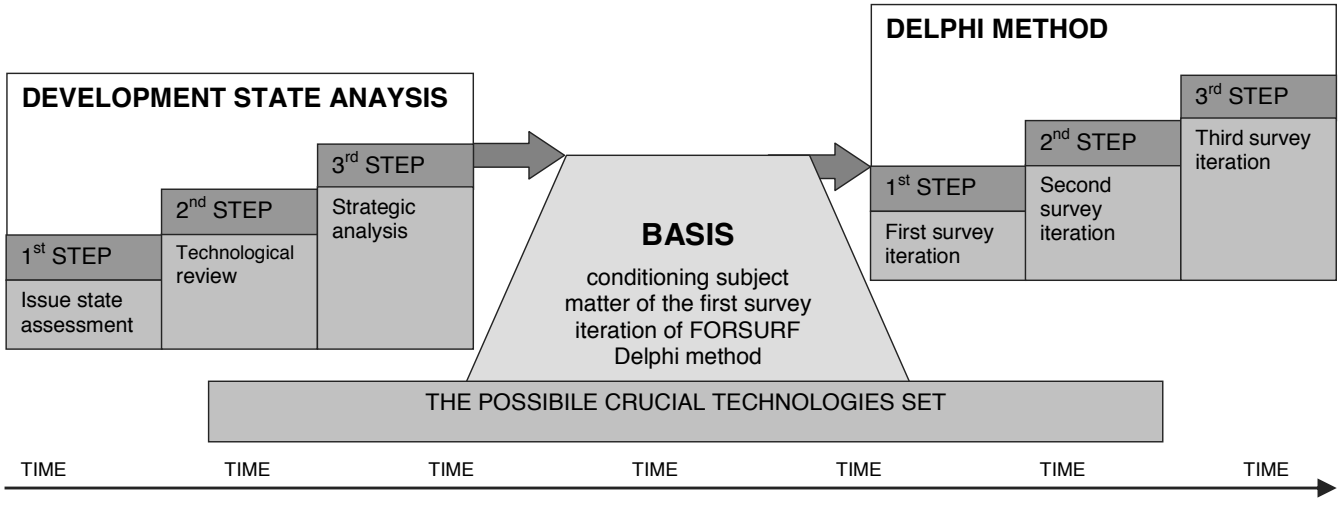

Fig.1. Development state analysis versus Delphi method

The detailed project works has been realised by the key experts appointed by open competition. The key experts group has been worked under the Project Management leadership. There is the Project Management in Gliwice situated in Silesian province at the technical university being the biggest one in Silesia and one from the biggest technical universities in Poland. The university entity responsible for the FORSURF project realisation is the Institute of Engineering Materials and Biomaterials belonging to Faculty of Mechanical Engineering of the Silesian University of Technology. That Institute is the biggest domestic scientific-research entity specialised in the field of engineering materials and biomaterials. Moreover, the advisory body supporting the project tasks realisation is the International Monitoring Committee (IMC). The members of the International Monitoring Committee are high-class experts representing societies of science, business and public administration from the country and abroad.

3.1. Issue state assessment

Issue state assessment is a first part of development state analysis. It is a set of elaborations connected with the consecutive research scopes. The following methods are 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;
- 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 are presented. Moreover, statistical data mainly shown within the confines issue state assessment are following:

- 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 project key experts in order to complete statistical data have been used many different source data. First of all the following raw data has been 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 have been 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 have been 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. According to the main assumptions of the FORSURF project the strategic research directions which development will be crucial during the next 20 years has been searched. Especially, theories which are controversial, untypical as well as non thoroughly confirmed and investigated in that part of the elaboration should be 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.

3.2. Technological review

The technological review is a second part of development state analysis. It is a set of fourteen pieces from which every one is connected with a given research scope. The following methods are recommended to key experts for the preparation of technological review: crucial 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 list;
- identification of a preliminary crucial technologies list.

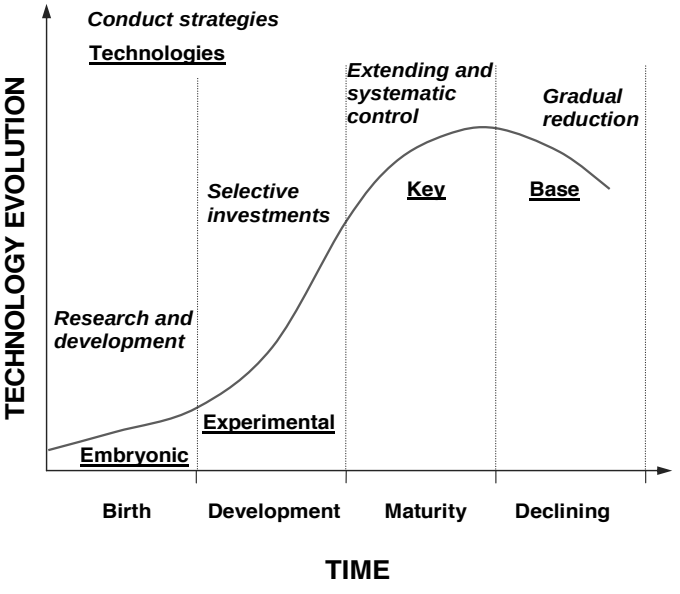

Fig. 2. Technology lifecycle

According to an issue called technology lifecycle all technologies can be assigned to one from the following groups:

- basic technologies; they are common available and used very often, they competitiveness decreases or is little yet; they are slowly falling into disuse;
- key technologies; they are the basis of the product competitiveness, they mastering is the key factor determining the enterprise success; the using perspective is ten years;
- experimental technologies; their application is not wide yet; they often are in testing or prototype building phase; a glorious future is prognosticated 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;

There are qualified into the next researches key technologies which are not common used in the country, experimental technologies and embryonic technologies. An assessment of technologies is carried out according to a defined scale as well as defined main and detailed criteria. The assessment scale is five-steps and there are the following possible marks: (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 researches realisation. Those main criteria concern attraction and potential. Moreover, six detailed criteria also has been outworked. There are following detailed criteria used in carried out researches:

- economic attraction (A_1); significance of a given technology for the country and/or World economic development;
- social attraction (A_2); significance and beneficial impact of a given technology for society;
- ecological attraction (A_3); significance and beneficial impact of a given technology for natural environment state;
- creative potential (P_1); the possibility of creation of new research and application directions;
- applied potential (P_2); the possibility of a given technology application in implementation sphere;
- research and development potential (P_3); the possibility of carried out of research and development works.

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

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

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 attraction 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*.

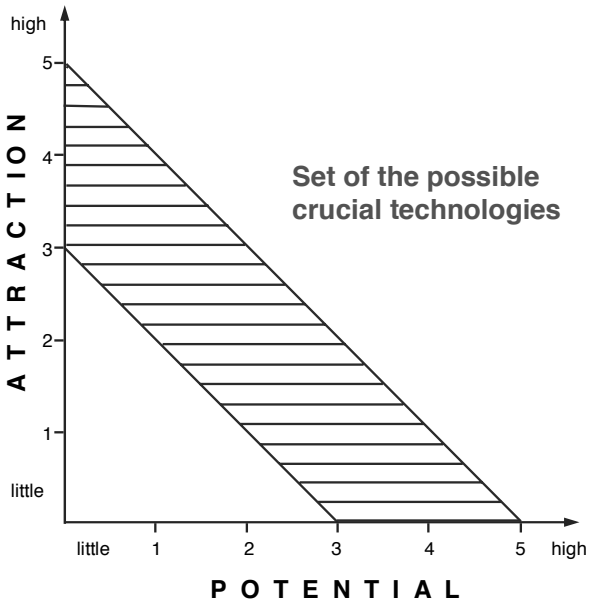

Fig. 3. A technology ranking according to attraction parameter and potential parameter

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

$$\text{If } O_i > 3, \quad \text{then the } i\text{-th technology belongs to possible crucial technology set.} \qquad (2)$$

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 an attraction parameter and a potential parameter in Fig. 3. is presented. The next stage of that research part will consist of verification of the set of possible crucial technologies as well as generating the final set of crucial technologies. It will take place with participation of outside experts during the first survey iteration carried out using Delphi method.

3.3. Strategic analysis

Strategic analysis using integrated methods is a last part of development state analysis. Fourteen pieces from which every one is 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 following methods play the supporting role during preparation of strategic analysis by key experts: multi-criteria analysis, trends

extrapolation, beneficiaries mapping, environment scanning, brainstorming, expert panels.

According to the STEEP analysis assumptions consecutive outside remarks reflect situation taking place in macroenvironment. 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:

S: Social;
T: Technological;
E: Economic;
E: Ecological;
P: Political.

All presented remark groups have been shown and described in Table 1.

Table 1.
Characteristics of different macroenvironment types

Symbol	Macroenvironment 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 in 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.

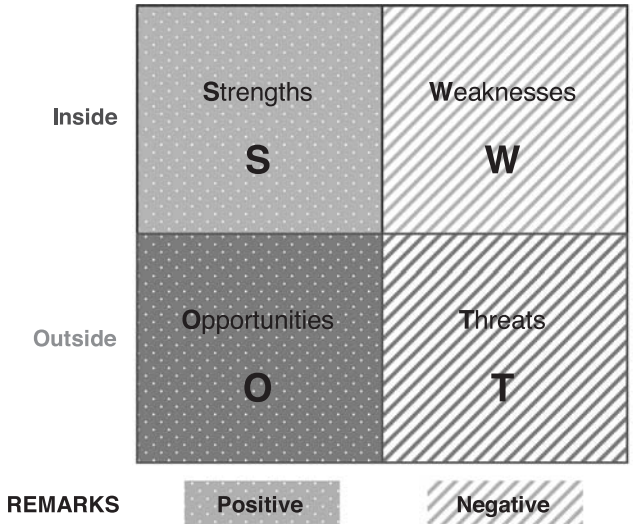

Fig. 4. Remark groups by SWOT analysis

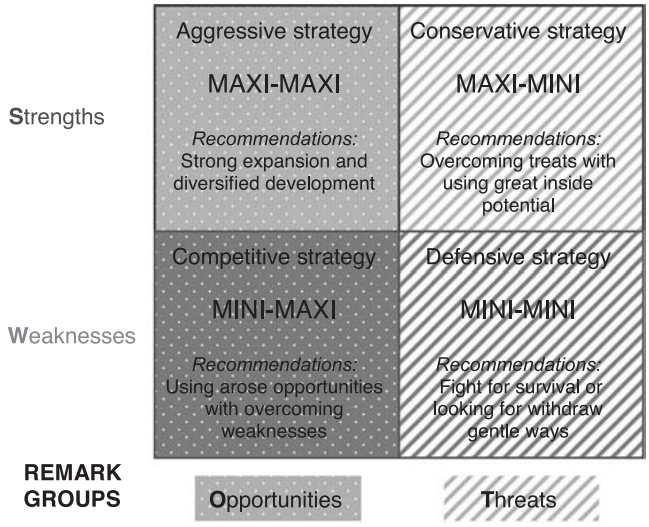

Fig. 5.Recomended conduct strategies

The STEEP analysis results have been directly utilised into the researches 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 [15]. 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 will be used in followed Delphi 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 clearcut 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.4 are presented.

Within the confines of SWOT analysis realised for needs of the FORSURF project the most important ten strengths and ten weaknesses of the given research scope have been chosen. Similarly, also the most important ten opportunities and ten threats of the given research scope have been completed. Next, the each remark impact is defined. The sum of the impacts determined for each from four remark groups is equal 1.The consecutive remarks using ten-steps scale has been assessed. The best mark is (10) meaning very high 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 have been presented. Each table correspond to each remark group. Next, overall statement including total weighted average of each remark group has been shown. For each technology one of four possible conduct strategies has been preliminary chosen.

The strategy choosing depends on inside and outside remark groups dominated with reference to the analysed research scope. Recommended conduct strategies in Fig.5. have been illustrated.

4. Questionnaire form

The carried out development state analysis leads to create the basic conditioning subject matter of the first survey iteration of Delphi method carried out within the framework of the FORSURF project. The consecutive project work step consists in the questionnaire form preparation. That questionnaire form serves the collection of the trade experts opinion about the given research scope. Especially, doubtful, controversial, uncertain and non-full confirmed opinions are really interesting. The thesis and statements included in the questionnaire form have been formulated on the basis of previously carried out issue state assessment, technological review and strategic analysis using integrated methods. According to established guidelines outworked questionnaire form should include 25 questions concerning given parts of development state analysis in following proportions:

- 5 questions connected with issue state assessment,
- 15 questions connected with technological review and
- 5 question connected with strategic analysis using integrated methods.

The set of fourteen questionnaire forms from which every one concerns one from defined research scopes creates the first survey iteration using Delphi method. The final version of the first survey iteration will be carefully prepared during experts panels carried out within the confines of 3rd FORSURF Workshop entitled “Current technology development state of surface engineering against a background of macro- and microenvironment conditioning subject matter of the first survey iteration of Delphi method carried out within the framework of the FORSURF project. Next, the

consecutive questionnaire forms will be sent in an electronic way to high-class trade experts representing societies of science, business and public administration.

5. Conclusions

In the presented paper the authority methodological fundaments of three-stage analysis applied into the project entitled "The foresight of surface properties formation leading technologies of engineering materials and biomaterials" is described. The shown development state analysis is applied into surface engineering technology against a background of macro- and microenvironment. That analysis is divided into issue state assessment, technological review and strategic analysis. Each from a presented analysis stage is unique and requires the characteristic set of methods application. The consecutive analysis stages concern every one out of fourteen-element set of research scopes. Thus, fourteen pieces of development state analysis fit together into a whole. The realisation of presented analysis leads to create the basis conditioning subject matter of the first survey iteration of Delphi method carried out within the framework of the FORSURF project. Especially, the selection of the possible crucial technologies set takes place. Planned three-stage Delphi method and the other researches serve to achieveg the following expected final project results: technology information cards, scenarios of possible future events, open public debate on the foresight subject matter. The project results will create good conditions for making objective decisions concerning innovativeness development and researches financing. Moreover, knowledge propagation in scientific and industrial group of people interested in the foresight subject matter is expected.

Acknowledgements

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