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High Organizational and Technological Level of Production Systems as a Condition for Economic Leadership

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Abstract The article examines the specifics of the influence of organizational and technological level of production systems on competitiveness of the companies, regions and national economy in general, development of methods of managing organizational and technological level of production systems under conditions of reindustrialization, establishment of Industry 4.0 and NBIC-convergence. The factors affecting the leadership positions of one or other production systems are considered. The importance of application of cognitive methods in the design and management of evaluated production systems is proved.

1 Introduction

The modern era of scientific and technological progress has actualized the problem of the continuous development of machines, the creation of fundamentally new technologies and technological systems. The character of the development of the technosphere encompasses increasingly more recent and more promising areas, enhances the power and intensity of scientific and technological progress. This process is applied to technology and industrial management projects (Roco and Bainbridge 2004; Marsh 2012; Rifkin 2011; Anderson 2012).

Leadership issues in the economy are directly related to the assessment of development level of particular enterprises, business groups and other production systems. The main criterion for determining the position of economic leader are indicators of product output, business value, added value and other output indicators. In this case, the main attention is paid to estimates at the macro- and mesoscale.

However, this approach does not take into account the fact that the conditions, in which modern enterprises and business groups operate, are determined by the ongoing processes of reindustrialization, NBIC convergence, the formation of a new technological paradigm and Industry 4.0. These particular processes determine the conditions and possibilities of creating modern advanced manufacturing and production systems, the presence of which is an indispensable condition for economic leadership.

It is obvious, that corporations following these trends acquire additional competitive advantages and, consequently, the best prerequisites for economic leadership.

The owner of production systems, that meet the requirements of NBIC convergence, takes a significant advantage in the struggle for economic leadership, since in this case he has the upper hand in human and social capital. This is due to the fact that when NBIC technologies are created, human capital increases significantly more than in other cases. This is due to the fact that:

1. New technologies, that meet the requirements of NBIC convergence, are created on the basis of results of fundamental and exploratory research in various fields of science and technology. Such research are an important source of new knowledge in relevant fields.

2. Fairly high complexity of biological (as well as biochemical and biophysical) processes; any processes associated with changes in subjects of labor at the nanosized level, as well as information processes require highly skilled specialists, conducting research and developing technologies. This leads to engagement of highly skilled employees to the new production systems. Besides, while studying and developing, the level of their qualifications increases.

3. The importance of cognitive processes, related to human cognitive activity in NBIC production systems, as well as the use of cognitive methods in generation new technological and organizational solutions improve the cognitive processes management and create methodological basis for the gradual use of artificial intelligence systems. This moment seems especially important, which is discussed in the following section.

4. NBIC technologies, due to their novelty and complexity, require new special technological equipment. This contributes to the development of appropriate mechanical engineering manufactures, which are traditionally characterized by high qualifications of workers.

5. The increased attention to the safety of NBIC production systems for humans and the environment makes it necessary to conduct appropriate special research and development. They also contribute to the growth of human capital.

Social capital, mainly associated with trust between members of society, as well as their trust in socio-economic institutions, thanks to NBIC convergence processes, can also increase, due to the following circumstances:

1. The increased attention to the safety of NBIC production systems for humans and the environment leads to the public debate about NBIC projects, conducted with the participation of experts and civil society representatives, which fosters confidence-building and growth of social capital in society.

2. The multidiscipline of research and development in the field of NBIC convergence requires the participation of representatives of various areas of knowledge that are in close coordination with each other. This strengthen mutual trust between them and significantly reduces the likelihood of opportunist behavior. The consequence of this is also the growth of social capital.

3. The research in the field of analytic philosophy and psychology, corresponded to NBIC convergence (primarily, research for the mind-brain problem) promotes the development of applied behavioral sciences, which contribute to harmonization of relationship between the individual and society as a whole and the growth of social capital. Studies (Dubrovskiy 2013), which analyze the strengthen of interinfluence and accelerated development of information technologies, biotechnologies, nanotechnologies and cognitive science on sociosphere, should be noted here.

Thus, research and development of approaches and methods of assessment of organizational and technological development level of production systems with consideration of characteristics of reindustrialization, NBIC convergence (Roco and Bainbridge 2004), the formation of a new technological paradigm (Perez 2003; Glaziev 2015) and Industry 4.0 (Schwab 2016; Schwab 2018) and identification of economic leaders based on these assessments at different economics scales are relevant.

2 Corporate management approaches and methods contributing to the level increase of production systems

Traditional methods of corporate management are methods based on cost parameters, and the growth of business value is commonly considered as a development goal and a criterion for the success of the movement towards leadership.

However, when evaluating innovation projects and the results of R&D, the use of cost parameters is complicated in many cases due to the limited possibilities of such assessment and the influence of factors not related directly to the nature of the evaluated object (inflation, market environment, etc.). It is noteworthy that these disadvantages of the cost estimation were reported by the classic scientists like Friedman (1968), Abalkin (1994), Odum (1971) and others in their writings.

It is obvious that in the case of implementation of R&D and engineering services it is necessary to evaluate the technical and economic level of development, for which it is vital to find a continuum between its technical and economic parameters (but not having purely cost nature). In order to do this, it makes sense to apply methods of evolutionary economics developed in the post-Schumpeter era in the studies of Foster (1994), Langlois and Everett (1993), Maevsky (1994), Sukharev (2012) and others.

One of the directions of development of evolutionary economics that has been recently developed is the theory of the technological orders.

This method is a particular instance of successful use of natural science methodology in solving problems of engineering activity as the most important transactional institution.

In the conditions of NBIC convergence, the assessment of belonging of particular projects and processes to different technological orders is especially necessary.

The application of the technological orders concept in a comprehensive assessment of production systems level is described in the following section.

Along with it, the growth of production systems level is promoted by the application of management methods based on cognitive science.

It’s obvious that in mechanical engineering, the role of cognitive methods is greatest in the design of machines and other technical systems.

In this case, formalized methods for generating new design ideas and other technical solutions are very important.

As noted above, attempts to shift the solution of design tasks "to the shoulders" of artificial intelligence in the foreseeable future are unlikely to be successful. However, various techniques that formalize the processes of the designer 's thought activity when generating new technical solutions, and therefore can be classified as cognitive, allow to increase efficiency of creation of new machines and other technical systems.

First of all, it is the behaviorism methods and some other applied methods allowing to formalize processes of generation of new knowledge and forming of technical solutions. Among the last the most effective represent methods of theory of inventive problem solving (TRIZ) developed by Altshuller (1984) in the second half of the last century in the Soviet Union.

Another economic method based on cognitive science that contributes to increase in technical and economic level of technical systems is the Hungarian economist Kornai’s system paradigm (Kornai 2002).

The development of Kornai’s system paradigm may serve as the fundamental basis for creation of production and technical systems in the conditions of NBIC convergence.

The nub of the system paradigm is that functioning of economy and society: implementation of manufacture processes, distribution, exchange and consumption of tangible and intangible values, is examined through the prism of creation, interaction and transformation of socioeconomic systems.

Kornai’s ideas in regard to the application of the system paradigm were developed mainly in the Russian researchers’ writings (Kleiner 2002). On that basis, methods for managing the formation and development of production (in fact, sociotechnical) systems in various manufacturing sectors were developed. This experience made it possible to hypothesize possibility of application of the system paradigm for managing the creation of technical systems and objects, creation of new technologies and solving other engineering problems in the conditions of NBIC convergence.

On this basis, methods for designing technical systems based on socioeconomic criteria defined using the system paradigm, which are related to the exclusion (reduction in the probability) of harmful impact of the created system on humans and environment, which is ensured by its design features, may be developed.

The cost performance of the designing proved by using the ideas of the system paradigm may be determined according to economically eligible expenses related to ensuring the safe operation of the creating technical system, and the system design is based on parametrical complexity of the system elements (subsystems) calculated on the basis of their previously calculated cost.

The approach to the creation of mechanical engineering technologies, known as functional-oriented (Mikhailov et al. 2012), is that an equipment detail is represented as hierarchical structured set, consisting of seven hierarchical subsets of executive elements in whole. At the same time, equipment detail is divided into functional elements according to following hierarchical levels: product level, product parts level, component level, zone level, macro zone level, microzone level, nanozone level.

Hereon, manufacturing technology of mechanical engineering product is being produced as functional-oriented. It is based on the technological impact on nano, micro, macro zones and product parts that functionally correspond to the conditions of their future operation.

In the conditions of NBIC convergence operation security, human focus and social significance of creating and operating technical systems and objects are especially important. This affects the development level of manufacture and, consequently, company’s position in the market and its competitiveness.

The safety of a technical system/object, as a condition of its social significance and human focus, includes two aspects: accident-free operation (since any accident is more or less likely to cause harm to human health and a threat to human life) and ecological well-being, which means no harm to human health with stable operation of the technical system/object.

A number of researches is known, in which the aspects of safe operation of technical systems are examined. For example, such situation was examined for locomotive designs in a study (Gorobets 2000). The occurrence of industrial disasters at railways is probabilistic in nature, although there are no representative statistics on such disasters due to their relatively small number. A similar approach was used in well-known research (Liderman 2002) in assessing the safety of mining equipment.

Another example of a probabilistic description of the safety conditions of technical systems figures in the study (Shchedrin et al. 2018), in which the functioning of hydro-reclamation systems was examined. Hydro-reclamation systems in the agricultural production prevent situations, in which acquisition costs for provision that many times exceed the costs for creating such systems are required in dry years. It is obvious that the onset of dry years is probabilistic in nature but, in contrast with the previous example, is very well statistically described.

Designing of technical systems/objects that have designation purpose related to prevention of emergency situations is not the only case of application of a probabilistic approach. The breakdown of any object or system with useful potential leads to crisis situations of various scale and duration.

When evaluating the performance results of designing objects or systems by the extent of risks reduction, the essence of the processes related to their functioning can be described via insurance models, and the corresponding cost parameters can be determined via actuarial models (Trowbridge 1989). In this case, the option of mass risk insurance is considered as an analogue (alternative) of the designing object/system performance, and a situation, in which economic effect of designing object/system functioning is assumed to be identical to the effect of creation of a special insurance fund that enables to overcome emergency situations caused by the relevant technical system or object collapse, is considered as a working model.

At the same time, individual insurance (actuarial) and design parameters correspond to each other. This correspondence is shown in the table 1.

Table 1. Correspondence of insurance and design parameters

Parameter designation	For insurance conditions	For design conditions
P	The amount of insurance premiums collected	The total cost of the function "ensure security"
B	Insurance indemnity paid	The amount of costs associated with the elimination of the consequences of a single accident
C	Total insured amount of the insured objects	The amount of costs associated with the elimination of the consequences of accidents for all objects with a permissible probability for Bayes
C_m	Sum insured per policyholder, ($C_m = C/m$)	The sum of the costs associated with the elimination of the consequences of accidents on one object with a permissible probability for Bayes
m	The number of affected objects as a result of the insured event	The number of accidents involving economic and legal consequences, the likelihood of which is excluded due to the cost of security.
L	The number of insurance events	The number of adverse factors that can lead to an accident
n	Number of insurance objects	The number of machines (objects) in the party (in operation)
K_t	The amount of insurance fund required to pay the insurance indemnity by the end of year *t*	The amount of capital investments in work to improve the safety of objects

Source: Liderman (2002)

Therefore, the value of *P* is assumed to be equal to the operating costs of the designing system maintenance during its life cycle, and the value of *B* is equal to costs for crisis situations overcome during the same period.

When predicting the hazard level of designing systems, for which there are no representative statistics on emergency situations that happens during their life cycle, the ideas of theory of the problem solving is applied, which is supplied with Bayes' formula (Bouzarour-Amokrane et al. 2015; Liu et al. 2016; Pérès et al. 2016).

Application of the above-mentioned methods to the greatest extent contributes to strengthen the leading position of a company if these methods are applied from the stages of planning and conceptualization of the product (stages of the technical task and technical proposal) during formation of the technical requirements, quality indexes, economic parameters of the creating technical system within the framework of managing the requirements and interactions with the customer (CRM – RqM).

Application of above-mentioned method is recommended in the conditions of MCAD, EDA and other CAX-systems. It can be used within the framework of invariant subsystem of technical and economic indicators as a part of calculation automation instruments (like CAE, CAA) (Kerr and Hunter 1993), which is the most effective in design management with the use of the AGILE ideology (Highsmith 2002). In this case, it is possible to quickly respond to changes in design conditions (both external and internal), to manage the use of new knowledge that is formed during the design of a technical system.

Solving these problems, along with others, will create an integral system for the formation of digital product doubles, which will strengthen company's leading position in the market.

3 Comprehensive assessment of the development level of production systems

The above-mentioned approach based on the technological order assessment underlies comprehensive assessment of the development level of production systems developed at Platov South-Russian State Polytechnic University (NPI).

Table 2. Technological relations and production functions

Technological relations type	Function number	Function name
Pragmatic	1	Goal setting, choosing the product to manufacture
	2	Grounding the product characteristics
	3	Developing the action program for the industrial engineering
Syntactic	4	Choosing the possible technologies
	5	Choosing the technological relations
	6	Grounding the production relations system
Semantic	7	Developing the technological processes system
	8	Fine-tuning of the technological processes
	9	Combination of the manual labor and machinery work
Cognitive and Emotional	10	Developing the system of the instrumental regulators
	11	Means of the instrumental operations' regulating
	12	Regulating of the instrumental process
Material	13	Investment goods reproduction
	14	Product reproduction
	15	Instrumental operating a subject of labor

Source: Yun (2001)

<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="6">Working out of the technological solutions is based on trial-and-error method and analogy approach</td></tr>
<tr><td>2</td><td rowspan="5">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 rowspan="3">4</td><td>Management of the enter-prise</td><td rowspan="2">9</td><td rowspan="6">Partially controlled biological processes are used for primary production</td></tr>
<tr><td rowspan="3">Business management</td></tr>
<tr><td rowspan="3">8–6</td><td rowspan="3">10–0.5 micron</td></tr>
<tr><td rowspan="2">5</td><td rowspan="4">Infor-mation</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>

Fig.1. Model of technological orders and NBIC factors
Source: Kolbachev and Kolbacheva (2018)

The quantitative characteristics of the technological structure is the materialization level of the production systems' information which level increases as far as the previous order is changed by the subsequent amount.

The original approach to this idea is shown by Yun (2001), who examined the technological relations and functions, implemented by the production system (Table 2). This approach should be used if we have to analyze the changing informational relations under the different technological structures.

Another quantitative characteristic of the technological structure is the forming processes' dimension scale. The forming processes should be analyzed for the dominating technology, which technology determines the economic result of the production. A model for assessment of a production system for attribution of it to a technological order adapted to NBIC convergence conditions is shown in Figure 1 that is depicted above.

4 Conclusions

Competitiveness of companies, regions and national economies in general and their positions in the struggle for economic leadership depend on the organizational and technological level of their production systems. At the same time, company's positions are significantly strengthened if cognitive methods are used in the managing of their production systems, and production systems are created as human oriented.

Comprehensive indicators of the proximity of company's production systems to economic leadership are the extent to which they correspond to the specific technological order. A model for determining the correspondence of the production system to the technological order in the conditions of NBIC convergence based on an assessment of the extent of information materialization in it, dimensional scale of shaping, and the leading economic resource used in the production system of biological and cognitive factors is proposed.

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