

Original Research Article

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

ABSTRACT

Aims: The aim of the article is to consider the generalized procedure of implementation the foresight-project on determination perspective directions of STD nanotechnology industry with use offered information technology.

Study Design: As initial data, during foresight-research are used statistical data for 2009 – 2013 years, namely, 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.

Place and Duration of Study: Scientific research center for industrial development problems of the National academy of sciences of Ukraine & Department of Engineering Software, National Aerospace University named after N.Y. Zhukovsky “KhAI” in 3-ty quarter of 2014.

Methodology: Content analysis has been used 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 of development high-tech industry for the next economy in different countries. As the formal basis 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: The organization of foresight-research in various country of world and in Ukraine is considered. Extent of automation of national foresight-projects is defined. The generalized procedure for implementation of the foresight-project by determine the perspective directions of scientific and technical development nanotechnologies is given. The result of the implementation of the foresight-research will be a number of priorities of the nanotechnology industry in Ukraine. The approach to integrated automation of foresight-projects in Ukraine is stated. Theoretical developments in the future will be implemented in the form of an interactive decision support system by members of foresight projects. Extent of automation of the developed methodical approach on realization of foresight-researches in Ukraine and their mathematical and methodical support is given. The priorities of the development of the nanotechnology industry are - nanomaterials and technology and special equipment for the development and production of nanomaterials and nanodevices, since their vector assessments constitute the Pareto set.

Conclusion: Features of the economies of different countries cause expediency of creating special models foresight for each of the countries. Ukrainian version of foresight which basis is the expert assessment, is imperfect, owing to excess subjectivity. Increase of efficiency of the Ukrainian foresight lies in the plane of his computerization. The received results serve as a methodological basis for the creation system of complex automation of forecasting process a STD of 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 the special programs of defining priority areas of development science and technique are periodically created. The methods used in development process of these programs received the generalized name *foresight*, from English - "foresight", and until now proved themselves as the most effective tool of a choice the priorities in the sphere of science and technologies [1 – 3].

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

The basic idea of foresight is to identify the strategic directions of 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 levels - from corporate to the national. On the basis of foresight developed medium- and long-term, 5-30 years, the strategy of development economy, science, technology, which are aimed at increasing competitiveness and, in general, to ensure the effective development of the socio-economic sphere.

Foresight represents much more integrated approach, than traditional technological forecasting because within foresight it is about an assessment of the possible prospects of innovative development connected with progress in science and technologies the possible technological horizons which can be reached at investment of certain means and the organization of systematic work, and also possible effects for economy and society are defined (tab. 1). Besides, communicative technologies of foresight are one of effective instruments of formation of public opinion and a position of professional communities - allow to direct and focus activity of the companies involved in process, the organizations and wide groups of people, to the uniform course, and, respectively to influence statement of the purposes and tasks, to the caused ideas of possible ways of development of the long-term future. Thus, foresight is connected not with forecasting of the future, and, more, with its formation - is the specific instrument of management of scientific and technological development, leaning on the infrastructure created in its framework.

Table 1. Characteristic features of foresight and technological forecasting

Name of a sign	Technological forecasting	Foresight
Essence	The special scientific research directed on identification of prospect of development the 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 in the long term will be able to have serious impact on economic and social development of object of foresight
Purpose	Definition of future conditions of forecasting object - prolongation of	On the basis of current scientific development and technologies to

	the tendencies allocated on the basis of the analysis of conditions of object in the past and for today	catch tendencies of future world and to create different its variants, i.e. specifies, in what direction the country, the city or the enterprise should develop
Tasks	- Definition of the possible purposes and the priority directions of development the predicted object; - An assessment of social and economic consequences of realization of each possible options of development the predicted objects; - Definition of the measures necessary for providing each of possible variants of developmen the predicted objects; - An 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 of cooperation business - the state in creation of competitive innovations; - Definition of measures which will allow to use new opportunities for improvement of quality of life, acceleration of 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 (power, producers and consumers of goods and services)

For today foresight is used as the system instrument of formation of the future which allows considering changes in all spheres of public life: science and technologies, economy, social, public relations, culture. However, analysis of the publications of domestic and foreign sources [5 - 12] devoted to the study of theoretical and practical aspects of the application of the methodology foresight has shown that there is a need for further study of the problem related to the automation of foresight technology. The authors analyzed the way by automation of each of the stages of the national foresight project [13 - 16]. As a result of this analysis it was offered information technology support foresight projects in Ukraine [17], based on the specialized techniques of choice the priorities [18]. The adoption of specified technology will allow to increase the efficiency of national foresight projects due to complete their computerization on the basis of formal methods.

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

2. METODOLOGY

Content analysis has been used 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 of development high-tech industry for the next economy in different countries. General scientific methods make up a methodological foundation of the research. They include: description, comparison, statistics review, system analysis and others, which help characterize this phenomenon development in a more comprehensive way. We also apply the methods of dialectic cognition, structural analysis and logic principles that provide for making authentic conclusions as regards 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 an information grounds for our research.

As an illustrative example of use the offered information technology [17], we will consider the generalized procedure of implementation the foresight-project on definition the perspective directions of STD nanotechnologies.

The initial data is an obligatory stage of the national forecasting technique of forecast and analytical researches [7], adapted under use within the computerized decision support system (DSS) of implementation by each stage of the methodology foresight [18].

Progress in solving the problem consists of the steps:

1. *Formation of expert panels*, i.e., formed number and structure of expert group to participate in the foresight project based on the evaluation of the competence level of each expert.

2. *Formation the initial list of the directions nanotechnology industry*. It is necessary to analyze the status and prospects of development the nanotechnology industry with the use of bibliometrics methods (method of counting the number of publications) [19], scientometrics (methods of citation analysis, content analysis, slang and thesaurus methods) [20] and patent analysis (analysis of curves the dynamics of inventive activity) [21]. Then, for the obtained lists of scientific and technical trends development of the nanotechnology industry 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 determine the number of priority.

3. *Selection of priority directions of development nanoindustry*. Initial data for the choice of priorities is a list of directions of nanotechnology industry, and also a set of values assessment criteria for each of the directions. The procedure for the selection of priority directions of development nanotechnology industry lies into 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] carried out strictly regulated procedure for coordination and approval of priorities.

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

3. RESULTS AND DISCUSSION

3.1. APPLICATION OF TECHNOLOGY FORESIGHT FOR THE MANAGEMENT OF SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT IN THE VARIOUS COUNTRIES OF THE WORLD AND IN UKRAINE

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

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Table 2. Foresight program of the countries of the world

Years	Foresights 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) Technology Foresight, Chile (Delphi) "Futur-1", Germany (mixed methods); Technology Foresight, Greece (mixed methods))
2001		Program technological foresight (1st cycle), Venezuela (mixed methods) Program technological foresight, Czech Republic (mixed methods) Program technological foresight,
2002		Roadmap for the National Institutes of Health, USA (roadmaps); 3rd Foresight program, Great Britain (mixed methods); Program Vision 2023, Turkey (mixed methods) Program technological foresight, Greece (mixed methods)
2003		Studies of the Academic Council in 2020, Norway (mixed methods)
2004		2nd program of technological foresight, (Sweden); 8ht Japanese Foresight program, Japan (mixed methods); "South Korea 2030", South Korea (mixed methods); Program technological foresight, Ukraine (Delphi); Program FuturRIS, France (mixed methods); Program AGORA, France (mixed methods); Program technological foresight (2nd cycle), Venezuela (mixed methods)
2005	Foresight of the global competition and development of innovative systems	Russian critical technologies, Russia (mixed methods) Program technological foresight (2nd cycle), Colombia (Delphi); Brazil 3 Moments program, Brazil (mixed methods); Program of scientific and technological foresight, Romania (mixed methods); FinnSight, Finland (mixed methods); The program FNR-Foresight, Luxembourg (mixed methods); The program of the USA Chamber of Accounts "Challenges of 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)

Present	Foresight as 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)
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121 In Japan, since 1971, foresight results define the forecast of development of science and
122 technologies in the country for the next 30 years [22, 23]. Thus results "are corrected" each
123 5 years. The main stages of foresight in Japan included the analysis of trends in the world of
124 science and technology; making the list of perspective "subjects" of economic, scientific and
125 technical and social development; two-round survey of experts on Delphi, ranging of the
126 chosen subjects on extent of their innovative importance; making the list of national scientific
127 and technical priorities and critical technologies.

128 In the United States in recent years the main efforts at the federal level have been aimed at
129 drawing up a list of technologies that are critical to the national economy. Due to disunity of
130 the conducted researches one of the most difficult challenges facing the US government in
131 the analysis of foresight research has been to bring together the different lists of critical
132 technologies and the identification of similarities between them, as different researches were
133 used different in the level and quality of a technique (survey experts, expert panels,
134 technology road maps), which often were formal character and were not the result of original
135 research [24 - 26].

136 In Great Britain three foresight-programs organized by the government were carried out [11,
137 27 - 29]. The "Foresight-1" (1994 – 1999th) takes into account only the technological and
138 market prospects. "Foresight 2" (1999 – 2002 years) and "Foresight 3" (2002 – 2004 years)
139 are characterized by the integration of technological, market and social problems, as well as
140 the involvement of a wide range of participants. Heads the program Government committee
141 into which representatives of 17 ministries and departments enter. Each program represents
142 three interconnected stages - the analysis, distribution of information and application of
143 results, preparation for the following program. As a result the state priorities in scientific and
144 technical programs, in training, in methods of state regulation are defined. The budgetary
145 priorities are formed on the basis of five-year plans, and from 1990th - taking into account
146 the long-term (15 - 30 years) forecast priorities of foresight and scenarios. The main
147 mechanism of realization - a program to stimulate cooperation LINK and methods – Delphi,
148 expert panel, scanning technologies and scenarios.

149 In Germany, there have been two rounds of Delphi - in 1993 and 1998 [12, 30 - 33], the
150 results of which were used in the formation of the state science and technology policy. The
151 initiator of them was the Federal Ministry by Education, Science, Research and Technology,
152 and spent - Institute of systems and innovative researches Fraunkhofer in Karlsruhe. An
153 overall objective of these inspections - not a prediction of the future, but preparation of
154 possible scenarios and gathering of information for decision-making, and also preparation of
155 the scientific basis for a national debate on the formation of the country's future. The result of
156 foresight studies in close cooperation with Japanese colleagues ("Delphi-93" and "Delphi-
157 98") has become its own unique program FUTUR [34] (another name - "The German
158 Research Dialogue") that allows you to create a strategic vision for the Ministry of Education
159 and science for the next 20 years.

160 In Sweden in 1997 started a national project "Technology Foresight" [32, 35]. Unlike other
161 countries, this project was initiated not by the government, but business and scientific
162 circles. It was organized by the Royal Swedish Academy of Engineering Sciences - IVA,
163 Swedish National Board for Industrial and Technical Development - NUTEK, Swedish
164 Foundation for Strategic Research and the Federation of Swedish Industries. The project
165 was realized with the support of the government, state agencies and other stakeholders.
166 Total funding amounted to 4 million SEK. Recommendations and priorities mentioned
167 foresight was almost entirely included in the government's science and technology strategy
168 (the Bill of Parliament in 2000).

169 Implementation of technological foresight in France in 1999 - 2000 years was carried out in 4
170 stages [22, 32]. A distinctive feature of the French foresight - its organization in two mutually
171 parallel directions. The first of them was implemented by the Ministry of Higher Education
172 and Research, and was carried out by Delphi method with broad involvement of experts
173 (about 3.5 thousand). Studying of important technological development in various areas
174 which will interest economy and society was its strategic objective. The second direction was
175 in charge of the Ministry of Industry and its aim was to study the technologies that are critical
176 for the French industry in the next 30 years. As the methodological basis of the research was
177 used bibliometric and patent analysis, as well as expert evaluation.

178 The history of foresight-researches in Russia totals nearly 15 years. Over the years, various
179 departments and research groups have been implemented projects aimed at determining the
180 prospects for the development of various scientific and technological areas, sectors of
181 economy and regions. However, the Long-term forecast of scientific and technological
182 development of the Russian Federation for the period till 2025 prepared by the Ministry of
183 Education and Science of the Russian Federation in 2007 - 2008 [36] became the most
184 large-scale and rather complex research of this sort. The forecast was developed within the
185 Federal target program "Researches and Development in the Priority Directions of
186 Development of a Scientific and Technological Complex of Russia for 2007 - 2012" with
187 application of the methods "critical technologies", "expert panels", "scenarios", and also with
188 direct support from Federal agency on science and innovations.

189 The conducted in Ukraine forecasting and analytical research, within approved by Cabinet of
190 Ministers the State Program on Forecasting of scientific and technological innovation and
191 development involving more than 700 experts. Ukrainian version of the technology foresight
192 [7], which purpose was a formation of the state scientific and technological and innovative
193 priorities provides realization of set a stages (Fig. 1), by questioning a group of experts
194 based on the Delphi method [4]:

195 – the first stage involves the solution of problem of choice the experts who will
196 participate in the foresight study; when forming the group of experts the method of
197 "snowball" is used;

198 – in the second stage, using of expert surveys, and "benchmarking" (comparison with
199 other countries or regions) is the formation of a preliminary list of thematic directions and the
200 criteria for their evaluation of the main goals of the country's STD;

201 – at the third stage experts need to estimate the received thematic directions by the set
202 criteria. This procedure is carried out by means of a method Delphi that assumes survey
203 (questioning) of experts and the organization of feedback (through carrying out three rounds
204 of survey). Results of research include the evaluation summary for each topic, as well as
205 analytical reviews of the thematic directions;

206 – the final stage is the coordination and approval obtained in the previous step lists of
207 thematic areas of STD country.

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

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

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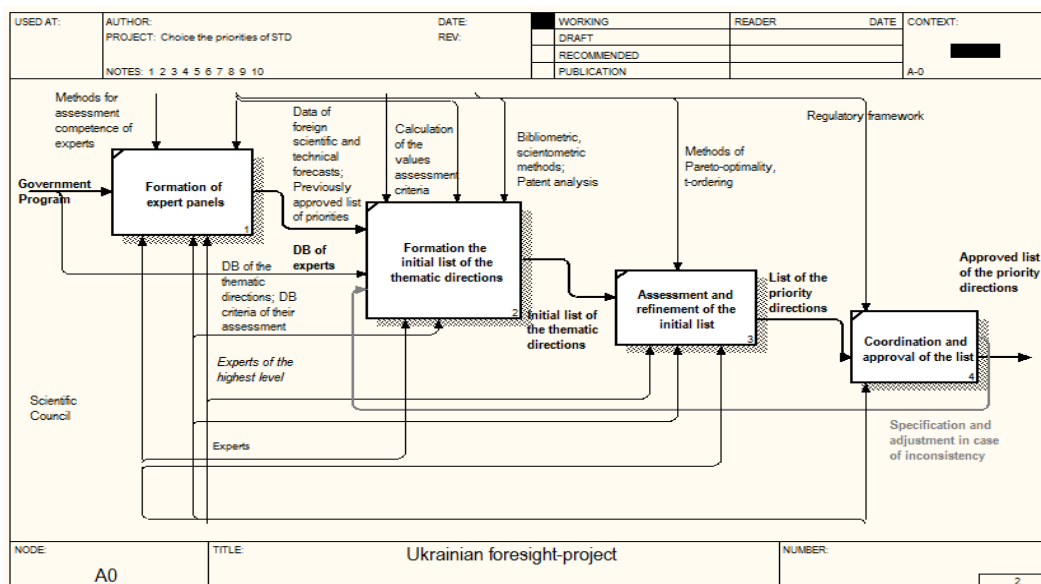


Fig. 1. Stages of the national forecasting and analytical research on the most perspective directions of science and technology development

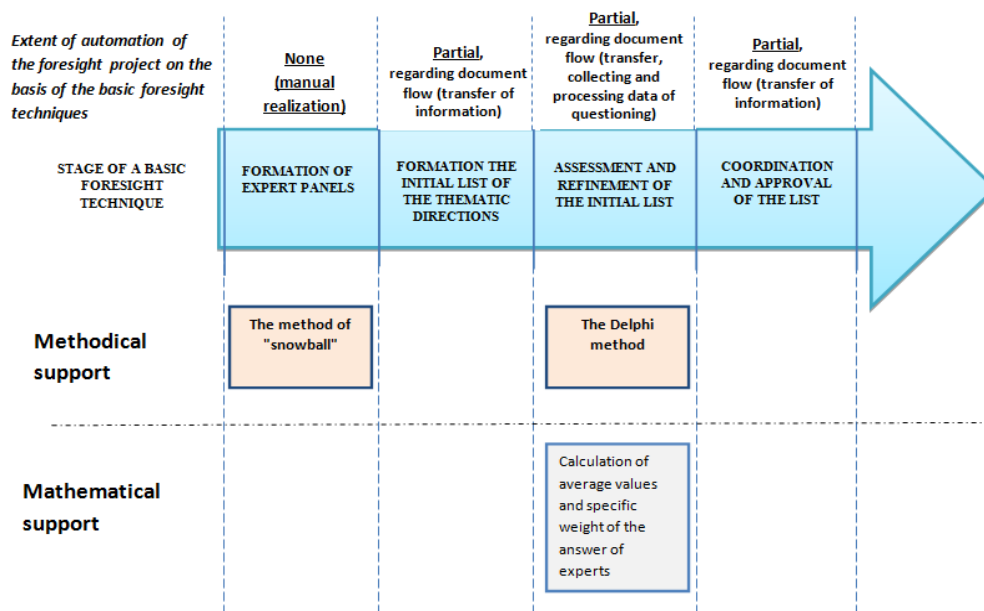


Fig. 2. Extent of automation of Ukrainian foresight-projects and their mathematical and methodical support

Thus, considering experience of the different countries it is possible to claim that today there is no uniform model of foresight, each country adapts this technology under the specific goals and requirements, and methods of its realization are badly formalized and generally are expert, therefore, there is a need of further research of the problem connected with increase of efficiency of foresight-projects.

3.2. APPROACH TO COMPLEX AUTOMATION OF FORESIGHT-PROJECTS, BY

DEFINITION OF SCIENTIFIC AND TECHNOLOGICAL PRIORITIES OF NANOTECHNOLOGY INDUSTRY

This foresight-research was carried out within 3-ty quarter of 2014 [37]. As initial data, during research are used statistical data for 2009 – 2013 years.

For an objective analysis of each of the directions 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 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 each stage of technology foresight [18], composed of the following stages:

1. *formation of expert panels;*
2. *formation the initial list of the directions nanotechnology industry;*
3. *selection of priority directions of development nanoindustry;*
4. *coordination and approval of priority directions.*

At the first stage such operations as calculations of necessary number of experts of research and the generalized indicator of level of competence of each expert on the basis of the coefficients reflecting both professional standard, and personal qualities of the expert are carried out [37]. Further experts are ranged on value of the generalized indicator of level of their competence and the final list of experts taking into account the number of expert group is formed.

Thus, in the context of forecast research conducted by us 20 candidates for experts were attested, from them 12 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	The generalized indicator of the level of competence expert, 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

Within the second stage there is a formation of the initial list of the thematic directions and calculation of values of criteria of their assessment. As basic data the directions of development of nanotechnologies stand out [38]:

- I. Nanomaterials.
- II. Nanoelectronics.
- III. Nanophotonics.
- IV. Nanobiotechnologies.

271 V. Nanomedicine.
 272 VI. Methods and instruments of research and certification of nanomaterials and nanodevices.
 273 VII. Technologies and special equipment for creation and production of nanomaterials and
 274 nanodevices.
 275 For the formation of the initial list of thematic directions use the methods of counting the
 276 number of publications and analysis of curves the dynamics of inventive activity, taking into
 277 account the assumptions made by us. Let us consider in detail the operation each of the
 278 methods.
 279 With the purpose to allocate the "leading" thematic directions in the method of counting the
 280 number of publications in the beginning analyze the number of the abstracted scientific
 281 documents from different fields of knowledge, and then calculated to the average growth rate
 282 of the number of publications for a certain period of time (5 and more years). For the
 283 analysis of the Ukrainian documentary flow on nanotechnologies we chose the nationwide
 284 abstract database (DB) "Ukrayinika naukova" [39]. The results of this analysis for the 5-year
 285 time period (2009 - 2013 years) are shown in table 4.
 286

287 **Table 4. Distribution of scientific publications in nanotechnology industry in the**
 288 **thematic directions for 2009 - 2013 years**
 289

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 instruments of research and certification of nanomaterials and nanodevices	57	35	42	46	47	227	13%
Technologies and special equipment for creation and production of nanomaterials and nanodevices	82	43	77	69	72	343	18%
Total publications	398	392	405	346	272	1813	100%

290 In patent research, for the purpose to determine the prospects of a particular direction to
 291 carry out analysis of curves the dynamics of inventive activity in each scientific and technical
 292 direction which consists in creation of the cumulative rows of patenting characterized by
 293 increase of summary number of the patents relating to this direction [21]. As a source of
 294 patent information was used interactive DB "Inventions (Utility Models) in Ukraine" [40].
 295 Search carried out with a time interval of 5 years (2009 - 2013 yy.) according to the
 296 International Patent Classification by the class B82 "Nanotechnology", and also on classes

related essentially to nanotechnology [41]: 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 [37] **in the initial list to identify the priorities of the nanoindustry includes** those who have received the highest marks - namely, nanomaterials, nanomedicine, methods and tools of investigation and certification of nanomaterials and nanodevices, and technologies and special equipment for creation and production of nanomaterials and nanodevices.

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

Table 5. The values of main coefficients for directions of nanoindustry

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 and instruments of research 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

At the third stage there is a processing of the results received at the previous stage taking into account ordinal information of the person making decision (PDM) 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, apply the method t-ordering considering ordinal information of the PDM on the relative importance of assessment criteria of the thematic directions. As a result we receive the ranged list of the priority directions STD which is draw up in the form of the list.

The task set by us, about a choice of the most priority directions of development of nanotech industry, belongs to the class of the multicriteria tasks of decision-making (MTDM). Reasons for the aforesaid statement are reflected by authors in [18]. The aim of the solution MTDM is

335 to separate Pareto set [42], i.e., to get directions, with the highest possible estimates for
 336 each criterion.

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

338
$$D_f = \langle X, f_1, f_2, \dots, f_m \rangle,$$

339 where X - set of admissible alternatives (thematic directions);

340 f_j - numerical function defined on the set X , in case of this $f_j(x)$ is an assessment of
 341 alternative $x \in X$ on j -th criterion ($j = \overline{1, m}$).

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

345
$$\forall x \in X : 0 \leq a \leq f_j(x) \leq b, j = \overline{1, m}.$$

346 Thus the least preferable on any particular criteria $f_j(x)$ alternative will get estimate a , and
 347 most preferably - estimate b ($a = 0, b = 1$) [43]. The values of the new criterion functions
 348 $\overline{f_j}(x)$ are shown in table 6.

349
 350

Table 6. Values of criterion functions in the 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 and 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

351

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

353

354 The numerical functions ($f_j(x), j = \overline{1, m}$), stated above, formed vector criterion $f = (f_1, f_2, \dots, f_m)$.
 355 For any alternative $x \in X$ a set of its estimates by all criteria, i.e. a set
 356 $(f_1(x), f_2(x), \dots, f_m(x)) \in R^m$ is a vectorial assessment of alternative x (R^m - space of m -
 357 dimensional vectors). All possible vectorial estimates form a set of possible estimates
 358 $Y = f(X) = \{y \in R^m \mid y = f(x) \text{ for some } x \in X\}$.

359 The vectorial assessment contains the complete information about the value (usefulness) of
 360 this alternative and comparing of any two alternatives is replaced with comparing of their
 361 vectorial assessments. The main relation on which are compared vectorial estimates
 362 (means, comparing of alternatives) – relation of domination according to Pareto [42]. Here
 363 such alternative for which there is no other alternative better this at least by one criterion and
 364 isn't worse than it on all rest of it is considered preferable.

365 In our case $m = 5$ and $Y = \{y_1, y_2, y_3, y_4\}$ i.e. according to the values of criterion functions

(tab. 6) we will receive 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 a 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 [44], using ordinal information of the PDM on the relative importance of criteria.

As the initial information for the t-ordering algorithm accepted a set S of statements about the relative importance of the PDM about particular criteria of the form:

$S = \{f_k = f_j; \dots; f_q > f_p\}$, is should be expanded by adding new transitive statements which are consequences of the 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 the received set (1) when comparing two vector assessments the preference relation on a t-ordering method is construction [44]:

$$Z^t \succ W \leftrightarrow [\exists W' \in WE : Z \overset{P}{\succ} W'] \vee [\exists W'' \in WI : Z \overset{P}{\succ} W''], \quad (2)$$

$$Z \overset{P}{\succ} W \leftrightarrow \forall j \in [1 : m] : z_j \geq w_j$$

where Z, W - vector assessments ($Z = (z_1, \dots, z_m); W = (w_1, \dots, w_m)$);

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

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

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

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

Thus, the vector y_1 is stored as a Pareto optimal, and together with the vector y_2 is removed from the set Y_1 . Receive a set of $Y_2 = \{y_3, y_4\}$. Vector y_3 and y_4 are not comparable on Pareto, therefore we apply to them a method t-ordering, thus vector y_3 we fix and y_4 we will transform based on a set of S . We resive: $y''''_4 = (0,46;0,02;1,146;0,004;0,02)$,

$$y''''_4 \succ y_3, y_4^t \succ y_3.$$

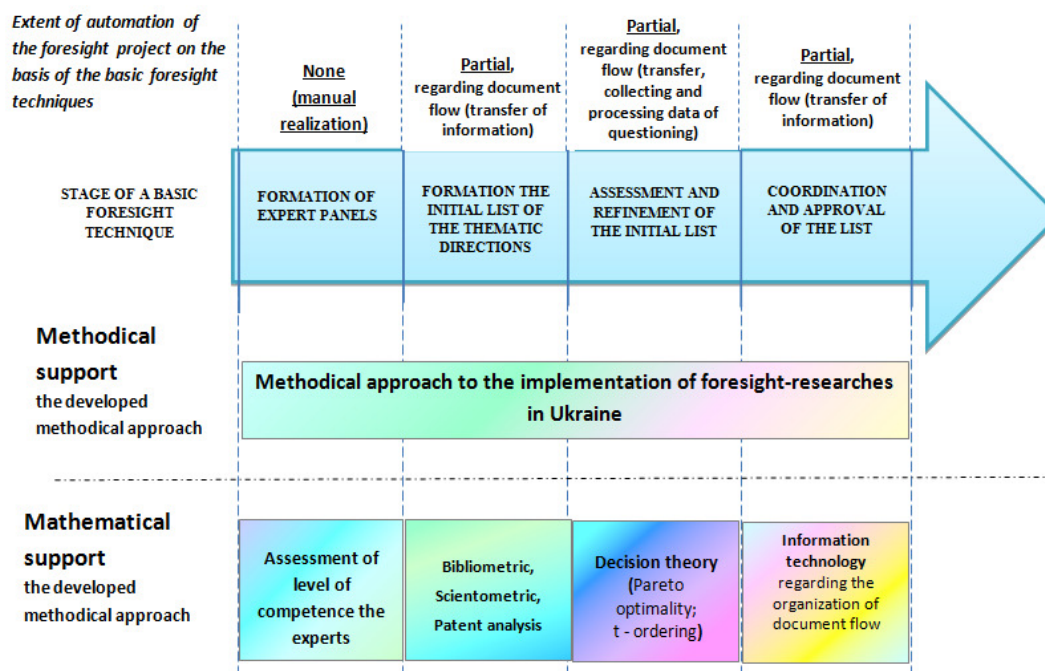
As a result, we resive the following set of Pareto-optimal vectors

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

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

The fourth stage serves for coordination and the approval of priority directions of STD received at the previous stage. Within the considered concept of complex automation of

405 foresight projects, coordination and approval of the list of thematic directions will be realized
 406 according to the approach stated in [45]. In accordance with this approach for the
 407 implementation of the foresight project synthesized a special computer environment in which
 408 all participants are immersed.
 409 Thus, introduction of the developed technique on realization of foresight-researches in
 410 Ukraine [18], is reached due to application of formal means that raises extent of automation
 411 of national foresight-researches of development of nanotechnology industry (Fig. 3).
 412



413
 414
 415 **Fig. 3. Extent of automation of the developed methodical approach on realization of**
 416 **foresight-researches in Ukraine and their mathematical and methodical support**
 417

418 4. CONCLUSION

419
 420 Features of the economies of different countries cause expediency of creating special
 421 models foresight for each of the countries. Ukrainian version of foresight which basis is the
 422 expert assessment, is imperfect, owing to excess subjectivity. Increase of efficiency of the
 423 Ukrainian foresight lies in the plane of his computerization.

424 Ways of automation of each of four stages of the national foresight-project at the choice of
 425 priorities when forecasting a STD of nanotechnology industry are analysed.

426 Is stated approach to complex automation of foresight-projects in Ukraine. Within the
 427 solution of a problem of automation of the stage "Formation of Expert Panels" selection of
 428 experts involved in the assessment, proposed to carry out on the basis of evaluation of the
 429 level of their competence, by means of the generalized indicator of the level competence of
 430 each expert.

431 For formation an output list of the directions of nanotechnology industry proposed use the
 432 technologies bibliometrics, scientometrics and patent analysis that allows to provide
 433 objectivity of initial data of foresight-research.

434 At the stage of assessment and refinement the directions of nanotechnology industry use a
 435 method of t-ordering and the principle of Pareto- optimality is offered, gives the chance to

increase adequacy of an expert assessment at a choice of the directions of nanotechnology industry.
The received results serve as a methodological basis for the creation system of complex automation of forecasting process a STD of large-scale objects.

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