



METHODOLOGY FOR CALCULATING ROI TO ASSESS THE EFFECTIVENESS OF IMPLEMENTING DIGITAL SOLUTIONS IN PRODUCTION SYSTEMS TAKING INTO ACCOUNT OPERATING AND CAPITAL EXPENDITURES

Dmitry Pshychenkoⁱ

Associate Professor,
National Research University Higher School of Economics,
Moscow, Russia

Abstract:

This article examines the methodology for calculating Return on Investment in relation to digital solutions in production systems, taking into account both capital and operating expenditures. The specifics of the structure of costs and benefits of digital projects are studied, including direct and indirect effects, as well as the temporal dynamics of their manifestation. The necessity of modifying the classical approach through the use of discounted indicators and integration with other investment analysis tools, such as Net Present Value, Internal Rate of Return, and Payback Period, is analyzed. Based on practical implementation examples, the applied significance of the methodology is demonstrated and the main drivers of the economic effect of digitalization are identified. Particular attention is paid to the limitations associated with the quality of initial data, the choice of discount rate, and the difficulties of accounting for intangible factors.

JEL: O33, M15, E22.

Keywords: return on investment, digital technologies, capital expenditures, operating expenditures, net present value, internal rate of return, time consideration

1. Introduction

The digitalization of production systems is becoming one of the important factors in increasing the efficiency and competitiveness of enterprises in the context of the global economy. The use of digital technologies makes it possible not only to automate individual processes but also to form new management models based on data and the integration of business functions. The implementation of such solutions requires

ⁱ Correspondence: email dmitry.pshychenko@rambler.ru

significant investments, which makes the task of an objective assessment of their economic effectiveness relevant.

Traditional analysis methods used in industry are mainly focused on capital expenditures (CapEx) and direct financial results. However, digital solutions (DS) are characterized by a more complex cost structure and a specific range of benefits. At the same time, existing approaches to calculating Return on Investment (ROI) do not always take their features into account, which limits applicability in strategic planning. The aim of this study is to analyze the methodology of ROI adapted to the specifics of DS.

2. Main part. Theoretical foundations of ROI and features of application in digital transformation

The ROI indicator is traditionally considered one of the most widespread tools for analyzing the effectiveness of investment projects. Its popularity is explained by the simplicity of calculation and the versatility of application in various industries. The basic definition reflects the ratio of net profit to the volume of investments:

$$ROI = \frac{NetProfit}{Investment} \times 100\% \quad (1)$$

Where,

NetProfit – profit from investment,

Investment – cost of investment.

Such an approach makes it possible to assess how justified the invested funds are and what income the project generates. In the context of traditional industrial production, it allows for the comparison of investments in new equipment, capacity expansion, or the implementation of individual technological solutions.

Nevertheless, digital transformation imposes different requirements on performance evaluation. First of all, the classical ROI does not take into account the time factor. The benefits of its implementation, as a rule, do not appear instantly but gradually. Thus, the use of a simple formula leads to the underestimation of the long-term effect [1]. In addition, it is limited in accounting for indirect benefits. Unlike capital-intensive modernization projects, digital initiatives create value through improving process quality, data integration, increasing production flexibility, and developing a culture of data-driven decision-making.

These difficulties have led to the active use of additional indicators that make it possible to take into account the temporal dynamics and the specifics of DS. The most common are Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) – table 1.

Table 1: Comparative characteristics of indicators for evaluating the effectiveness of DS [2, 3]

Indicator	The essence of the method	Advantages	Limitations
NPV	The difference between discounted cash flows and invested investments.	Takes into account the time value of money; reflects the long-term effects of digitalization.	Requires accurate forecasting of cash flows; is sensitive to the choice of discount rate.
IRR	The rate of return at which NPV = 0.	Allows you to compare alternative digital projects; takes into account the time factor.	It can provide several solutions for non-standard flows; it is difficult to interpret with high uncertainty.
PP	Time required for a return on investment.	Convenient for risk assessment; useful for projects with a high level of uncertainty.	Ignores the benefits after the PP; underestimates the strategic effect of digitalization.

Thus, classical ROI cannot be considered a universal tool, but its preservation as a basic indicator is justified when used in combination with the described indicators. Such an approach provides a more complete understanding of project effectiveness, allowing for the consideration of both short-term results and delayed effects of digitalization. At the same time, the validity of the final assessment is largely determined by how consistently the initial data on costs and benefits are structured.

3. Classification of costs and benefits in the implementation of DS

The construction of a correct ROI calculation model requires, first of all, the definition of the cost structure arising at various stages of the implementation of DS. Without clear classification, it is difficult to compare the initial investments and the obtained results, and therefore the final effectiveness indicator may turn out to be distorted (fig. 1).

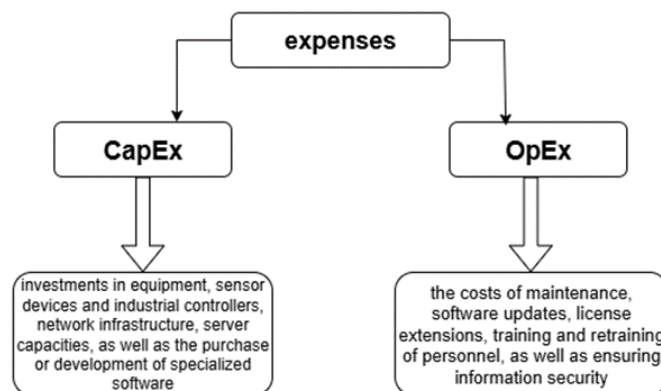


Figure 1: Classification of costs

The starting point of the project is formed by CapEx. They reflect investments that create the basis for obtaining future benefits throughout the entire life cycle of the DS.

These expenses are concentrated at the initial stage of the project and ensure the creation of a technological platform that will subsequently bring economic and operational benefits. Their characteristic feature lies in the long-term effect, that is, the investments made once are reflected in the financial statements throughout the entire period of operation of the digital system.

Operating expenditures (OpEx) appear as regular payments. They are necessary to maintain the operability and evolution of the DS. In modern conditions, they also include payments for cloud services, since many manufacturing companies are moving to hybrid infrastructure models. Thus, they reflect the dynamic component of the digital project and determine its sustainability in the long-term perspective.

The benefits of digitalization are also heterogeneous. Direct effects are recorded in immediate, easily attributable changes in costs and revenues. These may include a reduction in the share of defects and rework, lower consumption of materials and energy, reduced labor intensity of operations, increased line throughput, and decreased unplanned downtime. Their monetary valuation is based on the operational indicators of the enterprise. For example, if the implementation of a DS makes it possible to reduce the share of defective products, the economic effect is determined as the product of the reduced share of defects, the total output volume, and the unit cost of each defective item. In other words, the lower the percentage of defects at the same production volume, the greater the amount of saved resources.

A similar method is used to calculate the effect of reducing unplanned equipment downtime. Here, the amount of savings is expressed through the number of hours by which downtime was reduced, multiplied by the margin income that the enterprise usually loses for one hour of underproduction. Thus, each prevented hour of stoppage is converted into monetary terms through the indicator of lost profit. At the same time, improvements in overall equipment effectiveness (OEE) are recorded due to increased availability and productivity and reduced quality losses.

Indirect effects have a more complex structure and an influence. They are manifested in improved product quality, increased customer satisfaction, greater flexibility of production processes, as well as enhanced business resilience to external and internal risks. A significant part of these effects is associated with intangible factors such as increased transparency of operations, the development of analytical competencies, and the introduction of a data-driven management culture. In some cases, they can be partially converted into monetary terms, for example, through the reduction of penalties for late deliveries or by decreasing the volume of inventory as a result of improved planning.

Taken together, this classification creates the basis for the subsequent construction of the ROI calculation methodology. It makes it possible to break down the complex system of costs and benefits into separate components that can be measured, compared, and brought to a single time horizon of analysis.

4. Methodology for calculating ROI for DS

The basis of the methodological approach is the integration of CapEx and OpEx into a single cost system with their linkage to the life cycle of the solution. Such a representation makes it possible to correlate the moment of one-time investments with regular payments and to derive the real cost of ownership of the technology. In a parallel dimension, measurable and indirect effects are aggregated. At the same time, a significant part of the benefits arises with a time lag, which requires the application of special methods for stream alignment.

An important tool is discounting. It allows future benefits to be brought to their present value and thereby correctly correlated with costs, which are often concentrated at the beginning of the project (fig. 2).

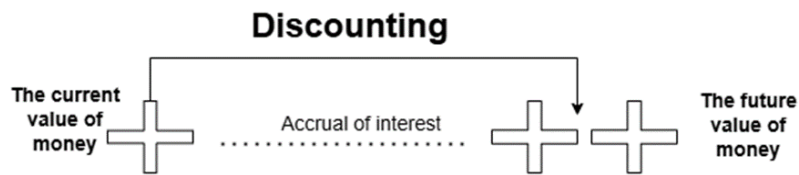


Figure 2: Discounting model

This approach eliminates distortions that arise when directly comparing current costs and deferred effects and makes the ROI calculation more accurate. It is important to emphasize that the choice of the rate in this case should take into account not only financial risks, but also technological uncertainty associated with the development of DS. Thus, to ensure a correct assessment, it is necessary to consider not only the cost structure but also the temporal dynamics of benefits. The logic of this approach is reflected in figure 3.

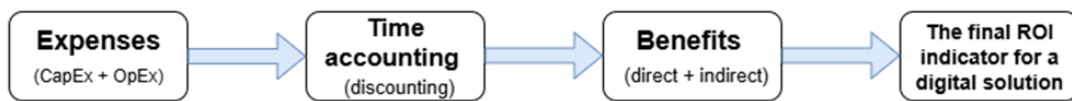


Figure 3: Logic of ROI calculation for DS

For the practical assessment of the effectiveness of implementing digital monitoring technologies, the indicator of discounted ROI (ROI_{disc}) is used, which makes it possible to correlate benefits and costs brought to present value. Its calculation is carried out according to the formula:

$$ROI_{disc} = \frac{\sum_{t=1}^T \frac{B_t}{(1+r)^t} - \sum_{t=0}^T \frac{C_t}{(1+r)^t}}{\sum_{t=0}^T \frac{C_t}{(1+r)^t}} \times 100\% \quad (2)$$

where

B_t – benefits (cash inflows or cost savings) in period t ;

C_t – CapEx and OpEx associated with the implementation and operation of the solution;

r – discount rate reflecting the cost of capital and the level of investment risks;

T – analysis horizon.

Such a format preserves the clarity of the basic indicator but at the same time reflects the specifics of digital projects, where financial results are often formed in the long-term perspective and are closely related to intangible factors.

Thus, the proposed methodology forms a broader understanding of ROI. It integrates the time aspect, takes into account the complex cost structure, and combines direct and indirect benefits. As a result, the indicator becomes not just a payback ratio but an analytical tool that makes it possible to justify digital investments in production systems and to compare alternative scenarios of their implementation.

5. Integration of ROI with corporate strategies

In modern manufacturing companies, the ROI indicator is no longer just a tool for evaluating investment projects and is increasingly regarded as an element of strategic management. Its role lies not only in reflecting the payback of solutions but also in serving as an indicator of their contribution to achieving the long-term goals of the enterprise.

The balanced use of this methodology is possible due to integration with the balanced scorecard system. This method involves considering several perspectives, namely financial, customer, internal processes, and innovation and development. In turn, ROI directly reflects financial performance while indirectly influencing increased customer satisfaction, reduced production cycle times, and growth of innovation potential. Thus, it becomes part of a broader system of metrics, which makes it possible to link it with comprehensive corporate key performance indicators (KPI) – table 2.

Table 2: Relationship between ROI of digital projects and corporate KPI

Balanced scorecard perspective	Corporate KPI	The role of ROI for DS
Financial	Earnings before interest, taxes, depreciation and amortization (EBITDA), marginality.	Confirms the economic effect of digitalization, expressed in increased profits and lower costs.
Client	Customer satisfaction, net promoter score.	Reflects the ROI in service and digital channels that increase loyalty.
Internal processes	OEE, labor productivity, cycle time.	Demonstrates the return from process optimization and loss reduction.
Innovation and development	Share of new products, speed of market launch.	Captures the ROI in new technologies and competencies.

Sustainable development	Environmental, social, and governance (ESG) indicators, energy consumption.	Connects digital projects with the financial impact of environmental and social initiatives.
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Such integration allows managers to see ROI as part of the overall picture of corporate performance. For example, the implementation of Manufacturing Execution System (MES) platforms may show a moderate ROI in the short term but at the same time improve OEE indicators and accelerate equipment changeovers, which in the strategic perspective increases EBITDA and profitability. Similarly, analytical platforms may demonstrate a moderate ROI at the implementation stage, but through optimizing energy consumption and reducing penalty risks, they strengthen ESG metrics, ensuring the company's sustainable development.

It acquires additional significance in portfolio management. Company management increasingly considers digital initiatives in aggregate, assessing their impact on strategic KPI and the resilience of the business model. In this context, ROI acts as a prioritization tool, meaning that projects with a high short-term effect can be financed in parallel with initiatives that create long-term value. Such a balance makes it possible to optimize resource allocation and reduces the risk of excessive concentration of investments in one direction.

It is important to emphasize that ROI, integrated with corporate strategies and KPI, ceases to be a static calculation and becomes a dynamic indicator. Its role lies in reflecting not only financial returns but also socio-economic results. As a result, its inclusion in the management system strengthens practice and contributes to a more balanced allocation of resources between projects of different scales and implementation horizons. This transforms ROI from a local financial indicator into a strategic tool that ensures the alignment of digital initiatives with the goals of sustainable development and the growth of enterprise competitiveness.

6. Practical application of the methodology

The methodology for calculating ROI for DS in production systems acquires particular significance when analyzing real implementation scenarios. To verify its practical applicability, it is advisable to consider the industry experience of industrial companies in the U.S. This approach makes it possible to identify the structure of costs and benefits, as well as to assess how performance indicators change when using various digital technologies.

The first example is related to the use of the Industrial Internet of Things (IIoT) for equipment condition monitoring. For instance, General Electric has implemented the Predix platform, designed for collecting and analyzing data from sensors installed on production units. Investments in the project included the installation of sensor networks, data collection equipment, and the development of analytical software, while current expenses concerned system maintenance and updates [4]. According to industry studies,

the use of these technologies in preventive maintenance made it possible to reduce equipment downtime by an average of 45-50% [5]. The obtained results indicate a high ROI_{disc} in relative terms, which confirms the economic feasibility of such initiatives.

Another direction is the implementation of MES platforms, covering dispatching, quality management, and product batch traceability. An example is the experience of Rockwell Automation, where the introduction of such a system made it possible to optimize production processes and improve the efficiency of supply chains [6]. The cost structure included CapEx for the purchase and integration of the solution, as well as OpEx for its support. The main effect was a reduction in defects, faster equipment changeover, and a decrease in work-in-progress. According to AMR Research, the use of such systems reduces production waste by 20% and accelerates equipment reconfiguration by 35% [7].

The final scenario illustrates the use of predictive analytics. Caterpillar actively applies it to optimize equipment maintenance and reduce total operating costs. Investments included the acquisition and integration of analytical platforms, while current expenses covered data processing and storage [8]. According to McKinsey, such implementation makes it possible to reduce maintenance costs by 10-40% and unplanned downtime by 30-50%. This approach strengthens both directions, namely increasing operational efficiency and reinforcing long-term financial sustainability [9].

Thus, the practical application of the ROI_{disc} calculation methodology demonstrates that the main drivers of the economic effect of DS are the enterprise's initial costs, the temporal profile of benefits, and the level of technology integration. These parameters make it possible to distinguish between short-term high-return initiatives and projects that create strategic long-term value.

7. Limitations and prospects of applying the methodology

The application of the ROI calculation methodology to DS in production systems makes it possible to formalize the assessment of economic efficiency and justify managerial decisions. However, when moving from the theoretical model to practical implementation, factors arise that can limit the accuracy of calculations and reduce their universality. They may be related both to the specifics of the cost and benefit structure and to methodological aspects of evaluation (table 3).

Table 3: Limitations of applying the ROI methodology for DS

Limitation	Content	Implications for performance evaluation
Quality of the source data	The presence of noise, incomplete or incorrect indicators, dependence on sensor calibration and stability of transmission channels.	Distortion of ROI calculations, overestimation or underestimation of the expected effect.
Selection of the discount rate	Difficulties in correctly assessing the cost of capital and risks in the context of technological and economic uncertainty.	Significant fluctuations in ROI values with small parameter changes.
Distribution of costs and benefits	Difficulties in attributing platform-wide costs and benefits between divisions.	The risk of incorrect allocation, reducing the accuracy of project comparison.
Accounting for indirect effects	Reputational, environmental, and social outcomes are difficult to express in financial terms.	Underestimating the strategic value of the DS.
Organizational barriers	Insufficient maturity of data management systems, KPI fragmentation, resistance to change.	Reducing the possibility of regular application of the methodology and deteriorating comparability of projects.

Along with the identified limitations, the ROI calculation methodology has significant potential for development. Of particular importance is the development of standards and procedures that ensure the comparability of calculations across different industries and companies. The unification of cost and benefit categories, the harmonization of calculation methods, as well as the application of unified operational metrics create the basis for conducting proper cross-industry benchmarking. This is especially important in the context of global digital transformation, when enterprises from different regions and economic sectors use similar technologies but interpret their results differently. Standardized approaches make it possible to eliminate methodological discrepancies and increase the reliability of comparative analysis.

A promising direction for the development of the methodology is the expansion of its scope through the inclusion of sustainability indicators. Factors ESG are becoming important indicators of investment attractiveness and are increasingly being taken into account by investors, regulators and society. The integration of these parameters into ROI calculation gives the metric additional value, making it possible to evaluate digital projects not only from the perspective of financial benefit but also in terms of their contribution to sustainable development. This approach reflects modern requirements for corporate responsibility and contributes to increasing trust from external stakeholders.

Further improvement of the methodology is also associated with increasing the accuracy of forecasts and the possibility of preliminary assessment of effects before the start of CapEx. In this context, a special role is played by the use of simulation modeling and digital twins. These tools make it possible to reproduce various scenarios of the functioning of the production system, analyze the sensitivity of indicators to changes in

important parameters, and forecast the potential benefits of technology implementation. Such practice reduces uncertainty and makes ROI calculation more reliable.

An equally important task is the development of data management methods on which the assessment is based. Quality control of information, validation of analytical models, regular monitoring of changes, and detection of data drift make it possible to minimize distortion risks and maintain the stability of the calculation system. Taken together, this contributes to the transition from one-time calculations to continuous analytical support of digital initiatives.

Thus, the ROI methodology cannot be considered a static and completed construct. It is gradually transforming into a comprehensive analytical tool that combines classical financial indicators with advanced methods of forecasting, modeling, and risk management. Such development ensures not only a more accurate reflection of the effectiveness of DS but also forms the basis for strategic planning in the context of the digital economy, where ESG effects are integrated into a unified evaluation system.

8. Conclusion

The methodological framework for evaluating digital initiatives in production systems requires adaptation to their specific features. The classical ROI does not reflect the full range of effects arising from digital transformation. Taking into account OpEx and the temporal structure of benefits, ROI_{disc} provides a more reliable understanding of the economic feasibility of such projects and creates the basis for strategically sound decisions.

The conducted analysis has shown that its use ensures a more accurate comparison of projects of different scales and implementation horizons. Unlike the simplified model, this approach considers the distribution of costs and benefits over time, making it possible to eliminate distortions in the evaluation of long-term initiatives. Practical examples from industry practice have demonstrated that the implementation of IIoT systems, MES platforms, and predictive analytics can not only increase operational efficiency but also create sustainable strategic value for enterprises.

At the same time, the identified limitations of the methodology do not diminish its importance but emphasize the need for further development. Thus, the ROI methodology in its updated form ceases to be only a payback calculation tool and transforms into a comprehensive analytical indicator. It provides the opportunity for strategic planning of digital initiatives, combining economic, social, and environmental effects into a unified evaluation system, and thereby becomes an important tool for increasing the competitiveness of manufacturing enterprises in the context of the global digital economy.

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Conflict of Interest Statement

The author declares no conflicts of interest.

About the Author(s)

Dmitry Pshychenko, Associate Professor, National Research University Higher School of Economics, Moscow, Russia.

SPIN: 5816-6510,

ORCID: <https://orcid.org/0009-0006-8866-8057>,

Email: dmitry.pshychenko@rambler.ru

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