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ARTICLE

TESTING THE METHOD FOR EVALUATING THE EFFICIENCY OF THE COMPLEX ECONOMIC SYSTEM DEVELOPMENT IN ACCORDANCE WITH THE INDUSTRY 4.0 CONCEPT

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ABSTRACT

The study is aimed at solving the issue of evaluating the efficiency of measures and projects implemented during digitalization, which is relevant for enterprises of various industries during digital transformation. The digital transformation is currently considered to be an important and even crucial criterion for the competitiveness of enterprises. Creating a method for evaluating the efficiency of the complex economic system development should form an understanding of the successful development of enterprises in the new reality – the digital economy. By applying an economic model with specific factors of enterprise development defined in the earlier works of the authors under the conditions of digitalization, the authors have managed to analyze an example of the automobile industry enterprise and draw a conclusion about its development efficiency in the context of the digital transformation. The obtained results can be used by the management to adjust or supplement the development strategy or to compile statistics for a group of industrial enterprises to calculate standard and other values in the new conditions of the digital transformation of the industry.

KEY WORDS
complex economic systems, efficiency of development, digitalization, industry, Industry 4.0

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INTRODUCTION

New concepts in production and logistics through digitalization promise to change the manufacturing sector (as part of the Industry 4.0 concept – abbreviated I4.0), which is secured by new information and communication technologies. These changes are relevant for most enterprises of various industries around the world.

As was noted earlier, the digital revolution offers enormous opportunities for building the capacity of national economies [1]. Wireless networks with connected devices gradually become automated, self-optimizing, and self-recovering; they increase productivity, reduce losses, and encourage economic growth, increasing, at the same time, the security risks (costs) associated with the rapid growth of interconnectedness and complexity of the systems. Costs and profits are distributed in the complex economic systems differently due to their digital transformation [2].

The objectives of the study are as follows:

- Testing the previously proposed method for evaluating the efficiency of the complex economic system development in accordance with the I4.0 concept;
- Estimating the desired indicator of the A_CESmodel [2];
- Making an analytical conclusion on the complex economic system development;
- Identifying weaknesses in the previously proposed method and formulating a hypothesis about the need to adjust the previously proposed evaluation model; and
- Making proposals about the research prospects.

The authors evaluate the efficiency of the complex economic system development in the context of digitalization at the levels of both specific enterprises and the country's economy. For example, at the level of the country, Goryacheva identifies a system of indicators that describe the efficiency of implementing the industrial policy at all levels: state, regional, and enterprise ones. The authors note the need to use indicators available in statistical and accounting reports as an important condition for the selection of the efficiency indicators [3]. Satunina notes the importance of a comprehensive evaluation and drawing up criteria for the functioning of the industrial sector of the economy. The authors propose to make a criterion analysis multilevel: first to evaluate the development and efficiency of each individual industry, then of the intersectoral interaction, and then the combined efficiency of the country's industrial sector. It is proposed to evaluate efficiency using standards. The authors propose to evaluate the investment and innovation potential using the following indicators: the level of innovation activities, the share of costs for innovation activities, efficiency of the costs for innovation activities, and the share of innovative products in the total volume of products shipped [4].

Some authors note the need to identify new factors and indicators that evaluate the development efficiency in the context of digitalization at the enterprise level [5, 6]. The efficiency indicators become systemically focused or multidimensional, expressing the ability of various social groups to adapt to changes and influence them. The key strategic characteristics of successful companies in Industry 4.0 are the flexibility, the ability to make changes in real time, and the acceleration of decision-making and adaptation processes [7]. The existing methods for evaluating the innovation-driven growth are based on

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the following methods: point rating, functional, integral, and combined. In this case, the combined technique is the most progressive as it combines the best aspects of the considered methods on the basis of multivariate or criteria analysis [8]. The method proposed by Muravyova [9] is an interesting methodology for evaluating the efficiency of the innovation-driven growth and innovation potential. This methodology is based on the integral evaluation, which provides an evaluation of factors (areas of activity) of the innovation-driven growth based on the analysis of various groups of indicators (potentials) describing this particular factor (area of activity). The integral indicator of the innovation-driven growth is found as the sum of points obtained according to the following components: the potential for expanding the current business activities and the innovation potential of the organization.

MATERIALS AND METHODS

Model for assessing the effectiveness of complex economic systems

The previously proposed model (hereinafter referred to as the Model) for evaluating the efficiency of complex economic systems (A_{CES}) from the standpoint of the intensity and efficiency of the selected indicators, which is an adiabat of eight functions, is presented below [2]:

$$A_{CES} = Int\_Fin() + Eff\_Fin() + \\ + Int\_Imp() + Eff\_Imp() \\ + Int\_Bis() + Eff\_Bis() \\ + Int\_Dev() + Eff\_Dev()$$

Refinement of the developed model

The main independent variables are presented in [Table 1]. The authors specified the indicators to form a more informative analysis of the results of evaluating the complex economic system efficiency. The testing was carried out at an automobile industry enterprise. The obtained A_CES coefficient should be taken for comparison between the enterprises in the complex economic system for the subsequent comparison of this indicator in benchmarking: either with enterprises within the economic system or with competitive systems. Another application is to introduce its standard value to maintain the complex economic system at a competitive level, the value of which is determined separately for each such system (depending on the industry).

Table 1: Updated independent variables for the A_{CES} model

Function	Details of the selected indicator
Function of intensity of the financial and economic condition $Int\_Fin()$	Turnover ratio (x1) Ratio of the turnover duration (x2) Capital productivity of fixed assets (x3)
Function of efficiency of the financial and economic condition $Eff\_Fin()$	Volume of production and sales (y1) Amount of consumption or cost of resources on production, i.e. cost price of production/service package (y2) Volume of added value of products/services (y3)
Function of intensity of improvement $Int\_Imp()$	Percentage of improved processes in the total number of processes (k1) Percentage of feedback received from customers on the improved processes in the total number of customers served (k2) Percentage of workforce engaged in improvement in the total workforce (k3)
Function of efficiency of improvement $Eff\_Imp()$	Percentage of ROI in improvement (z1) Percentage of increase in total revenue (z2) Increase in the cost of shipped products/service package per employee (z3)
Function of intensity of business development $Int\_Bis()$	Inventory turnover rate (m1) Percentage of intellectual services sold in the overall structure of industrial services (m2)
Function of efficiency of business development $Eff\_Bis()$	Cycle time (weighted average for all products by individual stages of production) (n1) Share of production using the I4.0 principles in the total production (n2) Share of digitalization costs in the total output (n3) Digital maturity index of the enterprise (n4)
Function of intensity of employee development $Int\_Dev()$	Percentage of personnel trained in customer requirements (p1) PPM ratio (parts per million) (p2) Percentage of personnel in constant rotation among the enterprises in the complex economic system (p3)
Function of efficiency of employee development $Eff\_Dev()$	Percentage of stops per shift (due to the operator's fault) (e1) Labor-output ratio (e2) Internal reject rate (e3)

Let us refine the A_CES model for testing purposes. The resulting model is as follows [Table 2]:

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Table 2: Detailing of partial summary indicators for the A_{CES} model

Function name	Function
Function of intensity of the financial and economic condition $Int\_Fin()$	$Int_{Fin} = \sqrt[3]{x1 + x2 + x3}$
Function of efficiency of the financial and economic condition $Eff\_Fin()$	$Eff_{Fin} = \sqrt[4]{y1 + y2 + y3 + y4}$
Function of intensity of improvement $Int\_Imp()$	$Int_{Imp} = \sqrt[3]{k1 + k2 + k3}$
Function of efficiency of improvement $Eff\_Imp()$	$Eff_{Imp} = \sqrt[3]{z1 + z2 + z3}$
Function of intensity of business development $Int\_Bis()$	$Int_{Bis} = \sqrt[3]{m1 + m2}$
Function of efficiency of business development $Eff\_Bis()$	$Eff_{Bis} = \sqrt[4]{n1 + n2 + n3 + n4}$
Function of intensity of employee development $Int\_Dev()$	$Int_{Dev} = \sqrt[3]{p1 + p2 + p3}$
Function of efficiency of employee development $Eff\_Dev()$	$Eff_{Dev} = \sqrt[3]{e1 + e2 + e3}$

The resulting data are to be processed by reduction methods to obtain unambiguous results. The authors made it a rule for the purposes of the study that the factors were equally significant due to the lack of statistical studies on the distribution of the weight of the aggregate indicator factors in the adiabatic function.

RESULTS

Based on the obtained data about the enterprise performance, financial statements, a survey conducted within the automobile industry in Russia, as well as a survey of the enterprise customers, the above indicators are calculated [Table 3]:

Table 3: Detailing of partial summary indicators for the A_{CES} model

Functions	2016	2017	2018
Function of intensity of the financial and economic condition	28.09	29.99	33.92
Function of efficiency of the financial and economic condition	16,380,001	9,869,887	104,264,117
Function of intensity of improvement	10.8	21.91	38.94
Function of efficiency of improvement	1.32	2.69	3.61
Function of intensity of business development	0.61	0.73	0.8
Function of efficiency of business development	0	0.07	0.11
Function of intensity of employee development	0.07	0.15	0.14
Function of efficiency of employee development	0.00135	0.0017	0.0013268

The model is a system of partial indicators, where objectives, subjects, objects, principles, methods, tools, and resources are considered separately. Economic and financial indicators of the efficiency and intensity of the manufacturing enterprise development are based on the study of the work of Russian and foreign authors, who distinguish them as the most informative. The authors use various methods for finding the weight values of individual coefficients to increase their reliability. Digitalization is a relatively new phenomenon for the Russian industry, and therefore, the weights of the indicators included in the groups are defined as single. Another research is needed to determine their exact weighted coefficients.

Data standardization

Two-stage standardization methods consisting of the reference indicators are used for the research purposes. It must be noted that the observed values are distributed uniformly without the statistically significant limitations. The positive ratio of aggregation to all components must also be noted. The unified data for each of them must be applied for this purpose. The data can be standardized and convenient to use if the variables are measured in scales and their orders, which is observed in this particular case. Given the condition that the indicators are zero for each factor, they do not reduce the generality.

The reduction is described below in accordance with the calculation formulas for discrete values:

$$x_j^* = \frac{x_j - x_{min}}{x_{max} - x_{min}},$$

Where

x_j^* is the unified value of the variable for the j-th observation;

x_j is the value of the variable for the j-th observation;

x_{min} is the minimum value of the variable; and

x_{max} is the maximum value of the variable.

It follows from the above standardization approach that if the model is equal to zero (0), then at least one of the three indicators was the worst for the enterprise over the observed period. If the aggregate indicator grows, it follows that the systemic effect of localization and digitalization grows as well, provided the ongoing overall development of the complex economic system.

As such, the following values of the reduced indicators are obtained [Table 4].

Table 4: Obtaining the coefficients for the A_{CES} model

Sl No	Function	MIN value	MAX value	2016(Norm)	2017(Norm)	2018(Norm)
1	Function of intensity of the financial and economic condition	28.09197	33.92206152	0	0.325921176	1
2	Function of efficiency of the financial and economic condition	9,869,887	104,264,116.6	0.068967287	0	1
3	Function of intensity of improvement	10.80123	38.94440482	0	0.394684312	1
4	Function of efficiency of improvement	1.316561	3.614784456	0	0.599001913	1
5	Function of intensity of business development	0.614576	0.801265073	0	0.625223136	1
6	Function of efficiency of business development	0	0.105594765	0	0.620211302	1
7	Function of intensity of employee development	0.070711	0.151974961	0	1	0.883375603
8	Function of efficiency of employee development	0.001327	0.001699735	0.063003496	1	0

Analysis of company development indicators

Let us visualize the obtained values of the indicators [Fig 1]. A significantly low level of development of the selected indicators was observed in 2016. The company also began working on the application of the digitalization methods at the enterprise in various areas of its activities in 2016. The period of 2017 looked very reasonable, it could be described as transitional, because the efficiency from the specific digitalization methods could not be achieved in one calendar year. The values of 2018 had a positive trend compared to 2016. The least efficiency was achieved in the personnel development due to the lack of proper retraining and advanced training for the factory personnel.

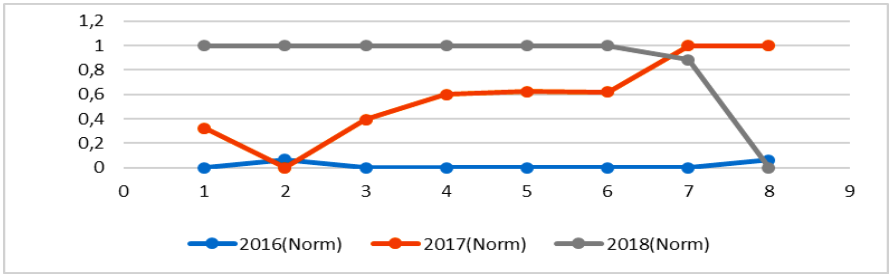

Fig. 1: Visualization of the obtained values for the A_CES model indicators

The obtained values allow to calculate the desired A_CES model. Let us calculate it with a simultaneous reduction to more convenient values for further analysis in the format from 0 to 1 [Table 5].

Table 5: The A_{CES} model calculus by year

A_CES_2016_norm	0.02
A_CES_2017_norm	0.57
A_CES_2018_norm	0.86

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In accordance with the model values obtained above, the following conclusions should be made about the measures taken by the company to increase the efficiency of the complex economic system in the context of digitalization:

- The conducted analysis allows asserting that, in accordance with the evaluation, the company is developing in a positive way. However, the attention should be paid to the indicators of the employee development, because the low value of this indicator will lead to an imbalance in the development of the company's internal systems, and as a result, the growth will be restrained.
- Uniquely high results of specific directions can be distinguished due to the proposed model. A strong growth of such indicators as the improvement efficiency and business development intensity is observed in many respects due to the accented business development strategy, namely, the work done to increase the efficiency of internal business and production processes using the digitalization capabilities.
- The results can be interpreted as follows: despite the general deterioration in the production and economic indicators of the enterprise, the work on the comprehensive improvement continued in the complex economic system, which included increasing additional resources aimed at improvements.

The personnel development indicators have lagging values in the aggregate indicator after reduction. A fairly common practice is that the enterprises in the complex economic system lose attributes of the balanced development. In this regard, the personnel are not developed as a labor resource, which should be taken into account in the context of the complex development in digitalization. According to Russian and foreign researchers, the need for the personnel retraining is the first challenge to digitalization – in this regard, this direction should be given priority.

DISCUSSION

It must be noted that the evaluation of the efficiency of enterprises in the context of digitalization is a poorly studied topic in the domestic and foreign science. To date, an exhaustive number of indicators have not been compiled to evaluate the effects of digitalization as comprehensively as possible. The existing scientific works on the evaluation of the efficiency of the complex economic systems contain the following differences from the method proposed by the authors. For example, Savin [10] uses an indicator of the efficiency of the chosen option for the development of the organizational structure to show whether the transformation of the organizational structure ensures the full achievement of the main goals of the organization operation, as well as the development and implementation of innovative projects at a fairly low cost of adaptation of the organizational structure. However, the authors believe that the evaluation of the efficiency within the digitalization phenomenon cannot be limited only to the results of the transformation of the organizational structure.

The authors agree with the approach proposed by Yashin and Schekoturova [11] to assign weight coefficients when calculating the integral indicator of the innovation-driven growth and selecting the expert method. The array of available information is not sufficient for economic conclusions about the weights of the coefficients in the context of digital transformation, with the availability of a relatively small array of data on the companies that have begun to apply the digitalization principles, and also taking into account the fact that digitalization has been actively used in the last two to five years. The authors also support the conclusions made by Konovalenko and Trofimov [8] that such methods require a careful classification of the development factors for a unified approach to linking the quality indicators of innovation to these factors. The factors can be added to the proposed methods in compliance with the criteria of adequacy and balance of the number of such factors. Strengths and weaknesses of the proposed method following the results of its testing are provided in [Table 6].

Table 6: Analysis of strengths and weaknesses of the method for evaluating the efficiency of the complex economic system development in accordance with the Industry 4.0 concept

Strengths	Weaknesses
1. Coverage of most areas of activity of the industrial enterprise in which digitalization methods and techniques can be used to date.	1. Lack of the exact weighting values of the coefficients.
2. Capabilities of calculating the basic indicator, as well as indicators for benchmarking in the enterprises of the same industry.	2. The calculation overload may occur when the method is used in the organization's ongoing operations.
3. Lack of complex auxiliary calculations.	3. Difficulty of calculating the selected model.
4. The method allows to develop and improve the efficiency of the final result.	4. Need for the preparatory stage of collecting information in the accounting system.

CONCLUSION

Evaluation of the development efficiency of complex economic systems within the framework of I4.0 projects is an urgent and little-studied issue in economic science. The complicacy and complexity of this issue lie in the fact that I4.0 projects affect not only well-known indicators, such as production and

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operational ones, but also have impact on all areas of the company. The main difficulty in assessing the effect of the management system implementation is the need to compare similar indicators of the financial and economic activities of the organization before and after the digital systems introduction, as well as ensure the possibility of accounting in the economic activities of the organization of the direct contribution from the digital systems implementation [12]. Evaluation of the possible profitability or loss-making of a particular investment in the I4.0 projects is a relevant and poorly studied issue in economic science. The complexity of this issue is associated with the fact that the I4.0 projects influence not only such well-known indicators as production and operation, but also all other areas of the company: customers and partners, employees and their functionality, safety and compliance in companies, infrastructure, and other aspects. The main difficulty in evaluating the effect of introducing a management system is the need to compare similar indicators of the financial and economic activities of the organization before and after the introduction of digital systems, as well as to provide the ability to account for the direct contribution from the introduction of digital systems in the economic activities of the organization [12]. An in-depth study of the effects and ROI of digitalization is aimed at supplementing the economic feasibility of investments with a budget deficit aimed at innovating in companies. The effects of digitalization arise as a result of events in various operational and strategic aspects of the company operation, while not all the advantages that can be achieved are associated with technologies; it is often assumed in the evaluation that business models remain unchanged. The aggregate quantitative indicators of the digitalization efficiency, such as productivity, performance, value added, jobs, production volume, and cost reduction, are most often used at the national level, as well as qualitative measurements describing competitiveness, confidence in business, and sustainable development. The impact of digital technologies is highly dependent on the country, industry, a set of technologies used, and their degree of maturity; the observed impact is usually lower than expected [13]. The authors conclude that different methods for measuring the efficiency of the digital transformation of production have a common basis; they do not contradict but complement each other, reflecting the specifics (levels of development) of countries, industries, and technologies used, and bring substantially similar results. As digital technologies are deployed and experience is gained in assessing their impact on business development in Russia, the existing methodological approaches to evaluating the efficiency of the complex economic system development will be synthesized in the nearest future.

CONFLICT OF INTEREST

There is no conflict of interest.

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None.

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