Evaluation of investment efficiency in cyber-physical systems and technologies in the construction industry

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Abstract. Currently, cyber-physical systems and technologies are being actively implemented in the international practice of developing technology companies. The theory and methodology of their implementation are devoted to the works of various scientists who have studied both the technical and economic problems of their implementation. The article focuses on the issues of economic evaluation of the effectiveness of investments in cyber-physical systems. A system of economic indicators for evaluation has been formed, these indicators are gathered into five groups for analysis. The costs of their implementation are structured in six groups and become the basis for the development of a performance evaluation calculator. Also, an assessment of the risks was made, these risks affect the results obtained from the technology implementation. Five organizational steps are proposed for the digital development of an industrial company, which have become the basis for determining its digital maturity. The proposed methods can be used in the implementation of cyber-physical technologies in production of building materials.

1. Introduction

Cyber-physical systems and technologies are actively introduced at foreign enterprises. Currently, such a trend has come to Russia. A number of researchers study these issues. However, issues related to assessing the payback of such systems remain debatable in both economic science and business practice. Nowadays managers of high-tech enterprises and factories in Germany, the USA and China often use analysis of return on investment in cyber-physical technologies. When making decisions on a company development, the payback of RFID and digital logistics technologies, additive manufacturing, and augmented reality (AR) are most often evaluated. Analyzing Return on Cyber-Physical Systems (RoCPS), manufacturing businesses are boosting digital development after a self-assessment of digital maturity. In this regard, it is viable to develop and submit a universal RoCPS calculation model and use this tool when planning the development of production companies.

2. Literature review

The concept of cyber-physical technologies (CPS) was given the attention of various researchers, the results of which are presented in a number of scientific studies. Edward Lee proposed the following...
definition of CPS: “Cyber-Physical Systems (CPS) are integrations of computation with physical processes” [1]. In his research monograph he also defined the principles of functioning of cyber-physical systems as a way of production development [2]. Broy, Cengarle and Geisberger understood cyber-physical systems as Internet services, embedded systems, logistics, coordination and control processes that use sensors to collect and respond to physical data and processes using actuators [3]. Paulo Tabuada argues that CPS usually includes a network of physically distributed embedded sensors and actuators equipped with computing and communicating capabilities [4,5]. To systematize the definition of CPS, researchers from RWTH Aachen University Burggräf, Dannapfel proposed six technology clusters, shown in Table 1 [5].

| Table 1. Six technological clusters of cyber-physical technologies |
|---------------------------------------------------------------|
| **Actuators** | Manipulation of the physical world via hardware and software |
| | Technologies: MES, Robotics, SPS ... |
| **Sensors** | Collect data from physical world and transform it to the cyber world |
| | Technologies: RFID, infrared, microphone |
| **Human-Machine-Interface (HMI)** | Interface for human interaction with cyber-physical system |
| | Technologies: Apps, smart glasses, dashboards ... |
| **Transmission Technologies** | Infrastructure for exchanging data between the cyber and physical world |
| | Technologies: Ethernet, 4G, 5G, Bluetooth, WiFi ... |
| **IT-Infrastructure** | Infrastructure for storing and handling data inside the cyber world |
| | Technologies: Cloud, servers, blockchain ... |
| **Data Analysis and Processing** | Capabilities to analyze and process data from/for business operations |
| | Technologies: Big data, ERP... |

This approach takes into account both the physical elements of the system and the elements that interact directly with the “customer” - the managerial staff of the company, whose task is to make decisions based on the information received. Thus, in the enterprise’s digital system, the cyber-physical system is the managing subsystem, and the enterprise management system is the controlling system. The effectiveness of the implementation of cyber-physical systems proposed by the same scientists [5] distinguishes the Return on Investment indicator as a basic indicator of assessing the effectiveness of investments. Scientists Borovkov, Kupriyanovsky, Gandalyan, Shevchenko were engaged in the introduction of cyberphysical technologies in production [6,7,10,12,15]. Scientists from the Moscow School of Management SKOLKOVO P.N. Bilenko, S.L. Lysenko [6] identified 15 key components and systems of a modern manufacturing enterprise, which become key factors in its competitiveness. Among these factors are the enterprise’s information platform, modeling and optimization, digital twins, workstations, digital logistics, etc. All of them are elements or they are created on the basis of cyber-physical systems and technologies. Thus, cyber-physical systems are a key factor ensuring the competitiveness of a company engaged in manufacturing processes and producing industrial goods. This also works for building and construction businesses, despite the "traditionality" of this industry. The same authors proposed a methodology for assessing the digital maturity of a company, showing its willingness to implement cyber-physical systems. However, issues of a comprehensive assessment of the effectiveness of cyber-physical system and technology implementation need to be polished in terms of Russian environment.
3. Materials and methods
The background of this research was the theoretical insights of foreign scientists on the development of cyber-physical technologies, scientific and practical experience of their implementation in research laboratories and engineering centers of European universities, for example, RWTH Aachen University, Germany.
The authors’ practical experience of these technology implementation into production at Russian enterprises has also become the basis for determining the directions for evaluating their effectiveness. Statistical methods, mathematical model approach, and the cash flow discounting method were also used in this research.
The implementation costs and the results obtained were grouped according to the main characteristics, which became the basis for the cash flow generation for the project and determined the break-even point. The time factor implies the need for discounting to a planning horizon of more than a year.
The assumption is made that the discount factor is not applied for a monthly division.
The return on investment is the main indicator characterizing the effectiveness of the cyber-physical system and technology implementation in production. To determine it, the authors have developed a calculator that allows to become the basis for making a managerial decision on the project implementation.

4. Results
The experience of international and private companies shows that the increase in the efficiency of even the smallest business process can significantly change the financial result of the entire company. That is why one of the most important results of the analysis of the digital maturity of a company is not just to determine one priority way for the development of the company, but to identify the whole complex of such directions, the implementation of which can give an economic effect.
To determine the most effective areas and fields of digital development, a comparative economic analysis of the financial model of each area should be carried out.
The system for assessing the potential economic effect of the cyber-physical technology implementation includes the following areas of analysis:
1. Total implementation costs;
2. Profit and other benefits;
3. Risks;
4. Potential capacity (future flexibility).

Costs and Expenses
When implementing production processes at the enterprise, groups of production, administrative, managerial and marketing costs arise.
The introduction of cyber-physical technologies (CPS) involves a new group of implementation costs, which include the following:
1. Purchase, delivery and installation of equipment;
2. Purchase, installation and integration of software;
3. Retraining of production and engineering personnel;
4. Searching and hiring new staff;
5. Training of administrative staff.
The implementation of CPS cuts the costs of production and sales of products as compared to the base-case, CPS ensures efficiency and the achievement of profit targets.
The main cost items in the implementation of digital technologies are:
1. Server and client equipment;
2. Server and client software;
3. Professional services of implementation, configuration and system integration;
4. End-user training;
5. Internal administration for future management and support;
6. Operating costs involved in implementation.
More comprehensive feasible cost areas for the implementation of cyber-physical technologies are presented in Table 2.

**Table 2. Systematization of the feasible costs of implementing CPS**

| Equipment costs | Software costs | Data security and protection |
|-----------------|----------------|-----------------------------|
| Acquisition costs | Application | Access control |
| Hardware Components | Administration tools | Authorization systems |
| Customization costs for user interfaces | Databank Systems | Storage media |
| Customization costs for hardware interfaces | Software module | Storage Encryption |
| Sensors | Software development | |
| Network infrastructure | Software Updates | |
| Infrastructure costs | Project costs | Other expenses |
| New building, if necessary | Staff costs | Maintenance costs |
| Repairs | Training costs | Energy costs |
| Construction equipment | Consulting Costs | Communication costs |
| Server rooms | Design costs | |
| Warehouse | Travel expenses | |
| Internal logistics | Cost of renting premises | |

**Infrastructure costs**

| Resource Reduction | An increase in the volume of production due to a reduction in the production life cycle, a decrease in the level of rejects due to control at all stages of the production process. |
|---------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Reduction of processing time | Reduce time-consuming manual processes, reduce setup time and processing time. |
| Reduce cost due to errors | Minimisation of error rate, reduction of losses due to errors and fault correction time. |
| Cost savings on tangible fixed assets | Savings due to increased labor productivity. |

**Profit and competitive advantage of a business**

Factors of profit growth and increase of competitive advantages of a company:

+ Increase in labor productivity and equipment efficiency;
+ Reduced quality assurance costs;
+ Improved forecast accuracy and reduced time of market launch;
+ Reduced storage costs and product maintenance

The potential benefits of introducing cyber-physical technologies are summarized in Table 3.

**Table 3. Potential Benefits of Implementing CPS [5, 7]**

| Resource Reduction | An increase in the volume of production due to a reduction in the production life cycle, a decrease in the level of rejects due to control at all stages of the production process. |
|---------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Reduction of processing time | Reduce time-consuming manual processes, reduce setup time and processing time. |
| Reduce cost due to errors | Minimisation of error rate, reduction of losses due to errors and fault correction time. |
| Cost savings on tangible fixed assets | Savings due to increased labor productivity. |

**Customer Satisfaction**

Reduce strategic mistakes, keep and cut production and lead time.

**Improvements in information acquisition**

Availability of information that contributes to better process management.

**Quantitative benefits that can be assessed directly**

Quality benefits that are impossible or difficult to assess
Risks
Risk is the third important component in the system of evaluating the economic effect. It is used as a filter to determine the error in various cost estimates and estimated profit. The risks associated with the implementation of digital technology projects can be divided into several categories.

The first group includes non-specific risks, that is, directly or indirectly threatening the project. In this category there are macroeconomic risks (slowdown in economic growth in the country, fluctuations in exchange rates, etc.), administrative risks (changes in harmonization rules, legislation, etc.), as well as force majeure circumstances. To reduce them is almost impossible. The project insurance is the main method of dealing with these risks.

Specific risks are a tool to influence project performance. They can and should be managed. Specific risk assessment indicators are divided into qualitative and quantitative. A qualitative risk analysis involves classifying them into groups, assessing the impact and likelihood of occurrence. The risk falling into the “critical” group requires the closest attention from the developers of the project who implement cyber-physical systems.

Quantitative risk assessment is carried out on the basis of an analysis of the project's sensitivity to changes in its cost items.

The most common risks when implementing CPS:
- Installation and testing may require more days for consulting services.
- The speed of implementation may be slower than planned.
- The increase in profit per employee in each group of employees may be lower.
- The amount of money saved may be less than intended.
- Estimated profit due to the reduction in the terms of project implementation, the reduction of trading cycles, cost savings may be lower than planned.

The risk adjustment is determined based on the risk limits. The risk limits are determined according to table 4.

| Risk magnitude | Project concept                        | R, %   |
|----------------|----------------------------------------|--------|
| Low            | Reduction of production cost           | 6 – 10 |
| Mid            | Increased sales of existing products   | 8 – 12 |
| High           | Production and marketing of a new product | 11 – 15 |
| Very high      | Investing in research and innovation   | 16 – 20 |

Potential capacity (future flexibility)
This element is an investment in additional opportunities or action speed today, which can be turned into additional profit for some additional costs in the future. This gives the company a “right” or ability (rather than an obligation) to be engaged in future initiatives.

The economic effect of a new technology implementation is determined by the formula:

\[ Et=(C_{base} – C_t)N_t=[(P_{costbase} + En_{Ibase}) – (P_{costt} + En_{It})]N_t \]  [6,15]

where

- Et – economic effect of new technology, rub.;
- C_{base} – unit production costs using a basic technology, rub.;
- C_t – unit production costs using a new technology, rub.;
- N_t – annual production using new technology, items.;
- P_{costbase} – basic product cost, rub.;
- P_{costt} – new technology product cost, rub.;
- En_{Ibase} – investment per basic unit of production, rub.;
- En_{It} – investment per basic unit of production using a new technology, rub.;
En – normative effectiveness ratio. This formula is the basis for calculating the economic effect of implementing a new technology in almost any company.

In addition to the absolute financial effect in monetary units, a key performance indicator is the profitability index, the return on investment.

The profitability index is the ratio of the sum of cash flows of the project’s income, reduced to unit time, to the volume of investments. An effective project is one with a profitability index of more than 1. This indicator must be considered in connection with the absolute effect of the project. When comparing two projects with the same absolute effect, choose the one whose profitability index is higher.

The return on investment is determined by the period of time necessary to ensure that the additional income generated from the new technology implementation covers the cost of its implementation.

For a preliminary calculation of the economic effect indicators, it is proposed to use the RoCPS calculator (http://bit.ly/2C5PCB4).

\[
\text{RoCPS} = \frac{(R_t - I_t)}{I_t} \times 100\%
\]

RoCPS - return on investment in cyber-physical technologies (Return On Investment)
Rt - amount of growth in revenue (income) from the technology implementation (Revenue)
It – amount of investment in technology (Investment)
An example calculation is presented in Tables 5-7.

### Table 5. Cyber-physical Costs (CPS), in nominal dollars.

| No | Name                          | Units | Quantity | Price per unit | Sum of money |
|----|-------------------------------|-------|----------|----------------|--------------|
| 1  | **Equipment**                |       |          |                | € 60,000     |
| 1.1| Server equipment             | pcs.  | 1        | € 10,000       | € 10,000     |
| 1.2| Client Equipment             | pcs.  | 100      | € 500          | € 50,000     |
| 2  | **Software**                 |       |          |                | € 30,000     |
| 2.1| Licenses                     | pcs.  | 100      | € 100          | € 10,000     |
| 2.2| Customization and Integration| work hr | 20 | € 1,000 | € 20,000 |
| 3  | **Other expenses**           |       |          |                | € 70,000     |
| 3.1| User training                | work hr | 50 | € 700 | € 35,000 |
| 3.2| Maintenance and support      | work hr | 100 | € 300 | € 30,000 |
| 3.3| Operating expenses and overheads | 1 | € 5,000 | € 5,000 |
|    | **Total costs**              |       |          |                | € 160,000    |

### Table 6. Calculation of the amount of revenue growth from the CPS implementation, in nominal dollars.

| No | Name                                | Units | Dif. | Base a month | Outcome in a month |
|----|-------------------------------------|-------|------|--------------|-------------------|
| 1  | **Performance Improvement Effect**  |       |      |              |                   |
| 1.1| reduction of direct costs           | %     | 2.0% | € 100,000    | € 2,000           |
| 1.2| reduction of the tax base due to depreciation | % | 0.5% | € 90,000 | € 450 |
| 1.3| reduction of working hours          | work hr | 100 | € 150 | € 15,000 |
| 2  | **The effect of improving the quality and speed to market** | | | | |
| 2.1| reduction of warranty costs         | %     | 5.0% | € 10,000    | € 500            |
| 2.2| increase of sales                  | %     | 5.0% | € 150,000   | € 7,500          |
| 2.3| rise of sales process              | %     | 3.0% | € 20,000    | € 600            |
| 3  | **The effect of process optimization** | | | | |
| 3.1| reduction of stocks, warehouses     | %     | 2.0% | € 30,000    | € 600            |
| 3.2| withdrawal of inefficient technologies | % | 2.0% | € 25,000 | € 500 |
3.3 Acceleration of technological processes

| Name                  | Risk ratio, % | Potential ratio, % | Plan  | Risk-based plan |
|-----------------------|---------------|--------------------|-------|-----------------|
| Costs and expenses    | 3.0%          |                    | € 160,000 | € 164,800       |
| Revenue growth        | -3.0%         | 5.0%               | € 27,300 | € 27,846        |

Table 7. Calculation of risk and potential impact indicators

Total revenue growth

Table 8. Adjustment of risk and potential indicators

| NO | Indicators             | Data       |
|----|------------------------|------------|
| 1. | Costs (investments)    | € 164,800  |
| 2. | Monthly revenue growth | € 27,846   |
| 3. | Return on investment, month | 5.9       |
| 4. | First Year ROI         | 102.8%     |

Figure 1. The effectiveness of the cyber-physical technology implementation in production (implementation of sensors for survey of structures)

After a preliminary assessment, which gives a preliminary idea of the economic effect of a particular technology implementation, all the factors of the model’s key indicators should be analyzed in more detail. That means to expand and verify the planned costs and profit growth and to assess the degree of risk and potential impact in the future.

5. Discussion

When implementing cyber-physical systems and technologies into production, special attention should be paid to the selection of priority areas or fields for the digital technology development, since it is more important to choose a system that has a long-term potential for total economic impact than one that has the best rate of return on investment or profitability in the first year. This, in turn, depends on the strategy chosen by each particular company.

A specific feature of digital development is that a company that has reached a high degree of digital maturity can create its own digital platform. It can help to diversify its core business, to implement industry services, in the whole range, from consulting to practical solutions. That is, thereby moving
from the use of digital tools and means in production to the production and sale of digital tools and means of production and services. It expands the company's production program with digital products. Companies implementing digital technology, have relevant data arrays. These assets are systematically organized and operate with high efficiency in highly organized and smart companies. But there is the potential to improve their quality using appropriate management approaches and technologies. Based on an analysis of the activities of a number of technology companies in Germany and Russia, five organizational steps for the digital development of the company are proposed. They are presented in Fig. 2.

Thus, it is necessary to diagnose digital maturity to ensure the competitiveness of the company, as well as to introduce dynamic financial models into its activities. To draw conclusions about the impact of technology on the efficiency of business processes, it is necessary to test hypotheses implementing short, low-cost iterations in corporate innovation offices and / or centers for digital development of industries.

6. Conclusions
1. After assessing the digital maturity of the company and before making management decisions on development, it is necessary to conduct business process modelling and calculate the economic effect of cyber-physical technology integration. That is the basis for making a managerial decision on investment in a project.
2. Currently, the most cost-effective technologies for a small or medium-sized manufacturing enterprise are:
   - Augmented reality (AR), in particular, for training and staff development;
   - RFID, RTLS, WMS - subsystems of cyber-physical logistics;
   - rapid prototyping and additive technologies;
   - digitization and integration of supply chains;
   - data collection and management of physical assets, workshops and production centres to monitor the implementation of production programs and company productivity management (MDC and MES);
   - CAE analysis - digital modelling and product optimization.
3. This article proposes a free RoCPS calculator that small and medium-sized enterprises can use to make decisions on investments in cyber-physical technologies based on the results of evaluating the

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**Figure 2.** Five organizational steps for the digital development of the company

- Diagnostics and benchmarking of digital maturity in selected areas of cyber-physical technologies for companies
- Financial modelling of change projects or technology implementation, RoCPS analysis
- Development of company teams in acceleration or educational programs
- Change management
- Achievement of goals and objectives of change projects - development of labour productivity and financial performance of business
company's digital maturity. A company can independently develop a similar economic tool to assess the return on investment in cyber-physical technology.

4. The most high-quality assessment of the return on investment in cyber-physical technologies is carried out by companies’ teams trained in practice-oriented educational programs at management schools and centers for digital development of constructional industries.

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