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Results on Foresight-Research for Nanotechnology Industry Development for the Next Economy in Ukraine

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Authors' contributions

Author IS designed the study and managed the analyses of the study, managed the literature searches. Authors IM and MD performed the statistical analysis and managed the literature searches. Author MD design the stage of international technology. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of the article is to consider the generalized procedure for implementation of the foresight-project for determining the perspective directions of STD nanotechnology industry using the suggested information technology.
Study Design: Initial data for foresight-research are statistical data of 2009 – 2013 years, namely, official statistical data of the state institutions and international organizations, publications of reference character, analytical monographs, annual statistical bulletins, and annual Ukrainian State Statistical Bureau reports.
Place and Duration of Study: Scientific research center for industrial development problems in the National academy of Sciences of Ukraine & Department of Software Engineering, National Aerospace University named after N.Y. Zhukovsky “KhAI” in 3-d quarter of 2014.

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Methodology: As the main method of research it was used content analysis that allowed to make a meaningful analysis of classic papers and researches of modern economists-practitioners devoted to peculiarities of the foresight-research in high-tech industry development in different countries. As the formal basis it is chosen methods of bibliometrics and scientometrics (counting the number of publications), multicriterion problems decision making (t-ordering, Pareto optimality) and patent analysis (analysis of the curves the dynamics of inventive activity) are chosen.
Results: It is considered the organization of foresight-research in different countries of the world and in Ukraine. It is defined the extent of automation for national foresight-projects. It us given the generalized procedure for implementation of the foresight-project for determining the perspective directions of scientific and technical development nanotechnologies. The result of the implementation of the foresight-research is a number of priorities of the nanotechnology industry in Ukraine. It is stated the approach to integrated automation of foresight-projects in Ukraine. In future members of foresight projects will implement the theoretical developments in the form of interactive decision support system. It is given the extent of automation of the developed methodical approach to realization of foresight-researches in Ukraine as well as their mathematical and methodical support is given. The priorities for the development of the nanotechnology industry are nanomaterials and technology as well as special equipment for the development and production of nanomaterials and nanodevices, since their vector assessments constitute the Pareto set.
Conclusion: Features of the economies in different countries cause expediency in creating special foresight models for each country. Ukrainian version of foresight based on expert assessment is imperfect due to excess subjectivity. Increase of efficiency in the Ukrainian foresight lies in the plane of its computerization. The received results serve as methodological basis for creating the system of complex automation of forecasting process for STD in large-scale objects.

Keywords: Foresight-project; nanotechnologies; scientific and technical development; t-ordering; scientometrics; Pareto optimality.

1. INTRODUCTION

At present practically in all developed countries, special programs for defining priority areas of science and technique development are created from time to time. The methods used in development process for these programs have got the generalized name of *foresight*, and until now showed themselves as the most effective tool for choosing the priorities in science and technologies fields [1–3].

The foresight concept arose in the 1950th in American corporation "Rand" that solved the problems defining perspective military technologies. Having faced with insufficiency in traditional predictive methods (quantitative models, extrapolation of the existing tendencies, etc.), experts in "Rand" developed Delphi method [4], which became the basis for many foresight-researches. In the 60th large-scale operations on prediction were carried out by Naval and air force departments in the USA. Since 1980th foresight is used in the European countries [5]. Foresight reached the heyday as analysis method in the mid-nineties within national programs of technological prediction that still remains the main scope of foresight applications.

The basic idea of foresight is to identify the strategic directions for development of science, technology, economy, social sphere, etc., which in 15-20 years will be determinative for the entire world community [1]. This methodology is used to predict the scientific and technological development (STD) on all the levels - from corporate to national. On the basis of foresight developed in medium- and long-term, 5-30 years, strategy in development of economy, science, technology, which are aimed to increasing competitiveness, in general, and to ensure the effective development of the socio-economic sphere.

Foresight is a more integrated approach compared to traditional technological forecasting because in foresight it is defined the assessment of the possible prospects for innovative development connected with progress in science and technologies, possible technological horizons that can be reached by investing certain means and organizing systematic work, as well as possible effects for economy and society (Table 1). Besides, communicative technologies of foresight are one of the effective tools for forming the public opinion and positions of professional communities. It allows to direct and focus activity of the companies involved in process, organizations and wide groups of people to the uniform course, and, respectively, to influence statement of the purposes and tasks, caused ideas of possible ways for development in the long-term future. Thus, foresight is no about forecasting of the future, but it is more about its formation - the specific management instrument for scientific and technological development, leaning the infrastructure created in its framework.

Nowadays foresight is used as a system tool for forming the future that allows considering changes in all spheres of public life: science and technologies, economy, social, public relations, culture. However, analysis of the publications from domestic and foreign sources [5-12] devoted to the study of theoretical and practical aspects in foresight methodology application showed that there was a need for further study of the problem related to the automation of foresight technology. The authors analyzed the way of automation for each stage in the national foresight project [13-17]. As a result of the analysis it was offered information technology support of foresight projects

Table 1. Characteristic features of foresight and technological forecasting

Name of feature	**Technological forecasting**	**Foresight**
Essence	The special scientific research directed to identify the development prospect of a phenomenon or process, i.e. certain methods to handle the available information on object of forecasting and get an impression about the directions of its evolution on the basis of the analysis of tendencies of its development	Process of systematic definition of the new strategic scientific directions and technological achievements which will be able to have serious impact on economic and social development of object of foresight in the long term
Purpose	Defining future conditions of forecasting object - prolongation of the tendencies allocated on the basis of the analysis of conditions of object in the past and nowadays	On the basis of current scientific development and technologies to catch tendencies of future world and to create its different variants, i.e. specify, in what direction the country, the city or the enterprise should develop
Tasks	- Definition of the possible purposes and the priority directions for development of the predicted objects; - Assessment of social and economic consequences for realization of each possible options in development of the predicted objects; - Definition of the measures necessary for providing each of possible variants of development of the predicted objects; - Assessment of the resources necessary for implementation of the planned programs of actions	- Definition of perspective technologies and the markets on a long-term outlook; - Definition of the directions for business cooperation - the state in creation of competitive innovations; - Definition of measures which will allow to use new opportunities for improvement of life quality, acceleration in economic growth and preservation of competitiveness
Methods	- Factual methods; - Expert methods; - Combined methods	Expert methods
Results	Different types of forecasts	- Report on foresight performance (scenarios, action program, list of priorities, etc.); - Creation of information network (establishment of the communications between participants occupied in various spheres of innovative development)
Participants	Scientists	Scientists, representatives of authorities, business and public officials (power, producers and consumers of goods and services)

Source: Own research

in Ukraine [18], based on the specialized techniques for choosing the priorities [19]. The adoption of specified technology will allow increasing the efficiency of national foresight projects due to their complete computerization based on formal methods.

The aim of the article is to consider the generalized procedure for implementation the foresight project on determination perspective directions of STD in nanotechnology industry using the offered information technology.

2. METODOLOGY

It was used content analysis as the main method of research, which allowed making a meaningful analysis of classic papers and researches of modern economists-practitioners devoted to the peculiarities of the foresight-research for high-tech industry development for the next economy in different countries. General scientific methods made a methodological foundation of the research. They include description, comparison, statistics review, system analysis and others, which help to characterize this phenomenon of development in a more comprehensive way. We also apply the methods of dialectic cognition, structural analysis and logic principles that provide making authentic conclusions regarding the investigated topic.

Official statistical data of the state institutions and international organizations, publications of reference character, analytical monographs, annual statistical bulletins, annual Ukrainian State Statistical Bureau reports serve as information grounds for our research.

As an illustrative example for the use the offered information technology [18], we will consider the generalized procedure of implementation the foresight-project on defining the perspective directions of STD in nanotechnologies.

The initial data is an obligatory stage of the national forecasting technique of forecast and analytical researches [7], adapted under the use in the computerized decision support system (DSS) of implementation by each stage of the foresight methodology [19].

Progress in solving the problem consists of the following steps:

1. *Formation of expert panels*, i.e., form number and structure of expert group participating in the foresight project based on the evaluation of the competence level of each expert.
2. *Formation the initial list of the nanotechnology industry directions.* It is necessary to analyze the status and prospects of nanotechnology industry development using bibliometric methods (method of counting the number of publications) [20], scientometrics (methods of citation analysis, content analysis, slang and thesaurus methods) [21] and patent analysis (analysis of curves on the dynamics of inventive activity) [22]. Then, for the obtained lists of scientific and technical trends of the nanotechnology industry development it is calculated value criteria for their assessment provided for national technique of foresight-researches [7]. Thus, all "leading" directions have quantitative assessments for each of the criteria, which will help to determine the number of priority.
3. *Selection of priority directions for nanoindustry development.* Initial data for the choice of priorities is a list of directions of nanotechnology industry, as well as a set of values assessment criteria for each direction. The procedure for the selection of priority directions of nanotechnology industry development is in ranking these directions criteria using the methods of Pareto optimality and t-ordering.
4. *Coordination and approval of priority directions*. In accordance with the current technique [7] it is carried out strictly regulated procedure for coordination and approval of priorities.

The result of the implementation of the foresight-research is a number of priorities of the nanotechnology industry in Ukraine.

3. RESULTS AND DISCUSSION

3.1 Application of Foresight Technology for Scientific and Technological Development Management in Various Countries of the World and in Ukraine

Today, in most countries of the world (USA, Japan, Great Britain, France, Sweden, Russia and so on.) and in Ukraine, in particular, the foresight methodology established itself as the most effective tool for setting priorities in the field of science and technology (Table 2).

Table 2. Foresight program in the countries of the world

Years	Foresight type	Foresight programs, country (foresight methods)
2000	Market and technological foresight	7th research STA, Japan (Delphi); "Prospektar", Brazil (Delphi); Technology Foresight program in Brazil (mixed methods); 2nd program of "100 key technologies", France (mixed methods) Program ET2000, Portugal (mixed methods)
2001		Technology Foresight, Chile (Delphi) "Futur-1", Germany (mixed methods); Technology Foresight, Greece (mixed methods)) Program technological foresight (1st cycle), Venezuela (mixed methods) Technological foresight program, Czech Republic (mixed methods)
2002		Technological foresight program, Roadmap for the National Institutes of Health, USA (roadmaps); 3rd Foresight program, Great Britain (mixed methods); Program Vision 2023, Turkey (mixed methods)
2003		Technological foresight program t, Greece (mixed methods) Studies of the Academic Council in 2020, Norway (mixed methods) 2nd program of technological foresight, (Sweden);
2004	Foresight of the global competition and development of innovative systems	8ht Japanese Foresight program, Japan (mixed methods); "South Korea 2030", South Korea (mixed methods); Technological foresight program, Ukraine (Delphi); Program FuturRIS, France (mixed methods); Program AGORA, France (mixed methods); Technological foresight program (2nd cycle), Venezuela (mixed methods) Russian critical technologies, Russia (mixed methods)
2005		Technological foresight program (2nd cycle), Colombia (Delphi); Brazil 3 Moments program, Brazil (mixed methods); Program of scientific and technological foresight, Romania (mixed methods); FinnSight, Finland (mixed methods); FNR-Foresight program, Luxembourg (mixed methods); The program of the USA Chamber of Accounts "Challenges in the 21st century", USA (mixed methods)
2006		Foresight SITRA, Finland (mixed methods); Program technological foresight "Poland 2020", Poland (mixed methods); Scanning the horizon, Great Britain (mixed methods); Research priorities, Germany (mixed methods); Technology Foresight, New Zealand (mixed methods)
Nowa-days	Foresight as a policy tool	OPTI - The future of the Spanish nuclear power in 2030, Spain (mixed methods); 9th Japan Foresight program, Japan (mixed methods); "Childhood 2030", Russia (mixed methods)

Source: Own research

In Japan since 1971 foresight results define the forecast in development of science and technologies in the country for the next 30 years [23,24]. The results "are corrected" each 5 years. The main stages of foresight in Japan included the analysis of trends in the world of science and technology; making the list of perspective "subjects" of economic, scientific, technical and social development; two-round survey of experts on Delphi, ranging the chosen subjects on extent of their innovative importance; making the list of national scientific and technical priorities as well as critical technologies.

In the United States in recent years the main efforts at the federal level were aimed to drawing up a list of technologies that are critical to the national economy. Due to disunity of the conducted researches one of the most difficult challenges facing the US government in the analysis of foresight research was to bring together the different lists of critical technologies and the identification of similarities between them, as different researches were different in the level and quality of a technique (survey experts, expert panels, technology road maps), which was often of formal character and was not the result of original research [25-27].

In Great Britain three foresight-programs organized by the government were carried out [11,28-30]. The "Foresight-1" (1994 – 1999th) takes into account only the technological and market prospects. "Foresight 2" (1999 – 2002 years) and "Foresight 3" (2002 – 2004 years) are characterized by the integration of technological, market and social problems, as well as the involvement of a wide range of participants. Heads the program Government committee into which representatives of 17 ministries and departments enter. Each program represents three interconnected stages - the analysis, distribution of information and application of results, preparation for the following program. As a result it is defined the state priorities in scientific and technical programs in training and methods of state regulation. The budgetary priorities are formed based on five-year plans and since 1990th - take into account the long-term (15 - 30 years) forecast priorities of foresight and scenarios. The main mechanism of realization is a program to stimulate cooperation LINK and methods are Delphi, expert panel, scanning technologies and scenarios.

In Germany, there were two rounds of Delphi - in 1993 and 1998 [12,31-34], the results of which were used in the formation of the state science and technology policy. The initiator of them was the Federal Ministry of Education, Science, Research and Technology, and spent - Institute of systems and innovative researches Fraunkhofer in Karlsruhe. An overall objective of these inspections was not a prediction of the future, but preparation of possible scenarios and gathering information for decision-making, and also preparing the scientific basis for a national debate on the formation of the country's future. The result of foresight studies in close cooperation with Japanese colleagues ("Delphi-93" and "Delphi-98") has become its own unique program FUTUR [35] (another name - "The German Research Dialogue") that allowed creating a strategic vision for the Ministry of Education and science for the next 20 years.

In Sweden in 1997 it was started a national project "Technology Foresight" [33,36]. Unlike other countries, this project was initiated not by the government, but business and scientific circles. It was organized by the Royal Swedish Academy of Engineering Sciences - IVA, Swedish National Board for Industrial and Technical Development - NUTEK, Swedish Foundation for Strategic Research and the Federation of Swedish Industries. The project was realized with the support of the government, state agencies and other stakeholders. Total funding amounted to 4 million SEK. Recommendations and priorities mentioned in foresight were almost entirely included in the government's science and technology strategy (the Bill of Parliament in 2000).

Implementation of technological foresight in France in 1999 - 2000 years was carried out in 4 stages [23,33]. A distinctive feature of the French foresight is its organization in two mutually parallel directions. The first of them was implemented by the Ministry of Higher Education and Research, and was carried out by Delphi method with broad involvement of experts (about 3.5 thousand). Studying important technological development in various areas that wouldl interest economy and society was its strategic objective. The second direction was in charge of the Ministry of Industry and its aim was to study the technologies that were critical for the French industry in the next 30 years. As the methodological basis of the research, it was used bibliometric and patent analysis, as well as expert evaluation.

The history of foresight-researches in Russia is nearly 15 years. Over the years, various departments and research groups implemented projects aimed to determining the prospects for the development of various scientific and technological areas, sectors of economy and regions. However, the long-term forecast of scientific and technological development of the Russian Federation for the period till 2025 prepared by the Ministry of Education and Science of the Russian Federation in 2007 - 2008 [37] became the most large-scale and rather complex research of this sort. The forecast was developed within the Federal target program "Researches and Development in the Priority Directions of Development of Scientific and Technological Complex of Russia for 2007 - 2012" with application of the methods "critical technologies", "expert panels", "scenarios", and also with direct support from Federal agency on science and innovations.

The conducted in Ukraine forecasting and analytical research, within approved by Cabinet of Ministers is the State Program on Forecasting of scientific and technological innovation and development involving more than 700 experts. Ukrainian version of the foresight technology [7], which purpose was a formation of the state scientific and technological and innovative priorities provides realization of set a stages (Fig. 1), by questioning a group of experts is based on the Delphi method [4]:

- the first stage involves the solution of problem of choice the experts who will participate in the foresight study; when forming the group of experts the method of "snowball" is used;
- in the second stage, using of expert surveys, and "benchmarking" (comparison with other countries or regions) it is made the formation of a preliminary list of thematic directions and the criteria for their evaluation of the main goals of the country's STD;
- at the third stage experts need to estimate the obtained thematic directions by the set of criteria. This procedure is carried out by means of Delphi method that assumes survey (questioning) of experts and organization of feedback (through carrying out three rounds of survey). Results of research include the evaluation summary for each topic, as well as analytical reviews of the thematic directions;
- the final stage is the coordination and approval of the obtained in the previous step lists of thematic areas of STD in the country.

With the analysis of each of the stages of the Ukrainian foresight-project described above it was allocated the extent of their automation, and also mathematical and methodical providing (Fig. 2).

It follows that Ukrainian foresight projects are based on the survey of expert groups (Fig. 1), thus the computerization of processes is limited only to fixing data from experts and their statistical processing (Fig. 2). Consequence of this is insufficient efficiency of foresight projects implemented in Ukraine, first of all due to the subjectivity inherent in the expert evaluation.

Thus, considering experience from different countries it is possible to claim that today there is no unified model of foresight, each country adapts this technology under the specific goals, requirements and methods of its realization which are hardly formalized and generally are expert-based. Therefore, there is a need in further research of the problem concerning the increase of efficiency in foresight-projects.

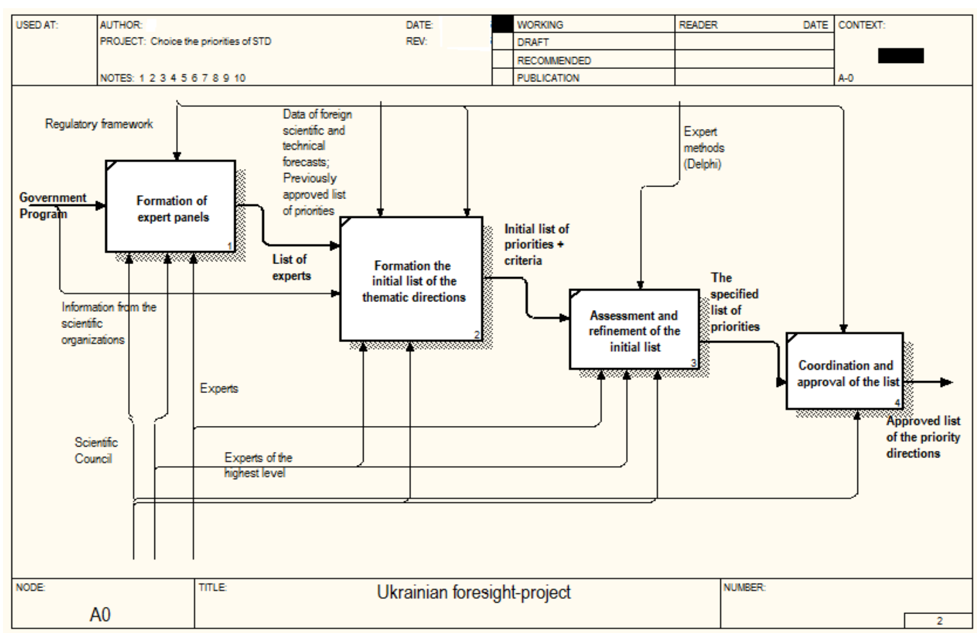

Fig. 1. Stages of national forecasting and analytical research on the most perspective directions of science and technology development
Source: Own research, [7]

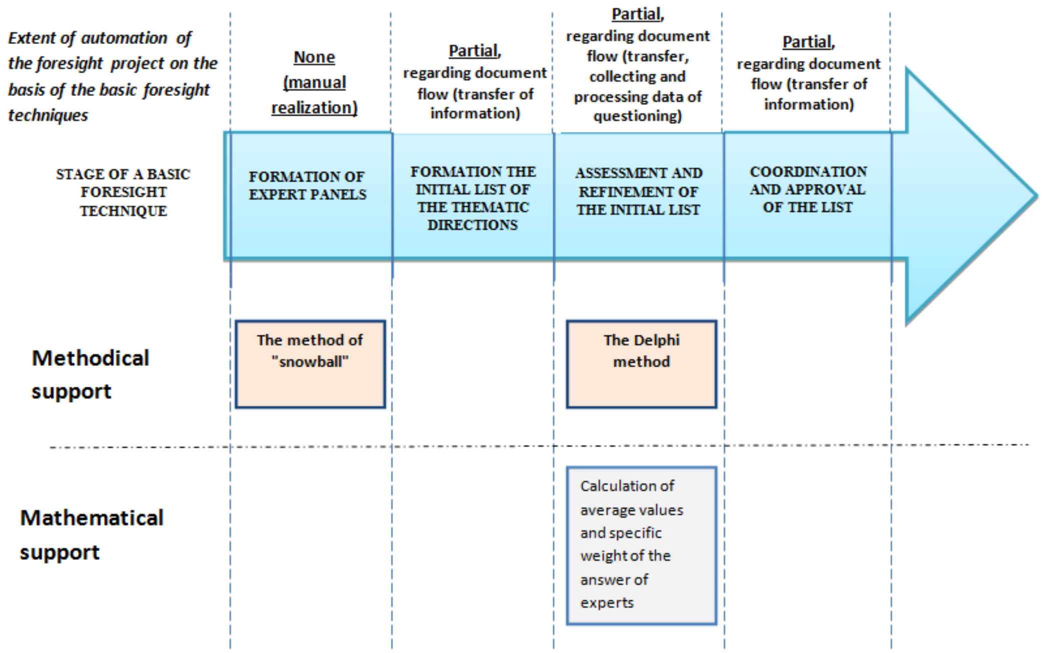

Fig. 2. Extent of automation in Ukrainian foresight-projects and their mathematical and methodical support

Source: Own research

3.2 Approach to Complex Automation of Foresight-Projects Defining Scientific and Technological Priorities in Nanotechnology Industry

This foresight-research was carried out within 3-ty quarter of 2014 [38]. As initial data in the research there are used statistical data for 2009 – 2013 years.

For an objective analysis of each direction of the nanotechnology industry in the beginning of foresight research the following assumptions of sufficiency were entered:

- information from the selected sources;
- specified time intervals;
- calculation of the values of the basic criteria for their assessment.

The result of the implementation of the foresight-research will be a number of priorities of the nanotechnology industry in Ukraine.

Course of foresight research, according to the national technique forecasting and analytical research (Fig. 1), adapted for use in the framework of the implementation of the computerized DSS for each stage of foresight technology [19], and consists of the following stages:

1. *forming expert panels*;
2. f*orming the initial list of the directions nanotechnology industry*;
3. *selecting the priority directions of development nanoindustry*;
4. *coordinating and approving priority directions*.

At the first stage it is carried out such operations as calculations of necessary number of experts for research and generalized indicator in level of competence for each expert based on the coefficients reflecting both professional standard and personal qualities of the expert [38]. Further experts are ranged on value of the generalized indicator of level of their competence and it is formed the final list of experts taking into account the number of expert group.

Thus, in the context of forecast research there were attested 20 candidates in experts, 12 of them were selected for further involvement in expertize that enters the calculated earlier allowable range. The final list of the experts participating in expertize is provided in Table 3.

Table 3. List of experts

Number in sequence	Code of the expert	Generalized indicator of the level of expert competence, K_i	Rank of the expert
1	Fn_0003	1	1
2	Fn_0011	0,98	2
3	Fn_0001	0,93	2
4	Fn_0005	0,91	2
5	Fn_0006	0,87	3
6	Fn_00017	0,81	3
7	Fn_0020	0,74	4
8	Fn_0002	0,72	4
9	Fn_0018	0,7	4
10	Fn_0007	0,65	5
11	Fn_0009	0,61	5
12	Fn_0015	0,57	6

Source: Own research

Within the second stage there is a formation of the initial list of the thematic directions and calculation of values of criteria for their assessment. As basic data the directions of development of nanotechnologies are [39]:

I. Nanomaterials.
II. Nanoelectronics.
III. Nanophotonics.
IV. Nanobiotechnologies.
V. Nanomedicine.
VI. Methods and instruments of research and certification of nanomaterials and nanodevices.
VII. Technologies and special equipment for creation and production of nanomaterials and nanodevices.

To form the initial list of thematic directions it is used the methods of counting the number of publications and analysis of curves the dynamics of inventive activity, taking into account the assumptions made by us. Let us consider each method in details.

To allocate the "leading" thematic directions in the method of counting the number of publications at the beginning analyze it was taken the number of the abstracted scientific documents from different fields of knowledge, and then calculated to the average growth rate in the number of publications for a certain period of time (5 and more years). For the analysis of the Ukrainian documentary flow on nanotechnologies we chose the nationwide abstract database (DB) “Ukrayinika naukova” [40]. The results of this analysis for the 5-year time period (2009 - 2013 years) are shown in Table 4.

Table 4. Distribution of scientific publications in nanotechnology industry in the thematic directions for 2009 - 2013 years

Direction	Number of scientific papers (articles, abstracts and books), pcs.						Specific weight in the total number of publications %
	2009	**2010**	**2011**	**2012**	**2013**	**Total**	
Nanomaterials	140	108	133	89	40	**510**	28%
Nanoelectronics	36	43	28	26	27	**160**	9%
Nanophotonics	25	26	31	29	22	**133**	7%
Nanobiotechnologies	54	36	13	32	22	**157**	9%
Nanomedicine	74	92	91	83	66	**406**	22%
Methods and tools for research and certification of nanomaterials and nanodevices	57	35	42	46	47	**227**	13%
Technologies and special equipment for creating and production of nanomaterials and nanodevices	82	43	77	69	72	**343**	18%
Total publications	**398**	**392**	**405**	**346**	**272**	**1813**	**100%**

Source: own research

In patent research to determine the prospects of a particular direction to carry out analysis of curves the dynamics of inventive activity in each scientific and technical direction which consists in creation of the cumulative rows of patenting characterized by increase of summary number of the patents relating to this direction [22]. As a source of patent information it was used interactive DB "Inventions (Utility Models) in Ukraine" [41]. Search was carried out with a time interval of 5 years (2009 - 2013 yy.) according to the International Patent Classification by the class B82 "Nanotechnology", and also on classes related essentially to nanotechnology [42]: A61K 9/51 - nanocapsules for medicines; B05D 1/00 - processes for applying liquids or other fluent materials on a surface; S01V 31/02 - obtaining carbon (carbon nanostructures, such as nanotubes, nanospirals and etc.); G01Q 10/00-90/00 - technique of scanning probe or device; various applications of techniques scanning probe such as scanning probe microscopy (SPM); G02F 1/017 - optical quantum wells; H01F 10/32 - multilayer structures with the spin connection, for example nanostructured superlattices; H01F 41/30 - methods and apparatus for applying nanostructures, for example by molecular beam epitaxy; H01L 29/775 - quantized by wire field effect transistor with a channel with crystalline carrier gas feeding to the gate voltage of one polarity (quantum wires).

Thus, according to the results of the bibliometric and patent analyzes [38] in the initial list for identifying the priorities of the nanoindustry those are included which received the highest marks - namely, nanomaterials, nanomedicine, methods and tools of investigation and certification of nanomaterials and nanodevices, technologies and special equipment for creation and production of nanomaterials and nanodevices.

The next step is calculation of criteria values provided by the national foresight research technique [7], for each initial direction. That is, we calculate the values of the quantitative criteria for each of the thematic directions, and then, by questioning the experts we obtain preliminary values of qualitative criteria of assessment for the thematic directions. After that, coordination of opinions of experts is carried out (in case of inconsistency - repeated questioning). Further it is made calculations of the aggregated assessment of each thematic direction for each qualitative criteria. The list of the approved thematic directions with quantitative values for each of criteria of their assessment is a result of this stage. Thus, we obtain a number of criteria values for each direction of the nanoindustry (Table 5).

At the third stage there is processing of the results obtained at the previous stage taking into account ordinal information from decision-making person (DMP) on the relative importance of assessment criteria of the thematic directions. Comparison of the approved thematic directions by means of the principle of Pareto-optimality is carried out. If comparison of the thematic directions across Pareto is impossible, we apply the t-ordering method considering ordinal information of the DMP on the relative importance of assessment criteria for the thematic directions. As a result we obtain the ranged list of priority directions of STD drawn up in the form of the list.

The task set about the choice of the most priority directions of development of nanotech industry, belongs to the class of the multicriteria tasks of decision-making (MTDM). Authors reflect reasons for the previously mentioned statement in [19]. The aim of the solution MTDM is to separate Pareto set [43], i.e., to get directions, with the highest possible estimates for each criterion.

A mathematical model of MTDM for our case can be represented in the following form

$$D_f = < X, f_1, f_2, ..., f_m >,$$

where

X - set of admissible alternatives (thematic directions);
f_j - numerical function defined on set X, in this case $f_j(x)$ is assessment of alternative $x \in X$ on j-th criterion ($j = \overline{1,m}$).

All the criterion function f_j reflects the usefulness of the thematic directions $x \in X$ from positions of the various criteria and shall be commensurable, i.e. value for each criterion function change in the same limits *[a, b]:*

$$\forall x \in X : 0 \leq a \leq f_j(x) \leq b, \ j = \overline{1,m}.$$

Thus the least preferable on any particular criteria $f_j(x)$ alternative will get estimate a, and most preferably - estimate b (*a = 0, b = 1*) [44]. The values of the new criterion functions $\overline{f_j}(x)$ are shown in Table 6.

Table 5. Values of main coefficients for directions in nano industry

Direction	K_f, **mln hrv**	K_{STA}, **pieces**	K_{fr}	K_{WM}	K_{SL}
Nanomaterials	44,5	17	26,96	11,21	11,04
Nanomedicine	30,7	18	27,33	13,2	10,86
Methods, research tools and certification of nanomaterials and nanodevices	36	12	27.89	11.1	10.93
Technologies and special equipment for creation and production of nanomaterials and nanodevices	65.8	19	28.47	15.82	12.74

Source: Own research

Table 6. Values of criteria functions in interval [0, 1]

Direction (x_i)	**Criterion function** $\overline{f_j}(x)$ *)				
	$\overline{f_1}(x)$	$\overline{f_2}(x)$	$\overline{f_3}(x)$	$\overline{f_4}(x)$	$\overline{f_5}(x)$
Nanomaterials (x_1)	0.61	0.11	0 29	0.01	0.003
Nanomedicine (x_2)	0.36	0.13	0.3	0.04	0
Methods, research tools and certification of nanomaterials and nanodevices (x_3)	0.46	0.02	0.31	0,004	0.02
Technology and special equipment for the development and production of nanomaterials and nanodevices (x_4)	1	0.15	0.32	0.09	0.09

*where $\overline{f_1}(x)$ corresponds to criteria κ_f, $\overline{f_2}(x)$ - k_{sta}, $\overline{f_3}(x)$ - k_{fr}, $\overline{f_4}(x)$ - k_{wm}, $\overline{f_5}(x)$ - k_{sl}.

Source: Own research

The numerical functions ($f_j(x)$, $j=\overline{1,m}$) stated above formed vector criterion $f = (f_1, f_2,..., f_m)$. For any alternative $x \in X$ a set of its estimates by all criteria, i.e. a set $(f_1(x), f_2(x),..., f_m(x)) \in R^m$ is a vectorial assessment of alternative x (R^m - space of m-dimensional vectors). All possible vectorial estimates form a set of possible estimates

$$Y = f(X) = \left\{y \in R^m \mid y = f(x) \text{ for some } x \in X\right\}.$$

The vectorial assessment contains the complete information about the value (usefulness) of this alternative and comparing two any alternatives is replaced to their vectorial assessments. The main relation to which vectorial estimates are compared (means, comparing of alternatives) is relation of domination according to Pareto [43]. Here such alternative for which there is no other alternative better this at least by one criterion and isn't worse than it on all the rest of it is considered to be preferable.

In our case $m = 5$ and $Y = \{y_1, y_2, y_3, y_4\}$ i.e. according to the values of criterion functions (Table 6) we will obtain the following vectorial assessments of alternatives:

$$y_1 = (0,61;0,11;0,29;0,01;0,003),$$
$$y_2 = (0,36;0,13;0,29;0,3;0,04;0),$$
$$y_3 = (0,46;0,02;0,31;0,004;0,02),$$
$$y_4 = (1;0,15;0,32;0,09;0,09).$$

To find the set of Pareto-optimal vectors we suppose $Y_1 = Y$ and compare the first assessment with others. These pairs (y_1, y_2; y_1, y_3; y_1, y_4) are incomparable on Pareto ratio. Thus, the task, narrowings of the initial set of alternatives, and as a result and Pareto set, for the purpose of a choice of several alternatives as final output is set. One of such methods is the method t-ordering [45], using ordinal information of the PDM about the relative importance of the criteria.

As the initial information for the t-ordering algorithm it is accepted set of statements S about the relative importance of the PDM about particular criteria of the form: $S = \left\{f_k = f_j ;...; f_q > f_p\right\}$, it should be expanded by adding new transitive statements that are consequences of already available. In this case, according to [7], we have the following set of ordinal information about the relative importance of criteria $S = \{f_1 = f_3 ; f_2 > f_5 ; f_3 > f_4\}$, which was later expanded by the addition of transitive statements. A finite set is as follows:

$$S = \{f_1 = f_3; f_2 > f_5; f_3 > f_2; f_3 > f_4; f_3 > f_5; f_1 > f_5; f_1 > f_2; f_1 > f_4\}. \quad (1)$$

Taking into account obtained set (1) when comparing two vector assessments the preference relation on t- ordering method is construction [45]:

$$Z^t \succ W \leftrightarrow [\exists W' \in WE : Z \overset{p}{\succ} W'] \vee [\exists W'' \in WI : Z \overset{p}{\succ} W''],$$

$$Z \overset{p}{\succ} W \leftrightarrow \forall j \in [1:m] : z_j \geq w_j \quad (2)$$

where

- Z, W - vector assessments ($Z = (z_1,..., z_m)$; $W = (w_1,..., w_m)$);
- WE - a set of W-equivalent vectors ($f_k = f_j$);
- WI - a set of W-improved vectors ($f_k = f_j; f_q > f_p$)

Based on (2) we compare the pair of vector assessments y_1,y_2. Vector y_1 fix, and on a vector y_2 received the following sets of the improved vectors according to (1):

$$y'_2 = (0,38;0,11;0,3;0,04;0);$$
$$y''_2 = (0,39;0,11;0,29;0,04;0);$$
$$y'''_2 = (0,39;0,11;0,29;0,01;0,03);$$
$$y''''_2 = (0,417;0,11;0,29;0,01;0,003)$$

Obtain $y''''_2 \succ y_2$, $y_1 \succ y''''_2 \succ y_2$ and consequently $y_1^t \succ y_2$.

Thus, the vector y_1 is stored as Pareto optimal, and together with vector y_2 is removed from set Y_1. Receive a set of $Y_2 = \{y_3, y_4\}$. Vector y_3 and y_4 are not comparable to Pareto, therefore we apply a method t-ordering to them, thus we fix vector y_3 and we transform y_4 basing on a set of S. We obtain:

$$y''''_4 = (0,46;0,02;1,146;0,004;0,02),$$
$$y''''_4 \succ y_3, \; y_4^t \succ y_3.$$

As a result, we obtain the following set of Pareto-optimal vectors

$$P(Y) = \{y_1, y_4\} \quad (3)$$

Based on these results, we can conclude that the priorities for development of nanotechnology industry are - nanomaterials and technology as well as special equipment for development and production of nanomaterials and nanodevices, since their vector assessments constitute the Pareto set.

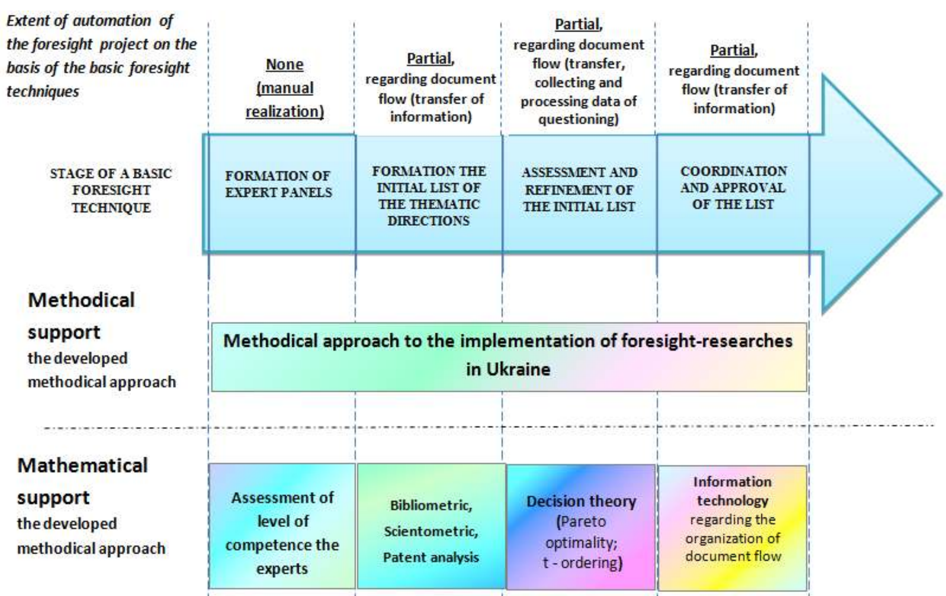

Fig. 3. Extent in automation of the developed methodical approach on realization of foresight-researches in Ukraine and their mathematical and methodical support
Source: Own research

The fourth stage serves for coordination and approval of priority directions of STD obtained at the previous stage. Within the considered concept of complex automation of foresight projects, coordination and approval of the list of thematic directions will be realized according to the approach stated in [46]. In accordance with this approach for the implementation of the foresight project it is synthesized a special computer environment in which all participants are immersed.

Thus, introduction of the developed technique on realization of foresight-researches in Ukraine [19], is reached due to application of formal means that raises extent of automation of national foresight-researches of development of nanotechnology industry (Fig. 3 above).

4. CONCLUSION

Features of economies in different countries cause expediency in creating special foresight models for each country. Ukrainian version of foresight based on the expert assessment, is imperfect due to excess subjectivity. Increase of efficiency in the Ukrainian foresight lies in the plane of its computerization. It is analyzed ways of automation for each of four stages in the national foresight-project in choosing priorities when forecasting a STD of nanotechnology industry. It is stated the approach to complex automation of foresight-projects in Ukraine.

Within the solution of the problem in automation of stage "Formation of Expert Panels" selection of experts involved in the assessment it is proposed to carry on the basis of evaluation of the level of their competence by means of the generalized indicator of the level competence of each expert. It is proposed to use technologies of bibliometrics, scientometrics and patent analysis that allows providing objectivity of initial data of foresight-research to form an output list of the directions for nanotechnology industry. At the stage of assessment and refinement the directions on nanotechnology industry it is offered to use a method of t-ordering and the principle of Pareto- optimality that gives the chance to increase adequacy of an expert assessment in choosing the directions of nanotechnology industry.

The received results serve as methodological basis for creating complex automation system for forecasting process of STD in large-scale objects. Besides, the results provided in this article can be applied to a wide class of tasks to determination the perspective directions of development of any industry application knowledge.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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