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Mathematic model of production technology transformation

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Abstract. Modeling the processes of creating and improving production technologies is one of the most important tasks in the sphere of providing competitiveness for enterprises, branches and complexes in the strategic aspect. For the moment, the model Gartner's Hype Cycle is used for the specified tasks, which describes changes in expectations from technologies in the course of a determined period of time from the moment when this technology appears to the moment of its complete development. At that, the results of analysis of literary sources on the explored theme speak about the lack of effective instruments for mathematical description of the process of developing and implementing production technologies in the practice of industrial enterprises. The given circumstance has validated the necessity of working out a mathematic model for the specified process; its elements should have a determined functional designation and it enables comparing the processes of development of different technologies.

1 Introduction

In modern conditions of development of the world economy and organization of functioning of innovative production systems on the basis of progressive digital technologies is the key factor for providing the state competitiveness in the respective branches of industry and economy. At that, the significance of every separate technology is determined by the spheres of applying this technology, the scales of respective markets and the volumes of resources which the supposed clients possess, rather than by the cost and labor inputs for implementing this technology. Currently, to describe the process of development and implementation of progressive technologies Gartner's hype cycle model [1] and Arthur D. Little's technology lifecycle model [2], also known as McKinsey's S-curve model, are used. Despite extensive application of the specified instruments in the wide sphere of fields (metal-rolling industry, manufacturing of microelectronic integrated circuits, etc.) including the sphere of planning scientific-research works, currently, instruments for mathematical description of the process of development and implementation of progressive technologies are practically absent. This problem is responsible for relatively low adequacy (objectivity) of the indicated models and, consequently, low effectiveness of their use for solving a wide range of applied tasks. The specified circumstance has determined the necessity of creating (based on the Gartner's hype cycle model) a mathematic model of the process of development and implementation of a

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progressive production technology which will be a frame for creating methods of solving application tasks for justifying the characteristics of the indicated process with different variants of structuring primary data.

2 Review of literature

At the initial stages of research a review of scientific works on the considered subject was made.

The generalized mathematical description of the Gartner's hype cycle model represented in the works of the scientists M. Steinert, L. Leifer [2], J. Fenn, M. Raskino [3] and others presupposes distinguishing in its composition a respective curve (which describes functional dependence of expectations (the technology development characteristics) from the time factor) of two components:

- Hype curve (in the form of a bell) which describes primarily positive and, as a rule, irrational perception of the considered technology in regard to perspectives and opportunities expected from it in the absence of concrete results of complete or partial implementation of the ideas which constitute the basis of the technology;
- S-curve which describes the maturity of the considered technology which, in its turn, is defined by the effectiveness of the performed experiments and, as a consequence, by the volumes of the respective investments.

It is important to note that the resulting curve which corresponds to the Gartner's hype cycle models and includes the above mentioned components in the general case is not the sum of the latest and is described by each component separately in different sections of the time factor scale: in the primary section the resulting curve repeats the form of the Hype curve, in the next section – the form of the S-curve. At that, the local minimum of the curve within the framework of the Gartner's hype cycle model (see Fig. 1) corresponds to the point of transition between sections.

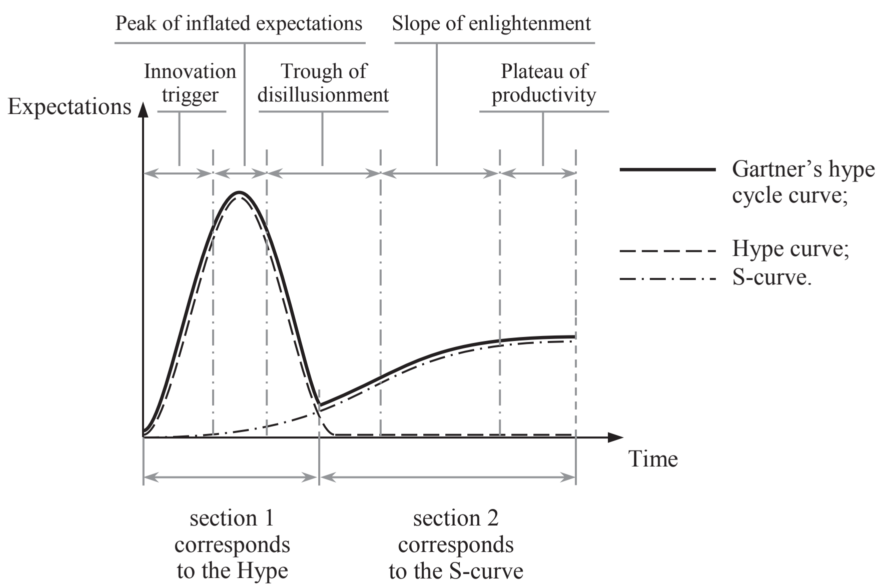


Fig. 1. The generalized mathematical description of the Gartner's hype cycle model.

A significant number of works is devoted to applying the Gartner's hype cycle model for estimating the current condition and forecasting the future development of informational technologies [4] including those in the sphere of education [5, 6], business [7–9] and entertainment [9], technologies for manufacturing innovative production – graphene [10], metamaterials [11], superconducting materials [12], transport vehicles with hydride engine and on fuel elements [13], fuel cells for stationary units [14, 15], etc. At that, for qualitative measuring of expectations from the technology and in every separate case one indicator is used, as a rule, which is objectively estimated on the basis of information obtained from reliable sources. As the specified indicator within the framework of the corresponding studies the specific (in the period of, as a rule, one year) quantity is considered in current events newspapers [7, 12, 13, 15, 16], the quantity of popular-scientific publications [4, 14], the quantity of the registered patents [13, 14], the distribution of the number of studies on separate kinds of production and technologies [8], the quantity of queries in the search systems of the Internet (Google, Yahoo, etc.) [13].

We should particularly distinguish the works of M. Steinert and L. Leifer [2] and also J. Kim et. al. [17] that contain the results of analysis of the large quantity (more than 40 in use [2], about 500 in use [17]) of applied and developed technologies in the field of power industry, public services, etc., in the part of correlating the stages of technologies development (in accordance with the Gartner's hype cycle model) with the concrete time periods.

However, it is important to mention that in a number of works [5, 6, 9–11] application of the Gartner's hype cycle model for estimating the current condition and the development prospects of technologies under research is carried out expertly (without analyzing any quantitative factors), on the basis of the published data of the former publications.

A relatively small quantity of works is devoted to the questions of mathematical description of separate components of the Gartner's hype cycle model. Thus, H. Sasaki in his research work [18], by analogy with the work of M. Steinert and L. Leifer [2], suggests to describe the Gartner's hype cycle model in the form of two components based, relatively, on non-cumulative (a bell-type curve) and cumulative (S-curve) values of the indicator of expectations from the technology, and in the research work by M. Fries and M. Lienkamp [19] analysis of dependencies of the effectiveness indicator for realization of the technology on the time factor (S-curve model) with the aim of determining the type and characteristics of the corresponding mathematic model – approximating function – is carried out. The main disadvantages of the above-mentioned research works [18, 19] are the primary inconsistency (compliance with different scales) of the values of the model components, the difficulty of qualitative interpretation of coefficients of approximating functions, and also the lack of distinct functional correlation (based, for instance, on the principle of summing up or multiplication) of the common indicator of expectations from the technology with its components.

Thus, according to the results of analysis of the literary sources regarding modeling the processes of developing and implementing technologies with the use of the Gartner's hype cycle model the following conclusions were made:

- a significant number of works concerning applying the Gartner's hype cycle model to exploring the processes of development of separate technologies does not address the questions of justification of the characteristics of mathematical interpretation of the model, and it contains only qualitative justification of the current or future stages of technology development on the basis of either expert estimation or the results of statistic analysis of quantitative data of the publishing or patent activity;

– a relatively small number of the developed mathematic models which describe the process of working out and implementing the technologies in accordance with the Gartner's hype cycle model have a relatively low practical significance and a limited sphere of application on account of the difficulty of interpretation of separate model characteristics.

3 The description of the mathematic model

The results of analysis of scientific publications on the topic under consideration represented in the previous section have defined the necessity of creating (within the framework of the next research stage) a mathematic model of the process of developing and implementing the production technology into the activity of industrial enterprises, based on the Gartner's hype cycle model. The main provisions of the worked out model are as follows:

– the mathematic model describes the process of working out and developing the technology of producing innovative materials and products which begins at the moment the idea of creating the material (product) appears and ends at the moment of realizing the technology in the full-scale production (single-piece production, batch production, mass production);
– the model represents the correlation of the characteristics of expectations from the technology with the time factor; the correlation has analytical and graphical description; both the quantitative categories are measured in percents, correspond to the range of values from 0 to 100;
– the time factor measured in the limits from 0% (the idea appears) to 100% (full-scale production is organized), is identified with the indicator of completeness of the technology development (Technology Development's Completion Indicator – TDCI);
– the main characteristics of the technology expectations – the generalized expectation indicator (Aggregate Expectation Indicator – AEI) – represents a sum of two components (secondary characteristics) – the indicators of subjective expectation (Subjective Expectation Indicator – SEI) and the indicators of objective expectation (Objective Expectation Indicator); the units of measure and the ranges of changing of the SEI и OEI values are analogous to AEI;
– SEI characterizes hypothetic expectations (from the studied technology), not confirmed by objective results of the undertaken studies – practical experiments, procedures of prototype or physical modeling, implemented pilot projects, etc.;
– OEI characterizes objective expectations confirmed with the cumulatively gathered results of the undertaken studies.

Analytical dependencies of the values AEI, SEI and OEI on the values of the time factor or TDCI are described by the determined mathematical expression of the form

$$E_{\Sigma}(t) = E_{\text{sub}}(t) + E_{\text{obj}}(t), \quad (1)$$

$$E_{\text{sub}}(t) = a_1 \cdot t \cdot b_1^{c_1 \cdot t}, \quad (2)$$

$$E_{\text{obj}}(t) = a_2 \cdot t \cdot b_2^{c_2 \cdot t}, \quad (3)$$

where E_{Σ}, E_{sub}, E_{obj} – relatively AEI, SEI, OEI, %;

t – time factor or TDCI, %;

$a_1, b_1, c_1, a_2, b_2, c_2$ – the parameters of functional dependencies of SEI and OEI on the time factor (TDCI), their designation is described in Table 1.

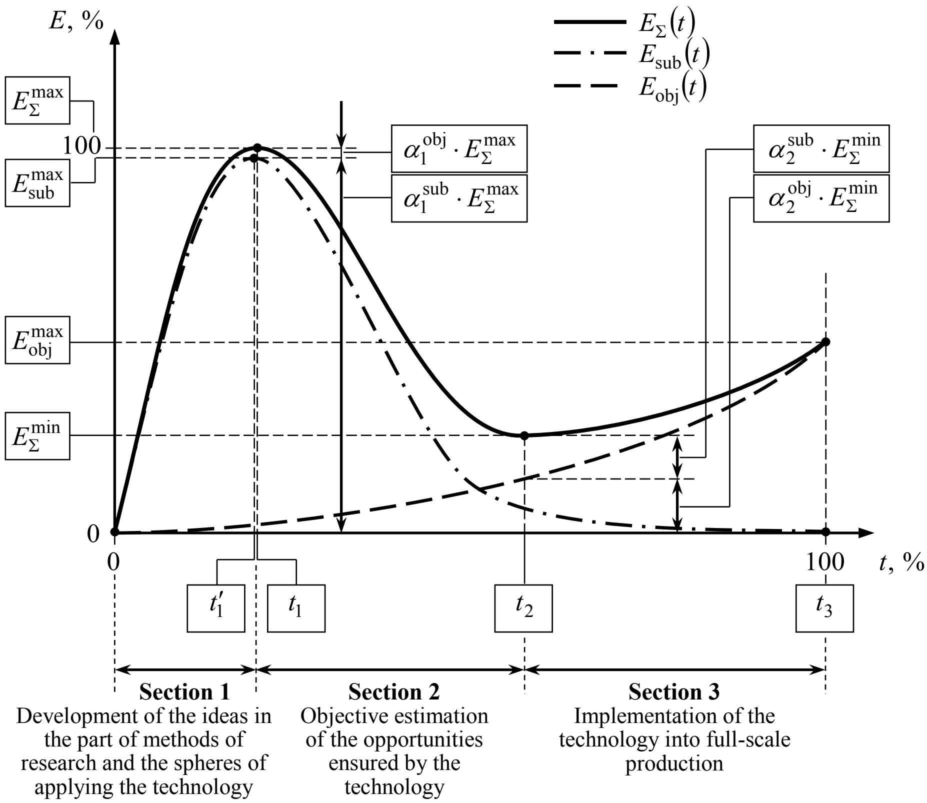
Graphic interpretation of the specified dependencies is demonstrated in Fig. 2.

Thus, the diagram of dependency of AEI on TDCI which characterizes the process of developing and implementing production technology into the activity of industrial enterprises can be represented in the form of a sequence of sections identified with the separate stages of the considered process.

1. Development of ideas in regard to research methods and spheres of application of the technology – the number of the formed hypotheses grows faster than the number of the tested hypotheses on account of the small number of the studies undertaken.
2. The objective estimation of the opportunities ensured by the technology – the number of the formed hypotheses virtually does not change (the limits are reached), at this the greater part of the growing number of tested hypotheses is constituted by negative (from the perspective of technologies development) results.
3. Implementation of the technologies in full-scale production – the number of tested hypotheses approaches the total number of formed hypotheses (and finally reaches it), at this, the part of the tested hypotheses with a positive result grows faster than the part of the hypotheses with a negative result.

Table 1. Description of parameters of functional dependencies of SEI and OEI on the time factor (TDCI).

No. of item	Parameter name	Indication	Designation	Note
1	The coefficient of the standard growth of SEI	a_1	Displays by what value in fractional expression the expectations from the technologies would increase in case the TDCI is increased by 1% if all the proposed hypothetic judgments turned out to be true	$a_1 > 0$
2	The coefficient of cumulative decrease of the SEI growth	b_1	Displays how many folds the standardly increasing SEI value decreases taking into account the accumulated data on the results of the undertaken studies in the part of objectively estimated opportunities ensured by the technology	$b_1 > 0$; $b_1 < 1$
3	The coefficient of influence of the TDCI on cumulative decrease of the SEI growth.	c_1	Displays how many folds the break between the standardly growing and the actually reached the SEI values increases in case the TDCI increases by 1%	$c_1 > 0$; $c_1 < 1$
4	The coefficient of the standard growth of the OEI	a_2	Displays by what value in fractional expression the expectations from the technologies would increase in case the TDCI increased by 1% if all the succeeding studies were undertaken independently of the preceding ones.	$a_2 > 0$
5	The coefficient of cumulative increase of the OEI growth	b_2	Displays how many folds the standardly increasing the OEI value increases taking into account the studies already undertaken in the studies which are being undertaken	$b_2 > 0$; $b_2 < 1$
6	The coefficient of influence of the TDCI on cumulative increase of the SEI growth.	c_2	Displays how many folds the break between the standardly growing and the actually reached the OEI values increases in case the TDCI increases by 1%	$c_2 < 0$; $c_2 > -1$



Note:

t_1', t_1, t_2, t_3 –	TDCI values corresponding to the characteristic points of the dependencies diagrams $E_{sub}(t)$, $E_\Sigma(t)$;
$E_{sub}^{max}, E_{obj}^{max}, E_\Sigma^{min}, E_\Sigma^{max}$ –	SEI, OEI, AEI values in the characteristic points of the dependencies diagrams $E_{sub}(t), E_\Sigma(t)$;
$\alpha_1^{sub}, \alpha_1^{obj}, \alpha_2^{sub}, \alpha_2^{obj}$ –	parts of SEI and OEI in the maximum and minimum AEI values.

Fig. 2. Graphical interpretation of the developed mathematic model

4 Conclusions and directions of the further studies

Thus, the developed mathematic model describes the key peculiarities of the process of development and implementation of the production technology and its components have a concrete functional designation (qualitative description) that helps to use the developed instrument for solving a wide range of tasks which, in their turn, can be divided into two groups:

– the tasks of justifying the characteristics of the processes of developing and implementing the production technologies into the activity of industrial enterprises with the aim of their further comparative analysis in the historical aspect within the framework of retrospective studies;

- the tasks of justifying the characteristics of the processes of developing promising production technologies with the aim of forming possible schemes of developing the technologies in future.

At the further stages of research it is planned to work out methods of justifying the characteristics of the suggested mathematic model within the framework of the two categories of tasks mentioned above.

It is suggested to implement these methods as exemplified by the technologies of manufacturing innovative materials (metamaterials, thermoelectric materials, bioceramics, etc.) and also by the new ways of constructing (including additive technologies, 3D-printing, etc.) necessary for the most effective functioning of innovative production systems with the use of advanced digital technologies [20].

The results of study are published within the context of implementing the project "Working out the estimation of realizing the priority of scientific-technological development specified in item 20a of the Strategy of scientific-technological development of the Russian Federation (transition to advanced digital intellectual production technologies, robotic systems, new materials and methods of constructing, creating the systems of processing large volumes of data, computer-aided learning and artificial intellect)", financed by the Ministry of Education and Science of the Russian Federation out of the subsidy within the framework of the Federal Program "Studies and workings according to the priority directions for developing the scientific-technological complex of Russia for 2014-2020", Action item 1.1, the Agreement on the Grant Policy No. 14.572.21.0008, October 23, 2017, unique identifier: RFMEFI57217X0006.

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