

Economic Assessment of the Effectiveness of the Introduction of Industry 4.0 Technologies in the Activities of Industrial Enterprises

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ABSTRACT

At the current stage of social development and the formation of new social relations, mankind has entered the next phase of its development, which is commonly referred to as the era of digitalization or the fourth industrial revolution. The economy digitalization in general and the transition to intelligent production or Industry 4.0 in particular is a global trend today. Large, leading industrial companies around the world are now in the process of digital transformation, the implementation of which requires an impressive amount of investment. The issue of evaluating the effectiveness of the technologies that Industry 4.0 introduces into the operations at industrial enterprises is therefore becoming increasingly important. This study considers the system for assessing the potential economic impact of the technologies introduction, which includes the following analysis areas: total implementation costs; profits and other benefits from the introduction; risks; and the potential that the company will acquire from the introduction of digital technologies in the future. It also proposed a KPI assessment system, which is important for understanding the effectiveness of production results in terms of the prospects for effective digital performance.

Keywords: *Industry 4.0, digitalisation, digital transformation, economic development, performance evaluation*

1. INTRODUCTION

The leading trend in the modern development of industrial enterprises is the mass introduction of cyber physical systems into production. "Smart Manufacturing, along with the Industrial Internet of Things (IIoT), forms the basis of Industry 4.0. This was the name given to the German government's high-tech development programme in 2011. A characteristic feature of Industry 4.0 is fully automated manufacturing, which is managed in real time and takes into account changing external conditions [1].

Industry 4.0 involves the connection of the latest information and communication technologies with production equipment and automation means aimed at organizing and controlling the entire value chain of products and services [2]. The most advanced production technologies in smart manufacturing are primarily included:

- digital design, including computer-Aided Design (CAD),
- digital twins (DigitalTwin);
- big data (BigData), generation of 'smart' big data (Smart BigData) based on digital twins;
- industrial sensors and industrial internet (IIoT);
- new materials (primarily composite materials, metamaterials, metal powders for additive production);
- additive and hybrid technologies;
- flexible production cells, robotic complexes;

- information systems for production and enterprise management;
- virtual and augmented reality technologies;
- expert systems and artificial intelligence [3].

The introduction of these technologies enables industry to meet the main requirements of the modern global market:

- Reduction of decision-making time (Time-to-Decision);
- shortening the time required to execute decisions (Time-to-Execution);
- shortening the time to market for products (Time-to-Market).

In high-tech production, the centre of gravity shifts to the design phase. And if at this stage an industrial enterprise uses mathematical modeling completely "in figure", then it is possible to eliminate errors faster and cheaper, introduce demanded products to the market faster than competitors, reduce costs, adapt a mass product to the needs of a particular consumer (customization).

From the economic point of view, any business transformation, including the introduction of new Industry 4.0 technologies, must contribute to at least one of the following conditions:

- an increase in profits from increased sales volume or an increase in profitability without a significant drop in sales volume due to price increases;

- cost reduction without compromising the quality of order fulfillment and product quality from a customer's point of view [4].

There are eight major transformations in value creation resulting from the introduction of Industry 4.0 technologies into production:

- optimisation of equipment operation modes;
- optimization of equipment utilization;
- increasing productivity and occupational safety;
- logistic optimization;
- improvement in product quality;
- improved demand forecasting;
- shortening the time it takes to bring products to market;
- improvement of after-sales services [5].

A prerequisite for the successful transformation of an industrial enterprise is its efficiency assessment. Therefore, it is very important to consider the issues related to the economic assessment of the effectiveness of digital enterprise transformation activities based on the Industry 4.0 concept, the digital economy platform and information and communication technologies.

2. METHODS OF RESEARCH

The study is based on a logical and systematic approach, as well as a comparative analysis of approaches to assessing the digital transformation of industrial enterprises. Comparative and system analysis methods have been used in order to solve individual problems. In addition, general scientific methods such as abstraction, induction, deduction and interpretation have been used to understand the interaction of factors affecting the digitalization efficiency of industrial enterprises. Moreover, the empirical method should be mentioned that related to the study of the existing practice of evaluating the efficiency of digitalization processes, as well as the results of the study of other authors who are considering the issues of evaluating the digital transformation of industrial enterprises.

3. RESEARCH RESULTS

As evaluation part of the implementation effectiveness of Industry 4.0 technologies, when making decisions about investments in the digitalization of a company, the payback of Industry 4.0 technologies and, in particular, the payback of complex systems of computing and physical elements, which constantly receive data from the environment and use it to further optimize management processes, are the most frequently assessed in global practice [6]. Such complex systems include six elements:

1) Executive mechanisms (Function - Physical reality management using hardware and software)

2) Human-machine interface (Function - Ensuring human interaction with the system of computing and physical elements)

3) Sensors (Function - Collection of data from the physical environment and its transmission to the digital environment)

4) Data transfer technologies (Function - Infrastructure for data exchange between the digital and physical environment)

5) Analysis and processing of data (Function - Analysis and processing of data from/for business operations)

6) IT infrastructure (Function - Infrastructure for data storage and processing within the digital environment) [7].

In order to determine the most effective directions for digital development, a comparative economic analysis of the financial model of each of these six elements should be carried out in the following directions: a) Total implementation costs; b) profit and other benefits; c) risks; d) potential (flexibility in the future).

a) Costs

During the implementation of production processes, groups of production, administrative, management and marketing costs arise at the enterprise. The introduction of complex systems of computing and physical elements involves a new cost group, as shown in Table 1.

b) Profit and other benefits

Factors of profit growth and increase of competitive advantages of the company are: increase of labour and equipment productivity; reduction of expenses for quality assurance; increase of accuracy of forecasts and reduction of time to market; reduction of expenses for storage of stocks and service of production.

c) Risks

Risk is the third important component in the economic effect assessment system and it is used as a filter for determining uncertainties in various cost and profit estimates. Risk-adjusted figures should be regarded as "proven" expectations, as they are risk-adjusted expectations. In general, risk-adjusted figures increase costs and reduce profits compared to the initial estimates. The most common risks in the implementation of industry technologies are 4.0:

- Integration and trial operation of technologies may take longer than planned;

- the increase in profit per employee may be lower than planned;

- the amount of saved money may be lower than planned;

- profit estimates due to shorter project times, shorter trade cycles and cost savings may be lower than planned [8].

d) Potential (flexibility in the future)

This element is an investment in additional opportunities or speed of action today, which in the future can be turned into additional profits at some additional costs. It gives the company the right or ability (and not the obligation) to engage in future initiatives.

Table 1 Costs structure of implementing complex systems of computing and physical elements (implementation of technologies Industry 4.0)

1. Equipment cost	4. Infrastructure cost
Acquisition, delivery and installation of equipment Hardware components Configuration of user interfaces Sensors Network infrastructure	Construction and/or renovation of the premises Construction equipment Server rooms Warehouse Inland logistics
2. Software cost	5. Project cost
Application program Administrative tool Data bank system Setting up the software module Software development Software updates Licenses	Search, recruitment of new specialists Retraining and retraining of production and engineering personnel Management Consulting Travel expenses
3. Data protection	6. Other expenses
System access control Authorization systems Data media and their encryption	Maintenance services Payment for consumed resources Telecommunication costs

The economic effect of introducing a new technology is determined using formula 1.

$$\text{Formula 1. } E_{nt} = (E_{bas} - E_{new}) \times N_{new} = [(C_{base} + E_n \times I_{bas}) - (C_{new} + E_n \times I_{new})] \times N_{new},$$

where E_{nt} is the economic effect of new technology, rub;

E_{bas} - the expences for producing a unit of production using a basic version of the technology, rub;

E_{new} - the expences for production of products with the help of new technology, rub;

N_{new} - annual production volume of products using new technology, units of;

C_{bas} - cost of production of base variant, rub;

C_{new} - cost of products using new technology, rub;

I_{bas} - capital investment per unit of production of base variant, rub;

I_{new} - capital investment per unit of production on the basis of new technology, rub;

E_n - normative efficiency factor.

This formula is the basis for calculating the economic effect of implementing the new technology in virtually any company. The profitability index is calculated as a ratio of the sum of project cash flows, reduced to a unit of time, to the volume of investments. A project with a profitability index of more than 1 is effective. This index must be considered in conjunction with the absolute effect of the project. When comparing two projects with the same absolute effect, the project which profitability index is higher is selected [9]. The timing of the return on investment is determined by the time period required to ensure that the additional revenue generated by the introduction of the new technology covers the cost of its introduction.

After evaluating the cost efficiency of new technologies, it is recommended that key KPIs be identified.

Key performance indicators (KPI, key performance indicators) are quantifiable calculation results that characterise the most important factors of the company

success. KPIs are important for understanding and improving the production results, both in terms of prospects for effective digital production and for achieving strategic goals.

Table 2 shows a rough list of KPIs for the different areas of production activity.

In June 2017, GOST R ISO 22400-2-2016 "Industrial Automation Systems and Integration" was adopted. Key technical and economic indicators (KPIs) for managing production operations. Part 2. Definitions and descriptions", which is identical to International Standard ISO 22400-2:2014. This standard defines the KPIs used in practice to assess the performance of equipment and production personnel in continuous, serial, discrete production as well as in storage and transport of products. The document considers formulas for calculating KPIs, the consumers of these indicators, and describes the methodology for applying KPI.

One of the main KPIs used to assess the performance of process equipment is the Total Equipment Effectiveness (OEE, Overall Equipment Effectiveness). The OEE takes into account the availability of equipment, its efficiency (productivity) and the quality of the products manufactured on that equipment (see Figure 1).

The world's best manufacturers reach a production process level with OEE values above 80% (for discrete processes), but the average OEE value for manufacturers does not exceed 60% and often ranges from 30-35% [10]. Thus, the target OEE can be 80%. With values below 60%, there is an urgent need to take active action because production capacities are not used efficiently and require the introduction of Industry 4.0 technologies.

4. DISCUSSING THE RESULT

The development conditions for the modern digital economy require industrial companies to improve not only

their production processes, but also their business processes, which can be achieved by implementing various innovations and adapting business models to modern realities. The approach by which companies change their

business models, processes and business ecosystems using digital technologies is called digital transformation.

Table 2 Key performance indicators of production activities

Equipment
overall equipment effectiveness (OEE - Overall equipment effectiveness), %; capacity utilization, %; share of wear and tear on existing equipment, %; fixed asset replacement ratio, %.
Quality
First time through (FTT), %; share of expenses for technological defects in the cost of production, %; share of claims to the number of finished products shipped, %.
Production
plan completion rate just in time (bsd - build to schedule), %; critical product/service family production process efficiency factor, %; share of cost of goods produced to finished goods volume, %; turnover of stocks of work in progress and stocks of raw materials, components, in days; share of finished product balances in revenue, %; turnover of inventory of work in progress and inventories of raw materials and components, in days; share of finished product balances in revenue, %; balances of work in progress as a percentage of finished goods produced, %; turnover of stocks of raw materials and components in days, %; balances of finished goods as a percentage of revenue; share of raw materials, supplies and components in finished goods, %; share of stocks of raw materials, supplies and components in finished goods, %.
Logistics
total production cycle time (TPT -Through put time), in days; share of finished products delivered to the customer just in time, %; quality of the supply chain to internal customers just in time (OTIF - On time in full), %; share of deliveries of raw materials, supplies and components from suppliers just in time, %.
Staff
output per employee, million rub; number of accidents, pcs; number of implemented improvement proposals per employee, pcs.

The digital transformation of companies, which has the potential to improve their performance, generally involves significant financial costs. This makes it advisable to determine the effectiveness of measures taken to justify and take managerial decisions in the area of digitalisation, which in modern times has already become a mandatory and integral part of competitive and breakthrough development.

Efficiency assessment of the company digital transformation, which is considered for the purpose of improving its management, must necessarily be comprehensive. Comprehensive effectiveness assessment of the digital transformation of an enterprise is a characteristic obtained through comprehensive research, including simultaneous and coordinated study of a system of indicators that takes into account all aspects of production and business processes, containing consolidated conclusions about the end results of the enterprise, as well as qualitative and quantitative differences in comparison with the comparison base.

This study offers a methodology for assessing the effectiveness of digital development and determining key performance indicators KPI from the introduction of

digital technologies in such areas of production activity as "Equipment", "Quality", "Production", "Logistics", "Staff".

Thus, the methodology under consideration will make it possible to carry out the most effective approach to the implementation of digital transformation, which consists in the use of a technique that involves, first of all, the definition of the result to be achieved, and only then the choice of a specific technology for implementation. It differs radically from the traditional approach of most companies when they first implement a pilot project using a particular technology and only then assess the technology effect.

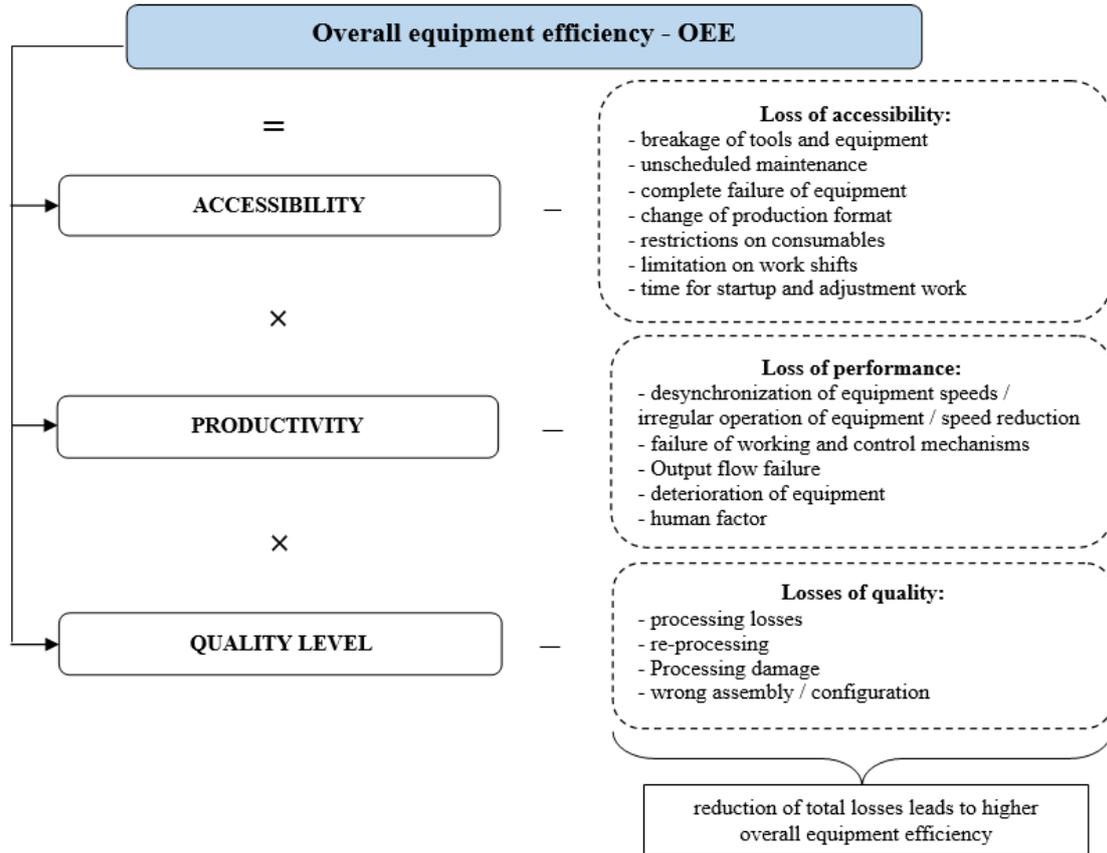


Figure 1 Calculation of technological equipment performance through the complex indicator "Overall Equipment Effectiveness" (OEE, Overall Equipment Effectiveness)

5. CONCLUSION

In today's competitive environment, companies need to develop long-term strategic plans with care. Planning processes are now undergoing a lot of uncertainty, global trends are changing very rapidly and by the time the planning result appears it is actually outdated. The modern market requires mass customisation of production, quick reaction to changes in customer preferences and other external factors. Fast service delivery speed for fast business decision making is the essence of digital service in Industry 4.0. When digital services are brought to the market, their degree of readiness is no more than 80%, and the remaining 20% are finalized as sales increase and customer response is received (in operation).

A digital strategy must first and foremost be defined as a focus on turnover growth rather than a struggle to reduce costs. It is "digitized" business solutions that are easily scalable (with fixed implementation costs volumes increase).

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Industry 4.0 involves the connection of the latest information and communication technologies with production equipment and automation means, aimed at organizing and controlling the entire value chain of products and services.

When deciding whether to invest in the enterprise digitalisation, the payback of Industry 4.0 technologies should be assessed based on the following elements: total implementation costs; profit and other benefits; risks; potential (future flexibility). After evaluating the cost-effectiveness of new technologies, it is recommended that KPIs be identified in such areas as equipment, quality, production, logistics and staff.

On the whole, the system under consideration for assessing the digital transformation of industrial enterprises provides a more rational approach to their digitalisation, and contributes to efficiency and management improvements.

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