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## PRODUCTION IN THE CONDITIONS OF NBIC-CONVERGENCE: THE ROLE OF SOCIO-EMOTIONAL AND COGNITIVE SKILLS

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### *Abstract*

The purpose of the article is to study the characteristic features of the socio-emotional and cognitive skills development in the industries based on NBIC-technologies; improvement of NBIC-convergence processes by means of human factor management. It is proved that one of the key factors determining conditions of creating advanced manufacturing technologies based on NBIC convergence, is the behaviour of researchers, developers and operators of such technologies. At the same time, the very important factor is the socio-emotional and cognitive skills of employees. This standpoint is confirmed by the results of some technologies and production systems analysis where NBIC-convergence has been partly implemented. This is also being proved in the article by analysing the processes of convergent technologies creation, their opportunities and threats related to their distribution. The analysis of the forms of human participation in the creation of new technologies has shown that the effectiveness of these processes increases significantly with a harmonious combination of creative human activity (which is largely determined by the social-emotional and cognitive skills of workers) and methods that allow objectively evaluate the techno-economic decisions this basis to optimize the processes and results of developments



**Keywords:** Cognitive skills, human capital, NBIC-convergence, production systems, social capital, socio-emotional skills.

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## 1. Introduction

The main tendencies of the production systems development in modern conditions are related to the NBIC convergence and reindustrialization. Roco and Bainbridge (2004) are recognized as the founders of the NBIC convergence theory. They discovered an interaction and mutual influence among information technologies, biotechnologies, nanotechnologies and cognitive science, which was determined as "NBIC convergence". This term became widely used and well known very soon.

The theory of reindustrialization has been developed in the works of Rifkin (2011), Marsh (2013) and Anderson (2012). Their concepts essence is possible replacement of traditional centralized business models with new structures. These structures are to be based on horizontal interaction between the economic agents. This concept is subject of numerous nowadays investigations devoting to the issues of technologies that resemble natural ones (Collinge, 2001).

## 2. Problem Statement

### 2.1. Problem of Preventing Risks and Threats from NBIC Technologies Spreading.

Numerous researchers dedicate their works (Simondon, 2001; Nishimoto et al., 2011) to risks and threats that may cause during wide spreading of these technologies. The most dangerous thing in this situation is how technologies may affect a human being, and change its biological and psychological essence.

It is obvious that working out of NBIC technologies and NBIC-based production systems requires new methodologies and instruments of process management and control. A certain part of these methods and tools is related to the socio-emotional and cognitive skills of these production systems workers.

### 2.2. Problem of Creating Human-oriented Production Systems Based on NBIC technologies

Many threats of NBIC technologies using can be minimized if production systems will be created as human-oriented ones.

Creating and development of the human-oriented manufacturing required numerous researches and design projects. These researches and projects were taken up in the second half of the 20 century. It was the final period of the Industrial Age and the beginning of deindustrialization.

For example, the well-known work by Tomotoshi, Shinya, & Tatsuya (2009) is based on the results of Toshiba Corporation's practical work. Author analyzes the production functioning as the derivant of human factor's acting. The attention is also paid to the kinds of influences that product lifecycle management (PLM), supply chain management (SCM) and project management (PM) bring to bear upon production actions.

### 2.3. Problem of Human and Social Capital Increasing in the Context of NBIC Convergence

As it was shown in our previous studies (Kolbachev & Kolbacheva, 2018), under the conditions of NBIC convergence processes human capital extends if new technologies and production systems are created. It extends much more than if traditional technologies and production systems are used.

It is appropriate to pay attention to the research by Dubrovski (2013). He analyzed the ways in which the increasing processes of mutual influence between the informational technologies, biotechnologies,

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nanotechnologies and cognitive sciences, and their galloping development affect a social sphere. He is also the author of NBIC convergence concept.

## 3. Research Questions

Taking into consideration the prospects of NBIC technologies development and above mentioned problems, it is possible to determine the research questions, which solution is necessary to achieve the main purpose - to identify the social, emotional and cognitive skills required in developing NBIC technologies and designing production systems while minimizing risks and threats associated with NBIC convergence.

The research is dedicated to the next questions:

- - analysis of human factor management methods in the technologies development and design of production systems, selection of the most suitable methods for NBIC technologies and NBIC-based production systems development;
- - determination of a specific role of social and emotional skills of employees involved in the creation of NBIC technologies and NBIC-based production systems, the formation of proposals and management methods;
- - determination of a specific role of the cognitive skills of employees involved in the creation of NBIC technologies and NBIC-based production systems, the formation of proposals and management methods;
- -identification of production organization methods while creating NBIC technologies and NBIC-based production systems.

## 4. Purpose of the Study

To identify the social, emotional and cognitive skills required in developing NBIC technologies and designing production systems based on them to minimize risks and threats associated with NBIC-convergence.

## 5. Research Methods

In the recent years it was published a great number of papers, which authors analyse actual problems of working out convergent technologies and of determining these technologies' place in nowadays engineering and science. Philosophers or other specialists in humanities present major of them (Sundmaeker, Guillemin, Friess, & Woelffle, 2010).

In context of this work, the interest of specialists in humanities in NBIC convergence is a positive tendency. The reason for such point of view is that their research results are applicable for research and development, and for human factor problem solving during working out of the convergent technologies.

### 5.1. Research Methods of Human Factors Influence on the Technology Development Processes

The role of cognitive and socio-emotional skills in the creation of various production systems (including the context of NBIC convergence) can be considered as a special case of the issue of the human factor role in the technology creation.

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Most of the known studies on human factors in production and business are based on the ideas laid down in classical works, among which, in our opinion, the most striking is the Rowntree's (1921) book.

There are known modern works in which the role of the human factor in the development of production is associated with the amount of human capital necessary for the implementation of development projects and growing as a result of these projects (Kucharchikova, 2011; Lucas, 1988; Mankiw, Romer, & Weil, 1992).

In practice, the human factor under the conditions of reindustrialization is the subject of a study (Kontorovich, 2017), which examines the new skills of workers required in the early 21st century.

The importance and specificity of the social skills of workers in the context of reindustrialization are shown in the studies of Deming, (2017), Liu & Grusky, (2013) who established that employment and wage growth were after 2010 the most favorable in occupations that require possessing developed social skills and a high level of cognitive skills.

### 5.2. Research Methods of Cognitivistics in the NBIC Technologies Creation Management

Speaking about the cognitive skills of a person in the context of NBIC-convergence is more correct, in our view, to bear in mind the use of cognitive achievements in general.

Making cognitive science one of the fundamental components of NBIC convergence is impossible without paying a special attention to a human factor as to a means of generating new knowledge, cognitive studies and work in the related fields of science. Traditionally the term "cognitive science" is interpreted as the interdisciplinary, scientific study of the mind and its processes. It examines the nature, the tasks, and the functions of cognition (in a broad sense) (Fodor, 1998). A great number of researches were carried out in this field in the last decades (Jackendoff, 1987; Isac & Reiss, 2013), and results of them are important for the development of cognitive science. However, most of them are formally the part of other spheres of science. That is why the cognitive science is to be characterized as the interdisciplinary field of knowledge.

Cognitive scientists work collectively in hope of understanding the mind and its interactions with the surrounding world much like other sciences do. The field regards itself as compatible with the physical sciences and uses the scientific method as well as simulation or modeling, often comparing the output of models with aspects of human cognition. Similarly to the field of psychology, there is some doubt whether there is a unified cognitive science, which have led some researchers to prefer 'cognitive sciences' in plural.

These features of the cognitive science make using its methods in the most efficient way for working out of NBIC technologies a complicated task. In other words, to use the methodology of cognitive science as a "growth factor" of NBIC convergence, the components of this science are to become convergent themselves. However, in the field of designing machines, designing structural structures and in other applied areas, in the last decade of the last century, techniques for the formation of technical solutions have been created that provide a reliable basis for the subsequent use of cognitive methods and the development of cognitive skills of developers.

The most well-known of these results is a behaviourist methodology (Staddon, 2014; Mace, 2010) and some other applied methods that give a possibility to formalize processes of creating original knowledge and working out engineering solutions. The theory of inventive problem solving (TRIZ) is one of the most efficient methodologies among them It was created in the second half of 20th century in Soviet

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Union by Altshuller (1984), and then developed by his followers Zlotin, Zusman, & Hallfell (2011). These methodologies and instruments are now widely used by corporations in the USA, e.g.

It also looks appropriate to use the method of generating the engineering decisions that was worked out in the end of 20th century by Polovinkin (1988), and developed by his followers (Ukustov, Fomenkov, & Polovinkin, 2013) in the recent decades. In authors' opinion, this methodology looks very interesting for the research, because its main idea is creating human-oriented production systems (so-called "blagodatnye systems") basing on the canons of Christian religion.

### 5.3. Research Methods of Socio-emotional Skills and Opportunistic Behavior Minimizing

A lot of research has been devoted to the study of socio-emotional skills in the last three decades. It should be noted the work of CASEL (2008), Deci & Ryan, (1985), Durlak, Weissberg, Dymnicki, Taylor, & Schellinger (2011), Griffin, McGaw, & Care (2012) and John & Srivastava (1999). In many of these works, the development of social and emotional skills is associated with modern technological progress.

In particular, in the well-known work (Griffin et al., 2012) it was proposed the term "*21st century skills*". The 21st century skills are the skills that along with substantive knowledge ensure the coordination of the actions of researchers and developers of different specialties and the integration of various spheres for success in activities. 21st century skills represent a wide range of competences including the ability to learn and innovative skills: creativity, critical thinking and problem solving, participation in communication establishing and collaboration (including project management).

Many researchers of social and emotional skills associate them with the need to prevent opportunistic behavior when creating new technologies (Hirshleifer, 1973). Chances for opportunistic behavior of individual participants in the development of NBIC technology are significantly reduced in case of using good-quality tools for evaluating the development (their separate parts), which allows quantifying the qualitative characteristics of a particular technical solution.

At the same time, an integrated assessment is important, which makes it possible to compare development with various particular parameters. In particular, this can be done by assigning the analyzed development to a certain technological way.

In this case, it is inevitable to use the solution of the administrative task to select the optimal technological variant of methods and tools borrowed from the natural and technical sciences.

## 6. Findings

### 6.1. Application of TRIZ Methods for Research and Design.

Cognitive skills combined with the application of TRIZ methods can be effectively used to formulate technological solutions during the development of NBIC technologies and NBIC-based production systems (including designing special technological equipment).

As a complement to TRIZ, when developing NBIC-technologies, methods can be applied: «brainstorming»; «C-K design»; «Lateral thinking»; «Method of focal objects»; «Morphological analysis» is a method for exploring all the possible solutions to a multi-dimensional, non-quantified complex problem (Ritchey, 2006).

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Their application is effective in case when employees have not only developed cognitive but also social and emotional skills, as it suggests active interaction between different professions representatives.

### 6.2. Methods of Opportunistic Behaviour Preventing

In Section 5.3. it has been shown that the main result of using social and emotional skills in the development of NBIC-technologies is to prevent opportunistic behaviour of participants in research and design.

Most authors who investigated the features of opportunistic behaviour in innovative activities (Williamson, 2002; Akayev & Rudskoy, 2014; Highsmith & Highsmith, 2002) suggest that the main reason of opportunistic behaviour is an information asymmetry due to the subjectivity of assessments of the technical and managerial decisions quality while implementing technology and machine projects.

The probability of opportunistic behaviour is significantly increased due to the fact that various project participants have their own commercial interests. Among the participants of innovative projects there are engineering companies that act as intermediaries and provide consulting services. Chances for opportunistic behaviour (on the part of customers, developers and engineering companies) are significantly reduced in the case of using good tools in evaluating developments, which allows quantifying the qualitative characteristics of a particular development. At the same time, an integrated assessment is important, which makes it possible to compare development with various particular parameters. As it was shown in Section 5.3, this can be done by assigning the analyzed development to a certain technological paradigm.

In the said situation, it seems appropriate to use and develop a model that was presented in our earlier work (Kolbachev, 2014). The improved variant of model is presented in Fig. 1. Each of model's parameters shows a level of one or another NBIC factor's development. If the technology meets all requirements of NBIC concept, it also meets the requirements of the seventh technological paradigm.

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<table>
<tr><th rowspan="2">Techno-logical paradigm</th><th colspan="6">Characteristics of the technological order</th></tr>
<tr><th>Basic econo-mic resource</th><th>Dominant management concept</th><th>Level of the infor-mation's materiali-zation</th><th>Dimension scale of the forming processes</th><th>Features of using biological processes for technology</th><th>Features of working out the engineering solutions</th></tr>
<tr><td>1</td><td>Materi-als (natural stuff)</td><td rowspan="2">Basic production management</td><td>15–11</td><td>1–0.2 mm</td><td>Uncontrolled biological processes (ecosystem agriculture and produce processing)</td><td rowspan="4">Working out of the technological solutions is based on trial-and-error method and analogy approach</td></tr>
<tr><td>2</td><td rowspan="3">Energy</td><td rowspan="2">11–10</td><td>100–50 micron</td><td rowspan="2">Partially controlled biological processes are used for auxiliary production</td></tr>
<tr><td>3</td><td>Production management</td><td rowspan="3">50–10 micron</td></tr>
<tr><td>4</td><td>Management of the enter-prise</td><td>9</td><td rowspan="3">Partially controlled biological processes are used for primary production</td></tr>
<tr><td rowspan="3">5</td><td rowspan="4">Infor-mation</td><td rowspan="2">Business management</td><td rowspan="3">8–6</td><td rowspan="3">10–0.5 micron</td><td rowspan="3">Working out of the technological solutions becomes formalized (TRIZ, etc.)</td></tr>
<tr><td>Cost management</td></tr>
<tr><td>6</td><td rowspan="2">Managing the techno-logical efficiency</td><td rowspan="2">5–2</td><td rowspan="2">100–0.1 nanometer</td></tr>
<tr><td>7</td><td>Totally controlled technologies that resemble natural ones are used for primary production</td><td>Human consciousness becomes a part of system that works out new technologies</td></tr>
</table>

**Figure 01.** Model of correspondence between technological paradigms and NBIC factors

### 6.3. Organization of Works on Development of NBIC Technologies and NBIC-based Production Systems

The TRIZ methods and other cognitive methods (described in Sections 5.1 and 5.2), as well as methods for preventing opportunistic behaviour based on the use of workers social and emotional skills can be effectively applied in organizing NBIC technologies and NBIC-based production systems development.

In addition to the above arguments in favour of the importance of social and emotional skills of participants in the processes of creating NBIC technologies, it is necessary to bear in mind the following.

Working out of NBIC technologies and production system requires participation of a great number of specialists, and interactions between them may be intricate. In the same time, existing information environment's dynamism and intensity of involved knowledge's renovation compel to speed up the product development and shorten unproductive losses of time. One of the reasons for such losses is a great number of used standards, norms and other documents that regulate production processes, and these documents' surplus complexity.

That is why it is appropriate to ground organization and managing of working out NBIC technologies and production systems on Agile ideology, also known as Flexible Project Management.

Applying of these methods is a way to decreasing the time for R&D and preproduction. In our opinion, the most efficient way of using presented approach is making it a part of CAx system (first of all,

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such systems as MCAD and EDA) for working out of the NBIC-based production systems' machinery. It may be applied as a part of invariant subsystem of technical and economic parameters for the computer-aided account facilities and for processes simulation (CAE, CAA) (Saaksvuori, 2008).

## 7. Conclusion

The key factors detrmining conditions of creating advanced manufacturing technologies based on NBIC-convergence, is the behavior of researchers, developers and operators of such technologies. At the same time, the very important factor is the socio-emotional and cognitive skills of employees.

It is necessary that the possible negative consequences of NBIC technologies impact on human beings should be evaluated and minimized. Such employee qualities as the ability for teamwork with the different kind of professionals and absence of motives for opportunistic behavior are very important as well. Availability of these qualities are determined by the relevant socio-emotional and cognitive skills of researchers and developers.

The analysis of the human participation forms in the creation of new technologies has shown that the effectiveness of these processes increases significantly with a harmonious combination of creative human activity (which is largely determined by the socio-emotional and cognitive skills of workers) and methods that allow evaluate the techno-economic decisions and optimize the processes and developments results.

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