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Development of the scientific and technological forecasting methodology based on using TIPS instruments

Abstract. Scientific and technological forecasting for a long run is essential when determining priorities in science, engineering, and technology development. The forecasting methods used in its development and based on the Delphi approach cannot provide a complete analysis of development trends, depending on the experts' professionalism, and allow facts of lobbying interests of various groups.
In this paper, the mechanisms for improving the quality of scientific and technological forecasts by using the theory of inventive problem solving (TIPS, or TRIZ) when forming and verifying forecasts have been offered. In this case, the forecast results are based not only on the expert's subjective opinion but also on the objective laws of the development of the technical systems. The material has come with detailed practical examples.
The integration of the TRIZ instruments in the state system for determining top priority technological areas will reduce errors in choosing the number of promising technological and technical areas that will make up the basis for the formation of new models and technologies.
Keywords: Innovation; Scientific Forecasting; Technological Forecasting; Forecast Quality; Problems Solving; TRIZ; TIPS
JEL Classifications: O31; O39; O32; C87
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Розробка методології науково-технологічного прогнозування на основі використання інструментів ТРВЗ

Анотація. Науково-технологічне прогнозування на тривалий період має важливе значення при визначенні пріоритетів у науці, техніці та розвитку технологій. Методи прогнозування, що використовуються при його розробці та базуються на підході Delphi, не можуть забезпечити повний аналіз тенденцій розвитку залежно від професіоналізму експертів, а також врахувати факти лобіювання інтересів різних груп.
У цій роботі запропоновано механізми підвищення якості науково-технічних прогнозів за допомогою теорії розв'язання винахідницьких задач (ТРВЗ) при формуванні та верифікації прогнозів. У цьому випадку результати прогнозу ґрунтуються не лише на суб'єктивній думці експерта, але й на об'єктивних законах розвитку технічних систем. Стаття містить детальні практичні приклади.
Ключові слова: інновації; наукове прогнозування; технологічне прогнозування; якість прогнозів; вирішення проблем; ТРВЗ.

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Разработка методологии научно-технологического прогнозирования на основе инструментов ТРИЗ

Аннотация. Научно-технологическое прогнозирование на длительный период имеет важное значение при определении приоритетов развития науки, техники и технологий. Используемые при его разработке методы прогнозирования, основанные на подходе Delphi, не могут дать полноценный анализ тенденций развития, зависящих от профессионализма экспертов, и допустить факты лоббирования интересов различных групп.
В статье предложены механизмы повышения качества научно-технических прогнозов за счет использования теории решения изобретательских задач (ТРИЗ) при формировании и проверке прогнозов. В этом случае результаты прогноза основываются не только на субъективном мнении эксперта, но и на объективных закономерностях развития технических систем. В материале приведены подробные практические примеры.
Ключевые слова: инновации; научное прогнозирование; технологическое прогнозирование; качество прогнозов; решение проблем; ТРИЗ.

1. Introduction

Nowadays, scientific and technological forecasting is an important part of the formation of the scientific and technical policy of the state, and, according to the foresight studies, forecast documents are the basis for developing the relevant long-term strategies and innovative programs for the development of regions and enterprises (Nagimov et al., 2018; Feng et al., 2020; Jia et al., 2021).

Scientific and technological forecasting is the main instrument to form the scientific and technical groundwork to create promising models of technology (Borgianni et al., 2018; Tsygankova, 2019; Wang and Dong, 2021). The importance of the predictive approach to enterprise management is confirmed by the fact that the cost of work at each subsequent stage of the equipment life cycle increases by about one order of magnitude. Thus, it is always more preferable to form the scientific and technical groundwork at the early stages of the technical system (TS) development than at later ones. This is substantiated by the fact that the earlier refusal from implementing inefficient projects causes the lowest cost. At the same time, it is necessary to note that scientific and technical solutions have the highest potential for use at their early stages. Forecasting errors cause economic losses by one order of magnitude greater than, for example, in the case of planning errors. The project that has been forecast on a comprehensive basis is more than twice cheaper as the original version. Therefore, in modern conditions, it is considered important not to make systematic errors and reduce risks in long-term forecasting (Golubev et al., 2017; Sheu et al., 2020), and improve scientific and technological quality forecasts.

In the paper, the development of the methodology for modern scientific and technological forecasting by additionally using forecasting instruments of the theory of inventive problem solving (TRIZ) is considered.

In the future, the forecasting method was improved by accomplishing LTSD and the forecasting technology (Sengupta et al., 2010; Sheu et al., 2020; Wang and Dong, 2021). In order to improve the quality of forecasting, laws of the need's development (Petrov, 2005), as well as the functional approach (Coccia, 2019; Jia et al., 2021), were worked out. They were used by experts to identify trends in the development of future needs and form the system's future functional model.

2. Methods and Materials

Let us consider the authors' methodology for scientific and technological forecasting by using TRIZ instruments till the year 2021. Figure 1 shows the general methodology for scientific and technological forecasting.

The methodology for the Forecast formation suggests the use of modern forecasting methods, instruments of the theory of solving inventive problems. It is based on the comprehensive analysis of national and foreign experience, expert assessments, and the introduction of machine methods for searching and processing of information and implementing the following principles:

- Identification of breakthrough scientific areas that have the greatest impact on the creation of samples (systems, subsystems, elements);
- Assessment of potential threats to the state security and the establishment of interrelations and the degree of impact of scientific achievements on their compensation. At the same time, the intensity of impact and the term when this impact becomes the most considerable are assessed for each threat;
- Use of scenario approaches to scientific forecasting that allows assessing the possibility to obtain specific results in some scientific regions with various financing options;
- Combining quantitative and qualitative approaches to identifying trends in the development of science, engineering, and technology;
- Use of modern research methods, in particular, the TRIZ;
- Involvement of a wide circle of specialists and highly qualified experts specializing in the forecast.

These are used as the main sources of forecast information:

1) The results of processing factual information of retrospective data on the development of science, engineering, and technology,
2) The current results of implementing State programs for the development of science, engineering, and technology, the development of industry and improving its competitiveness, the development of the aviation industry, the development of electronic and radio-electronic industries,

Methodology for long-term scientific and technical forecast

Characteristics of the organizational activity

Peculiarities:
- Analysis of global challenges in science and technology
- Identification of threats and opportunities windows, and
- More complex structure and depth of the general concept elaboration

Principles:
- Identification of breakthrough research areas.
- Assessment of potential threats to the state security.
- Using scenario-based approaches to scientific forecasting.
- Combining quantitative and qualitative approaches to identify trends in tire development of scientific areas, engineering and technology, and
- Attracting a wide range of specialists and highly qualified experts.

Terms and conditions:
The forecast for the development of two options (scenarios) of scientific and technological development:
- Innovative scenario.
- Forced scenario.

Activity area:
- Machine analysis of Internet resources.
- Identification of global technology trends.
- Assessment of the achieved level of technology development.
- Assessment and forecast of the results of programs of scientific and technical, and technological development, and
- Assessment of the current state of fundamental science and HR training

Logical structure of the activity

Object (subject) of the forecast:
Scientific, technological, technical achievements and results

- The forecast structure includes three sections:
- Forecast of the science, technology and technology development

Sources for the forecast:
The results of the factual processing of information and retrospective data on the science, technology, and technology development.
Results of the previous forecast of scientific and technological development.
Results of the implementation of State programs for the development of science and technology, and industries, as well as programs implemented abroad.
«Background» forecast data based on contextual search and analysis of Internet resources.
Results of the targeted survey of the expert community, general designers and managers of top priority technological areas, experts of scientific organizations of the Russian Academy of Sciences, and
Results of analyzing the forecast data from foreign sources (MCTL, etc.).

Competence centers:
- Higher School of Economics national research institute,
- Center for Macroeconomic Analysis and Short-Term Forecasting,
- Russian Academy of Sciences,
- Industry centers for scientific and technological forecasting on the basis of leading universities,
- Research centers (NRC «Kurchatov Institute», Krylov State Scientific Center, etc.), and
- Technological platforms («Aviation mobility», «BioTech 2030», etc.).

Methods:
Foresight methodology,
Delphi method,
TRIZ method,
Method of extrapolating trends,
Citation index method,
Factor analysis method,
Critical technology method, and
Scenario method

Means:
Specialized software and hardware, and systems.
iFORA.
TcxtApp. and
Filtratus.

Technologies:
Online TechCact.
Big Data.
Text mining, and
Machine learning

Temporary structure of the activity

Stage I
- Development of forecast proposals for fundamental research and development

Stage 2
- Development of forecast proposals in terms of technologies and equipment
- Formation of technological development roadmaps

- Terms of the forecast Federal Law No. 172 dated June 28, 2014 «On Strategic Planning in the Russian Federation» (amended)
- The forecast should be developed on a regular basis in order to form a system of scientifically based ideas about the areas and expected results of the country's scientific and technological development in relation to other documents of state strategic planning

Forecasting long-term scientific and technological development

Analysis of strategic priorities for the development of sectors of the economy, assessment of the feasibility of program activities (finance, human resources, etc.)

Determining the areas to diversify technology transfer from the civilian area to the defense industry and ensuring the technological security

Forecast of long-term socio-economic development of the state

Figure 1:
The methodology of Scientific and Technological Forecasting
Source: Compiled by the authors

and other programs on related themes of forecast studies, as well as programs implemented abroad,

3) «Background» forecast data based on the contextual search and multidimensional analysis of Internet resources, and

4) The results of a targeted survey of the expert community representing industry centers of competence in the area of science, engineering, and technology, general designers in the most important areas of the technology development, heads of top priority technological areas, opinions of experts from leading scientific organizations of the Russian Academy of Sciences, higher schools, defense enterprises.

In order to prepare the results of the factual processing of retrospective data on the development of science, engineering, and technology, a comprehensive analysis is carried out in the following areas:

- Machine analysis of Internet resources, identification of global technological trends,
- Assessment of the achieved (current) level of technology development based on the generalization of the data from defense industry enterprises passports,
- Assessment and forecast of the results of scientific, engineering, and technological development programs according to the data of the responsible federal executive bodies (RFEB) and the current state of fundamental science and HR training.

To perform the work in these areas, the well-known methods of extrapolating trends, the Online-Techcast technology, and modern methods for searching and processing forecast information in Big Data are used.

The hypothesis of the study is that the use of TRIZ instruments when forming and verifying scientific and technological forecasts should improve the quality of the forecast. Such basic characteristics characterize the quality of the forecast as reliability, accuracy, and veracity (see Figure 2).

Figure 3 shows the algorithm for using TRIZ instruments when forming scientific and technological forecasts.

TRIZ instruments are quite fully described in the literature (see Figure 4). Their use for the formation and verification of scientific and technological forecasts are peculiar by the fact that when forming forecasts, a systematic approach and a multiscreen thinking scheme, as well as instruments for creating technical solutions, such as techniques for resolving technical contradictions, an ideal end result, substance-field analysis, standards, and the algorithm for solving inventive problems are used. The obtained new technical solution to the problem is subject to the functional-cost analysis. This ensures the formation of a high-quality forecast at a high scientific and technical level because the use of TRIZ instruments in forecasting will allow experts to develop forecasts that can be patentable and highly efficient.

The formed scientific and technological forecast is then discussed and verified in the relevant centers of competence that are the leading organizations in the area of science, engineering, and technology under study.

The verification of forecasts is a special procedure that involves determining the degree of reliability, accuracy, and validity of the forecast. Direct verification involves the development of the forecast using a method that differs from the one used initially. The authors offer to use the TRIZ and technical systems development patterns as such method.

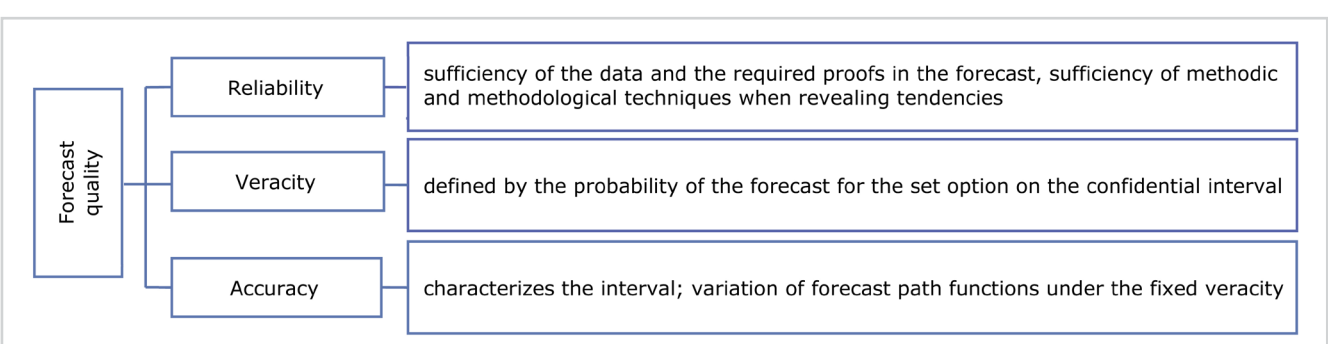

Figure 2:
Main Characteristics of the Forecast Quality
Source: Compiled by the authors

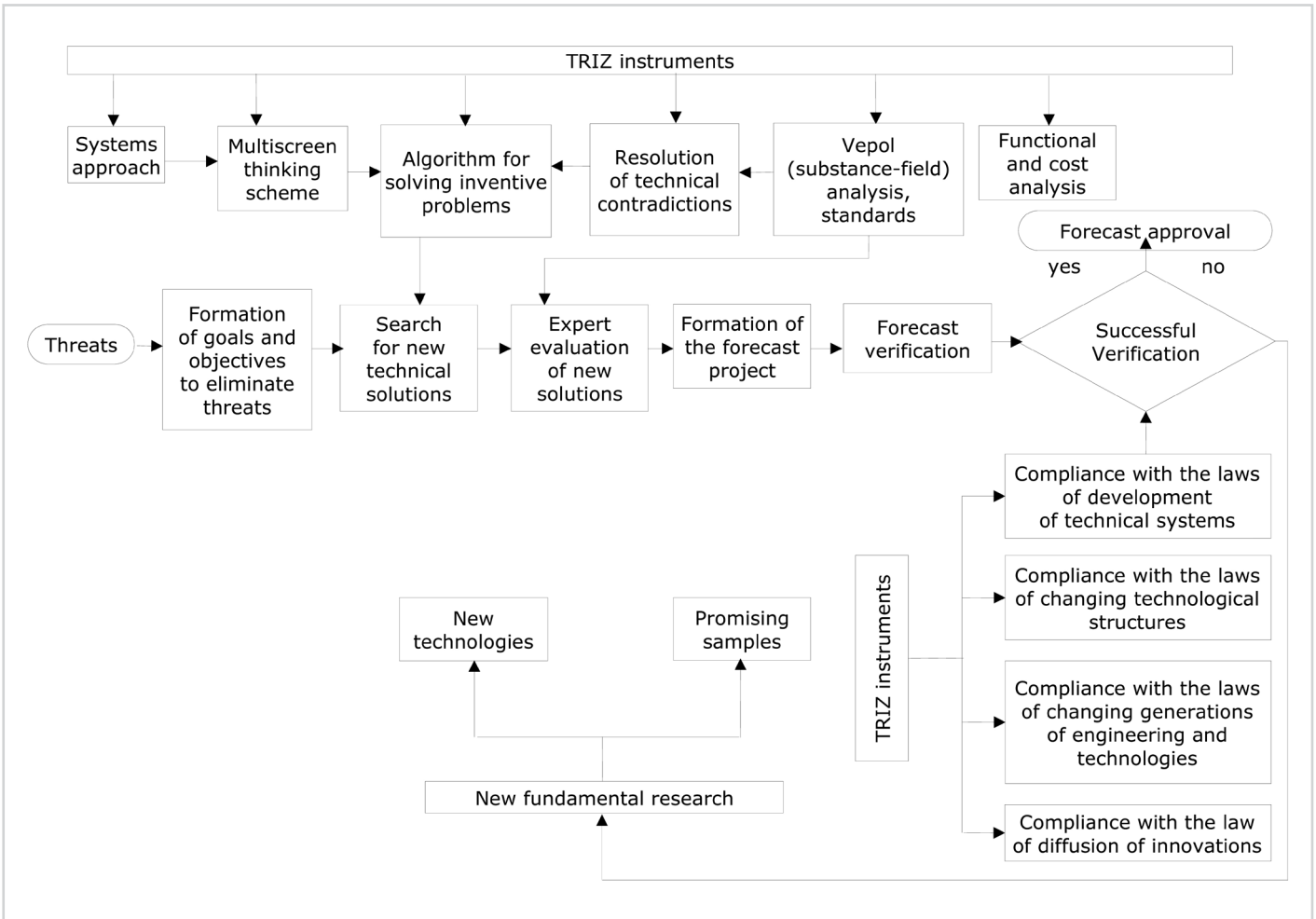

Figure 3:
Algorithm for Using TRIZ Instruments when Forming Scientific and Technological Forecasts
Source: Compiled by the authors

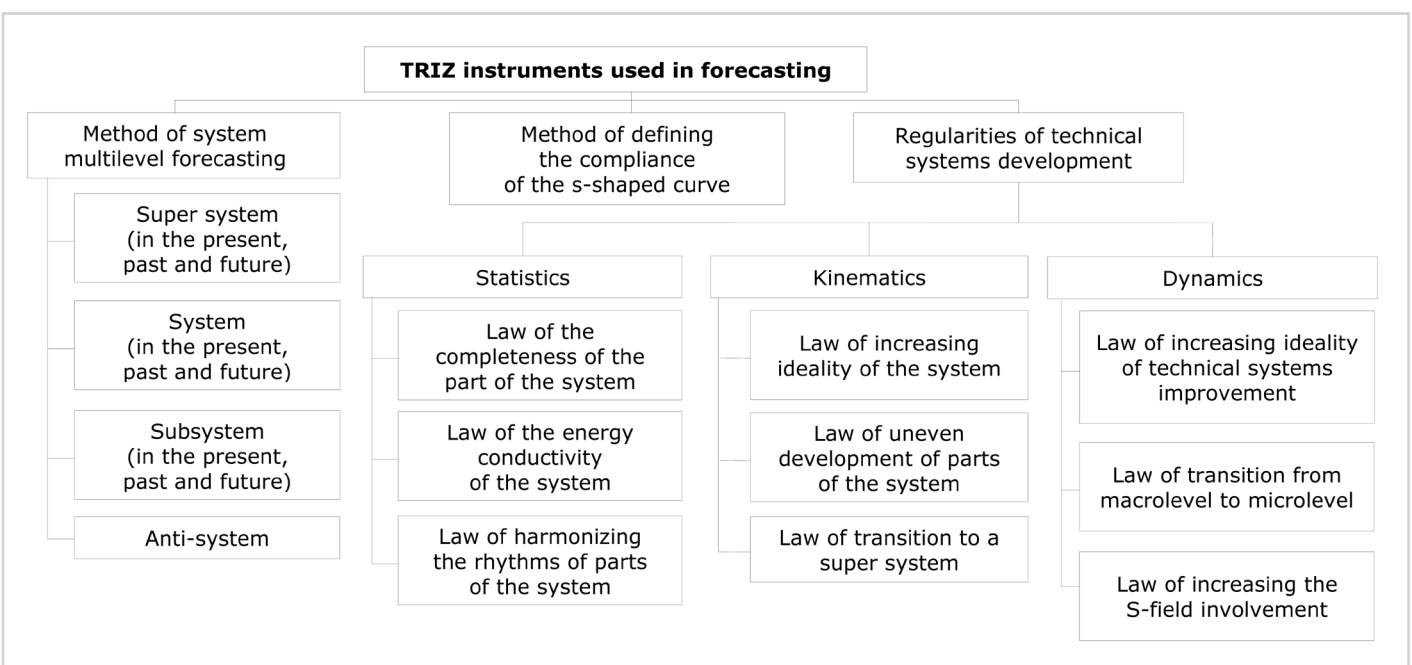

Figure 4:
TRIZ Instruments Used in Forecasting
Source: Compiled by the authors

When verifying the formed forecasts, other TRIZ instruments are used. They reflect the general laws and patterns of science, engineering, and technology development and the laws of innovation. These include LTSD, the laws of changing technological structures, the laws of the evolutionary development of engineering and technology, laws of changing generations of engineering and technology, and the laws of diffusion of high and critical technologies (Da Silva et al., 2020; Feng et al., 2020; Wang and Dong, 2021).

In order to carry out the system analysis of the forecast object, a multiscreen thinking scheme or a system operator can be used. It is described in work (Nagimov et al., 2018; Feng et al., 2020; Jia et al., 2021; Golubev et al., 2017; Sheu et al., 2020).

It makes it possible to see the relationship of variable elements, which is especially important when formulating a task or a problem. The system approach helps to solve not only technical but also economic problems, and at the same time, many technical problems are solved by using organizational methods.

The scheme works as follows. The forecast is formed on the basis of the expert survey method. Then the forecast is transferred to the supersystem or subsystem. Thus, the vertical forecast is formed. Afterward, the horizontal forecast analysis is carried out: past, present, future. At the same time, one forecast expands or clarifies another. Based on the iterative step-by-step forecast, the system of interrelated forecasts that experts can work with is formed.

3. Results

Modern software products and information about their development have the following features. It is possible to find out the year of development of all types of software. Requests about all types of software are regularly made in search engines. If one assumes that software (a parameter characterizing this development) is developed along the S-shaped curve, the starting point will be known - this is the year of this software creation.

Let us suppose that the number of requests in the search program http://wordstat.yandex.ru is an indirect parameter characterizing the degree of software distribution. In that case, it is possible to determine one more point on the S-shaped curve of the requests for a certain software. It is possible to consider the fact that the logistic equation (S-shaped curve) is analytically described by the above formula. For example, the authors compare the development (prevalence) of file formats for text editors: doc, docx, and pdf (Table 1 and Figure 5).

Figure 5 shows the logistic curves made on the basis of the obtained information.

This approach can be used to forecast not only software but also other types of systems.

The logistic curve suggests that when creating new and improving the existing TSs, it is necessary to take into account the sequence of stages. It is impossible, for example, to pass from the first stage to the third one, and omit the second stage because it will be a failure.

Table 1:
Information about appearance of text editors with various file formats

The file format of the text editor	Year of appearance (appearance frequency – zero)	Appearance in February 2020 (thousand per month)
PDF	1991	850
DOC	1993	320
DOCX	2007	70

Source: Compiled by the authors

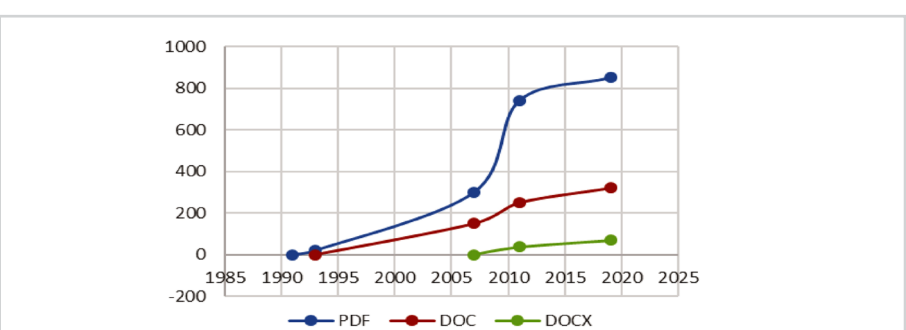

Figure 5:
Formation of the curves on distributing requests by file formats
Source: Compiled by the authors

The TS life is subject to the laws. This means that since the occurrence of new TS, it is possible to draw up a plan for its development. A mature system is characterized by conflicts with the environment. Thus, in the 1920s, no one thought that the rapid increase in the number of cars would lead to the pollution of the environment. Now it is necessary to solve these urgent problems, although it was possible to start solving them half a century ago. A similar situation is developing today with laser technology. Quantum optics is more and more applied in various areas, and the power of generators is growing rapidly, which causes chemical reactions in the air and the formation of harmful compounds. Thus, today it is necessary to forecast, set, and solve tasks on preventing almost invisible laser pollution of the atmosphere.

According to the forecasting studies, the development of methods and principles for forming intelligent control systems for mobile robotic complexes' operation will be an urgent problem in the long term. This forecast corresponds to the law of displacing a person from a TS and, therefore, can be considered quite correct.

The law of displacing a person from TS is clearly manifested when forecasting the creation of uncrewed aerial vehicles and submarines.

4. Discussion

The use of TRIZ instruments, in particular the logistic curve, for forecasting the software development was tested (Jia et al., 2021). The obtained results are consistent with the hypothesis of the study that the use of TRIZ instruments when verifying scientific and technological forecasts helps to improve the quality of forecasts due to the development of their creative imagination and the potential of experts, as well as because the results of the forecasts are based not only on the subjective opinion of the expert but also correlate with the objective laws of the TSs development that do not depend on their opinion. This certainly helps to improve the quality of forecasts.

The study was limited to scientific and technological forecasting, although the capabilities of TRIZ instruments can be extended to socio-economic forecasting because the LTSD can be distributed and transformed to identify the laws of economic systems development. The study has proved the possibility and feasibility of using TRIZ instruments to forecast science, engineering, and technology development.

In order to practically use the TRIZ instruments when forming scientific and technological, and socio-economic forecasts, it is necessary to clarify and adjust the forecasting methods currently used for these purposes. It is natural that for each area of forecasting, changes and additions in forecasting methods based on the TRIZ will be defined by these directions' peculiarity.

5. Conclusions

Thus, the methodology for solving inventive problems is applicable for forecasting the development of science, engineering, and technology. Moreover, the use of TRIZ instruments for scientific and technological forecasting requires professional skills in applying and adapting TRIZ instruments to the peculiarities of scientific and technological forecasts. At the same time, the TRIZ methods make it possible to solve the problems of scientific and technological forecasting based on the system approach. The rule of «the supersystem entry» as applied to the scientific and technological forecast suggests that in order to assess the results of the forecast at the system level, it is necessary to go to a higher level of this system.

The integration of the TRIZ instruments in the state system for determining top priority technological areas will reduce errors in choosing the number of promising technological and technical areas that will make up the basis for the formation of new models and technologies.

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