ASSESSMENT OF THE IMPACT OF ROBOTIC SYSTEMS ON THE REDUCTION OF PRODUCTION COSTS IN MASS PRODUCTION CONDITIONS

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Abstract. *This article examines the impact of robotic systems on the reduction of production costs in mass production conditions. It explores the transformation of the cost structure of products under the influence of automation, including changes in the share of labor costs, reduction of losses due to defects, equipment downtime, and logistical inefficiency. The potential for integrating industrial robots, automated lines, and cyber-physical systems is analyzed in the context of lean manufacturing, just-in-time, and computer-integrated manufacturing concepts. Special attention is given to methods for assessing the economic efficiency of robotization, including the calculation of net present value, internal rate of return, as well as the analysis of the impact on product quality and labor safety.*
Keywords: *robotization, production costs, automation, mass production, digitalization.*

Modern industrial companies operate in the environment of global competition, unpredictable macroeconomic environment, and constantly increasing demands to the quality of products and terms of delivery. All of the above necessitates the revision of traditional approaches to the organization of the production process and the search for sustainable mechanisms of efficiency improvement. One of them is the application of robotic systems capable of changing the structure and dynamics of production costs.

In recent years, there has been active dissemination of the Industry 4.0 concept, which involves deep digital transformation of the industrial sector through the integration of intelligent technologies, the Internet of Things (IoT), cyber-physical systems, and automation tools. The introduction of robotics under mass production conditions allows not only for the optimization of individual stages of the production cycle but also creates conditions for the sustainable reduction of product cost through minimization of the human factor, increased equipment productivity, and reduced production defects. The purpose of this article is to assess the impact of robotic systems on the reduction of production costs in mass production conditions.

Theoretical foundations of mass production robotization

Modern industry is undergoing a phase of profound structural transformation caused by the transition to the fourth technological paradigm. One of its fundamental directions is **robotization**. It represents a set of technical and software solutions capable of performing production functions without direct human involvement. Its use significantly transforms approaches to organizing mass production, changing production cycles, management structures, and principles of interaction between system elements. Based on the International Federation of Robotics (IFR) estimation, around 3,9 million industrial robots worked worldwide in 2022. Their count is estimated to grow by 7-10% per annum, especially in process-intensive industries with high levels of standardization, e.g., production of automobiles, electronics, and metal processing. This confirms a steady trend towards the transition from partial to full automation of production operations [1].

Modern industrial robotics represents a multilevel system encompassing both individual manipulator units and integrated complexes, combined with software control, sensor platforms, and IoT systems. Table 1 presents the classification accepted in international practice, based on various criteria.

Table 1. Classification of robotic systems [2, 3]

Classification criteria	Types of robotic systems	Application examples
By design and kinematics	Articulated multi-axis manipulators, SCARA robots, delta robots, as well as Cartesian structures with linear motion trajectories.	They are used, for example, at welding posts in the automotive industry, in the assembly of electronics, and on food packaging.
By appointment	Robots are classified according to their functions: assembly, welding, transportation, packaging, and quality control.	They are used on KUKA assembly lines, ABB packaging lines and in logistics movements.
By the level of autonomy	Fixed-algorithm systems, adaptive robots with feedback, as well as intelligent self-learning complexes using artificial intelligence (AI).	They are used in tasks of adaptive processing, self-learning based on production data and sensor-controlled production.
By the nature of human interaction	Isolated systems operating in a fenced area and collaborative robots capable of safely interacting with humans in a common space are different.	A typical example is a manual assembly and hybrid station, where operators and robots perform related tasks.
By application area	Robots are used in continuous production lines.	They are used in logistics (AMR in Amazon warehouses), pharmaceutical machine vision control, and GE Aviation flexible assembly cells.

In the author's opinion, the classification makes it possible not only to identify the main types of applied solutions but also to trace the relationship between the structural features of robots, their level of autonomy, and areas of use in industry. This is particularly important in the context of mass production. Its distinguishing features are a high degree of operation repeatability, stability of product assortment, and significant duration of production series. These requirements allow for such systems to be implemented at a large scale because high standardization reduces equipment adaptation and design costs, and stable production guarantees a return on investment in automation in a relatively short time.

One of the central features of the development of mass production is the rethinking of its bases of organization in situations of automation. The concepts underlying it imply a close interconnection between logistics, management, and technical support of the production process (table 2).

Table 2. Modern production organization concepts and the role of robotization in their implementation [4]

The concept	The main goal	The role of robotics
Just-in-time	Minimizing inventory and accurately synchronizing supplies with the production process.	Ensuring high accuracy and timely execution of operations to maintain a synchronized flow.
Lean manufacturing	Reduction of all types of losses, improvement of overall production efficiency.	Automate routine operations, reduce time loss and improve quality.
Computer integrated manufacturing	Integration of all production functions into a single computerized system.	Digital communication between design, planning, management and logistics systems.

Thus, the theoretical foundations of mass production robotization are formed at the intersection of technological and organizational innovations, where automated and cyber-physical systems become integral tools for increasing production efficiency. This represents an optimal environment for realizing the potential of robotization, especially when based on the concepts of lean and integrated manufacturing.

Structure of production costs and prerequisites for their reduction

The transition to robotic forms of production organization is impossible without understanding the economic structure into which they are implemented. **The cost of production** represents the total expenses incurred by an enterprise in producing a unit of output. Under mass production conditions, it is shaped by various cost components (fig. 1).

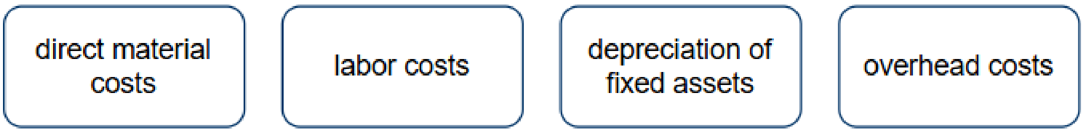

Fig. 1. Structure of production costs under mass production conditions

Despite the apparent stability of these elements, their quantitative and qualitative characteristics are subject to change depending on the level of technical equipment of the enterprise. Robotics affects several aspects at the same time, which ensures a cumulative effect and creates prerequisites for sustainable growth in efficiency.

Labor costs are the most sensitive to its influence. In traditional production systems, they occupy a significant share in the overall cost structure. The implementation of automated systems reduces dependence on human resources for routine, repetitive, and hazardous operations. This leads not only to a reduction in direct wage costs but also to decreased expenses for social security, labor protection, and personnel administration. According to a study by McKinsey & Company, organizations that automated at least one-third of their processes increased efficiency by an average of 15% and reduced costs by 12% [5].

At the same time, robotization does not exclude the participation of personnel, but changes its role from operational to managerial and engineering. A great instance is the factory of Ford where F-150 electric vehicles manufacturing was initiated with the utilization of industrial robots taking on primary assembly phases [6]. Through such a mechanism, not only labor expenses could be reduced but efforts could also be reallocated for development, diagnostic, and optimizing processes, yielding a greater level of technological company maturity.

Cost reduction is also achieved through a **change in the logic of quality assurance**. Under manual labor conditions, control is carried out selectively, and the degree of deviations from the norm remains high. Robotic systems, particularly those with machine vision and AI technologies, enable ensuring continuous quality checking at each production stage. This reduces the number of reworks and diminishes the necessity for follow-up inspections. Consequently, expenses related to defects and corrective actions can also be optimized. This approach has proven its effectiveness, in particular, at General Electric production sites, where built-in automatic control allowed for a reduction in the level of technological defects [7].

Special attention should also be paid to **losses resulting from equipment downtime**. In traditional production systems, they can be caused by human factors, insufficient synchronization of supplies, untimely maintenance, or planning errors. Robotic systems integrated into a digital production environment are capable of operating with minimal pauses and independently signaling the need for technical maintenance. This creates conditions for a shift from a reactive equipment management model to a preventive and predictive one, which ultimately reduces the level of unplanned downtime and the associated losses (fig. 2).

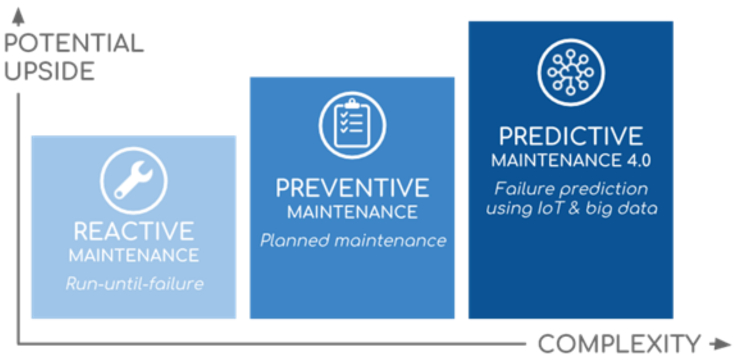

Fig. 2. Evolution of maintenance strategies in the context of production digitalization

The use of sensors, IoT, and big data analytics allows for real-time diagnostics of equipment components and the prediction of potential failures. According to McKinsey, predictive analytics in manufacturing reduces equipment downtime by 30-50% and extends its service life by 20-40% [8].

In addition, an important area of cost saving is the **flexibility of the production system**. Robotic modules capable of quick reconfiguration and adaptation reduce response time to changing demand. This makes it possible to decrease expenses related to overproduction, storage, equipment readjustments, and logistical losses.

Finally, **losses due to defects**, being one of the costliest items in mass production, are also reduced when transitioning to robotic technologies. The high precision and repeatability of operations they provide eliminate the majority of errors caused by human factors, fatigue, or inconsistency in actions. As approximated, within the highly automated firms, the rate of defects in quality is reduced by 1,3 to 3,5 times, or even higher, due to the decreased influence of the human element on product quality [9].

Thus, the impact of robot systems on the cost profile is not merely at the discrete cost item level. It is systemic in nature, permeating labor, quality, time-based, and material considerations. This renders robotization feasible to be viewed not only as a technological innovation, but as a strategic tool for production resource management, forming the ground for improving the economic efficiency of the enterprise.

Methods for assessing the impact of robotic systems on cost reduction

The assessment of the effectiveness of the use of robotic systems in the environment of mass production should be performed on the basis of a multifaceted approach taking into account not only economic but also technological, organizational, and social aspects. The simple comparison of the expense of automation and direct economies is inadequate because they alter not individual functions but the entire production system, its structure, quality, stability, and flexibility. In this context, evaluation methods have to consider not only the short-term financial outcomes but also the long-term effects on the operational and strategic soundness of the business.

The point of departure is **the cost-benefit analysis**, which forms the foundation of any investment proposal. The installation of a robotic system involves significant capital outlays, including equipment acquisition, installation, integration with existing information systems, training of staff, and organizational changes. On the other side of the equation are the expected benefits: reduced labor costs, defect reduction, increased production volumes, improved productivity, and decreased maintenance costs. Analyzing this ratio makes it possible to identify the point at which the savings begin to exceed the initial investments (fig. 3).

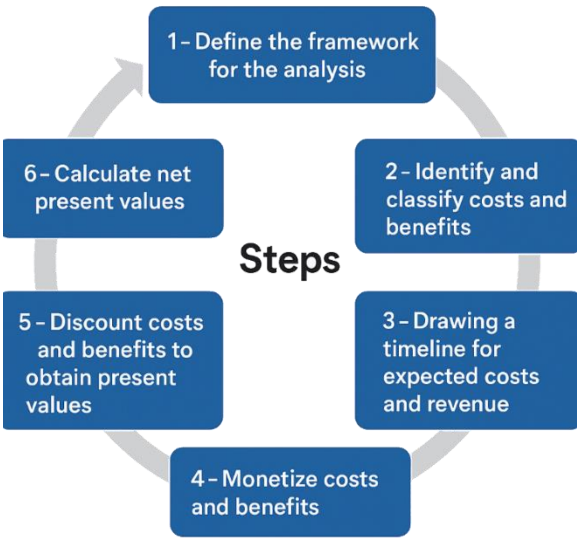

Fig. 3. Stages of cost-benefit analysis in the evaluation of investment projects for robotization implementation

This logic is further developed through the indicator of the **payback period**. It reflects the time frame within which the investments are recouped through the reduction of operating expenses (fig. 4).

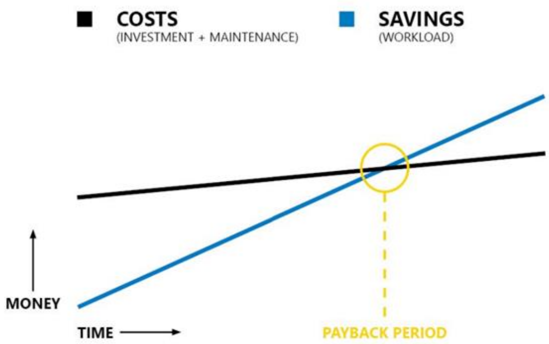

Fig. 4. Calculation of the payback period of the automation process

In mass production with high equipment utilization and a stable product range, this period is usually shortened. At enterprises with high production intensity and stable output volume, the return on investment in industrial robots can range from 1 to 5 years, making them economically justified given the equipment's service life of more than 10-15 years [10].

However, for a comprehensive assessment of the effectiveness of robotization implementation, payback analysis alone is not sufficient. In an unstable external environment and with growing demands for resource efficiency, **integrated profitability indicators** become particularly important. They can account not only for current cash flows but also for risks, alternative costs, and long-term strategic effects (table 3).

Table 3. Integrated methods for assessing the economic efficiency of robotization projects

Evaluation method	Economic importance	Role in the evaluation of robotics
Net present value (NPV)	Determines the difference between the reported revenues and the project costs at a given discount rate. A positive value indicates profitability.	It allows you to quantify the excess of benefits from automation over costs, taking into account the time cost of money and the duration of the production cycle.
Internal Rate of return (IRR)	Shows the expected return on an investment project. If the IRR exceeds the opportunity cost of capital, the project is considered economically feasible.	It is used to compare the effectiveness of automation with other investment opportunities and to analyze the sustainability of a project in the context of market and technological risks.

A separate direction of assessment is related to the qualitative parameters of production, primarily the quality **level of the manufactured products**. Use of robotic systems with machine vision technologies and sensor control delivers high accuracy in operations and has inclusion of quality control in the production process. Reduction of defects, failure, and complaints not only affect direct costs but also the reputation of the company, especially in highly competitive and highly regulated markets. Thus, assessing the impact of robotization on product quality acquires strategic importance and should be considered part of the overall efficiency indicator.

No less important is the aspect of **labor safety and the working environment**. Robotization allows excluding the involvement of man in hazardous, heavy, and toxic operations such as welding, chemical substance activities, heavy workpiece handling, and noise or vibration-intensive situations. This reduces the threat of industrial injuries, decreases insurance costs, raises employees' satisfaction, and minimizes staff turnover. Although these effects are difficult to formalize in the context of orthodox economic analysis, they have long-term consequences for the organization's overall efficiency and sustainability.

Thus, the method of measuring the effectiveness of using robotic systems should be through a multi-dimensional approach considering both quantitative and qualitative elements. Cost-benefit analysis, payback period evaluation, profitability calculation, monitoring of product quality impact, and labor safety indicators form a unified measurement system in which robotization is viewed not as a local project but as an element of transforming the entire production model. The use of integrated efficiency indicators makes it possible not only to justify the decision to implement but also to manage their operation during the life cycle stage, ensuring maximum economic and social effect.

Strategic effects of reducing production costs

The reduction of production costs achieved through the implementation of robotic systems influences not only the current economic indicators of the enterprise but also leads to broader and more sustainable changes that affect its strategic market position. The transition from predominantly manual labor to automated processes results in a systemic reallocation of internal resources, transforms the operational management model, and strengthens the company’s ability to adapt to the external environment (fig. 5).

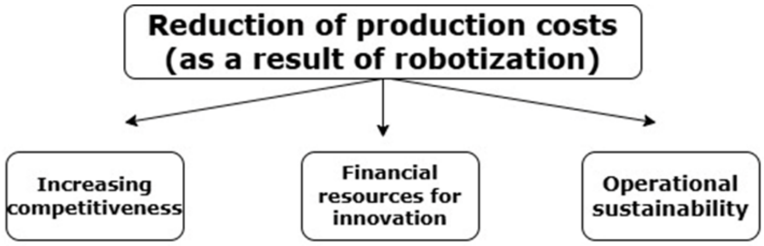

Fig. 5. Strategic effects of cost reduction resulting from robotization

One of the long-term effects is an increase in **competitiveness**. In the context of globalized markets and high supply saturation, the reduction of production costs enables enterprises to adopt a more flexible pricing policy without compromising profitability. This becomes especially important in industries where price competition is a distinguishing feature. At the same time, automation encourages consistency of product quality and speeds up order fulfillment time, further deepening customer trust and the strength of customer relationships. A company using robot systems can fulfill contractual obligations with high degrees of certainty, which is particularly useful in business-to-business markets and export markets.

Along with this, **cost reduction frees up financial resources** that were otherwise engaged in manual labor, elimination of defects, losses due to downtime, and inefficient logistics. They can be reallocated to promising areas, for example, research and development, market expansion, introduction of digital solutions, personnel development, and ecology. In this manner, robotization improves not just short-term profitability but also makes it possible to create innovation potential, without which it is impossible to achieve long-term sustainability.

Systematic reduction in costs also leads to **operational resilience of the business**, especially under the condition of an uncertain macroeconomic climate. Businesses with a high ratio of automated procedures display less dependency on fluctuations in labor costs, availability shortages of trained personnel, and supply chain disruption. Increased production flexibility via adaptable robotic cells makes it possible to respond faster to changes in consumer demand and the rearrangement of production lines without significant time and financial loss. Outside economic shocks impact businesses with high technological maturity and automation levels less severely. Robotization, in this case, is both a means of improved efficiency and a dimension of strategic business resilience.

Therefore, the reduction of production costs through robotization should be viewed not as an isolated measure but as part of an integrated transformational strategy. It sets the stage for the development of a new competitive framework of the firm, in which technological progress, financial agility, and operational adaptability become interrelated elements of sustainable growth. In the long run, these impacts can considerably change the market position of the company and define the possibilities for innovative development amidst accelerating external environment changes.

Conclusion

Automation is an important mechanism in the formation of a new economic logic for managing production resources. Robotization reshapes the structure of the production process at the system level, affecting labour, technological, managerial, and logistic dimensions of the space of production. Its cost-saving effect is two-sided and is manifested in immediate cost reduction and indirect strategic impact expressed in terms of increased resilience, flexibility, and innovativeness of the company.

Mass production, characterized by repetitive operational structures, a high degree of standardization, and significant production cycle duration, creates optimal conditions for large-scale integration of robotics. Under these conditions, such solutions provide a significant reduction in labor intensity, minimize losses from downtime and defects, contribute to the stabilization of product quality, and increase order fulfillment speed. Empirical data indicate that enterprises with a high degree of automation show substantial improvements in operational performance, both in absolute terms and in relative comparison with traditionally organized production systems.

Methods for assessing effectiveness, including cost-benefit analysis, profitability calculation, and evaluation of qualitative effects, provide a systematic approach to decision-making regarding the implementation of robotic systems. Their use makes it possible to consider not only short-term payback parameters but also the long-term consequences for economic stability, market adaptability, and innovative development. Improved operational precision, reduced dependence on the human factor, and the potential for integration into the digital environment shape a new production architecture in which automation becomes a source of competitive advantage, not merely a means of cost reduction. Thus, robotization under mass production conditions should be viewed as part of the enterprise's strategic transformation aimed at enhancing its efficiency, resilience, and capacity for innovative renewal.

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ОЦЕНКА ВЛИЯНИЯ РОБОТИЗИРОВАННЫХ СИСТЕМ НА СОКРАЩЕНИЕ ПРОИЗВОДСТВЕННЫХ ИЗДЕРЖЕК В УСЛОВИЯХ МАССОВОГО ПРОИЗВОДСТВА

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Аннотация. *В данной статье рассматривается влияние роботизированных систем на сокращение производственных издержек в условиях массового производства. Исследуется трансформация структуры себестоимости продукции под воздействием автоматизации, включая изменение доли трудовых затрат, сокращение потерь от брака, простоев оборудования и логистической неэффективности. Анализируется потенциал интеграции промышленных роботов, автоматизированных линий и кибер-физических систем в контексте концепций lean manufacturing, just-in-time и компьютерно-интегрированного производства. Отдельное внимание уделяется методам оценки экономической эффективности роботизации, включая расчет чистой приведенной стоимости, внутренней нормы доходности, а также анализ влияния на качество продукции и безопасность труда.*

Ключевые слова: *роботизация, производственные издержки, автоматизация, массовое производство, цифровизация.*