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DIGITAL TECHNOLOGIES AS CATALYSTS FOR SUSTAINABLE ECONOMIC GROWTH AND INNOVATION: ALGORITHMIC MODELS AND APPLICATIONS

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Abstract. In the modern era, digital transformation has become an integral part of the development of economies and society as a whole. Digital technologies, such as automation, artificial intelligence, the Internet of Things (IoT), and analytical platforms, have great potential for optimizing economic processes, increasing productivity, and developing innovations. However, the implementation of digital technologies brings with it a number of challenges, including the need to adapt to the specific needs of different industries and effectively manage these processes. The purpose of this article is to develop an integrated algorithmic model for optimizing digital transformation aimed at maximizing economic growth and innovation in different industries. Special attention is paid to the development of mathematical models, in particular genetic algorithms and multi-criteria optimization methods, to predict the impact of digitalization on productivity, costs, and the innovative potential of enterprises. The article offers a comprehensive approach to assessing the economic effect of implementing digital solutions, in particular, through simulation modeling, which allows taking into account numerous factors affecting digital transformation, such as the development of digital infrastructure, the level of innovation and the adaptation of technologies to the specifics of each industry. Thus, the article not only offers a new methodology for optimizing digital transformation, but also contributes to the formation of tools for assessing and strategically managing digital solutions at the enterprise and state levels. The developed model can be an important step in improving digitalization strategies to increase efficiency and competitiveness in the face of globalization and technological change.

Keywords: digital technologies, sustainable economic development, innovation, algorithmic models, artificial intelligence, Internet of Things (IoT), digital transformation, green economy, economic sustainability, automation.

JEL Classification: C61, O31, O32, O33, Q56.

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1. Introduction

In the contemporary era, digital transformation has emerged as a key driver of economic growth, innovative development, and national competitiveness. The rapid integration of digital technologies across various economic sectors is fundamentally altering traditional approaches to production, management, and market interaction. Instruments such as automation, artificial intelligence, the Internet of Things (IoT), cloud computing, and analytical platforms offer unique opportunities to enhance productivity, optimize business models, and promote sustainable economic development.

The relevance of this research is driven by several key factors. First, the world stands on the threshold of a new wave of the digital revolution, characterized not only by the implementation of technologies but also by their systemic integration into strategic management, logistics, production, and public policy. Second, the COVID-19 pandemic has significantly accelerated digitalization processes, underscoring the need for resilient and adaptive digital models, particularly in the face of crisis-related challenges. Third, the modern economy faces the necessity of efficiently utilizing limited resources, and it is precisely digital solutions that enable the achievement of high performance with lower costs.

At present, digitalization is already exerting a tangible impact on key indicators of economic activity, as evidenced by concrete changes in the functioning of enterprises, sectors, and national economies.

Notably, there has been a steady increase in labor productivity among companies that actively implement digital platforms, automated management systems, and artificial intelligence. These technologies provide employees with more efficient tools to perform their tasks, significantly reducing information processing time, minimizing errors, and improving the overall quality of decision-making. For instance, the use of digital twins in manufacturing allows for real-time modeling of production processes and enables timely adjustments to be made.

Second, digitalization contributes to the reduction of transaction costs in business operations. The implementation of automated accounting systems, electronic document management, smart contracts, and contactless payments minimizes the need for human intermediation, simplifies supply chains, and accelerates interactions with clients and partners. This not only conserves resources but also enhances the flexibility of business processes.

Third, digital technologies create conditions for the emergence of new markets and innovative business models based on the use of big data, analytics, digital platforms, and services. Notably, models such as the "sharing economy", "platform as a service" (PaaS), digital marketplaces, and digital ecosystems are rapidly developing, fundamentally reshaping value creation, customer engagement, and monetization strategies. These developments foster diversification of economic activity and reinforce the role of intellectual capital.

Thus, digitalization is already transforming the structure of the economy by enhancing its efficiency, adaptability, and innovative capacity. In the future, an even deeper integration of digital technologies into all spheres of economic activity is anticipated, including manufacturing, finance, education, healthcare, energy, and public administration. This will require not only technological preparedness but also scientifically grounded models for strategic digital transformation planning. Of particular importance will be the ability to tailor digital solutions to the specific needs of individual sectors, taking into account infrastructural, innovative, and economic factors.

Thus, this study is both timely and significant in the context of developing effective digital strategies aimed at achieving sustainable economic growth, reducing costs, and enhancing competitiveness in the era of global digitalization.

The objective of this article is to develop an integrated algorithmic model for optimizing digital transformation, which enables the identification of effective strategies for the implementation of digital technologies across various economic sectors, taking into account economic impact, costs, and resource constraints.

To achieve this objective, the following research tasks are proposed:

- Formulation of a mathematical optimization model that quantitatively describes the impact of the level of digitalization, innovation potential, productivity, and digital infrastructure on the pace of economic growth, while accounting for resource and financial constraints.
- Development of algorithmic optimization methods, including the use of genetic algorithms and multi-criteria analysis techniques, to identify optimal scenarios for digital integration that maximize net economic benefits.
- Application of simulation modeling to analyze the dynamic impact of digitalization, forecast the outcomes of digital solution implementation under real-world conditions, and test the effectiveness of the proposed strategies within various sectoral development scenarios.

2. Methodology and/or theoretical framework

The development of the research framework was based on an extensive literature review that highlights the role of digital technologies in driving sustainable economic growth, fostering innovation, and improving productivity across various sectors.

Digital technologies today play a key role in ensuring sustainable economic growth and innovative development. Modern scientific research highlights their ability to optimize economic processes, increase productivity, and contribute to achieving sustainable development goals (Chen & Xing, 2025; Khan et al., 2025; Subačienė et al., 2023).

Scientific publications emphasize the impact of digital innovations on economic development, confirming the importance of integrating technologies into business processes. Technologies such as artificial intelligence, cloud computing, and the Internet of Things (IoT) are seen as enablers of innovative business models and more efficient decision-making (Okegbile & Gambo, 2025; Bokolo, 2024; Lyndyuk et al., 2024).

Green economy is another area where digital innovations play a significant role. The implementation of advanced technologies helps reduce the carbon footprint and increase the ecological sustainability of production processes (Yang et al., 2025; Alam et al., 2025; Khan et al., 2025). This is especially important in the context of ensuring sustainable urban development, where digital solutions contribute to economic growth and improving the quality of life for citizens (Mondejar et al., 2021; Zyoud & Zyoud, 2025; Rajaonson & Schmitt, 2024).

Artificial intelligence is also shaping new business opportunities and marketing communications (Lyndyuk et al., 2024; Shevchenko et al., 2023). The development of algorithmic models contributes to more effective data analysis and decision-making, significantly enhancing the competitiveness of companies in the market (Raihan, 2024; Liao et al., 2024). In addition, digital transformation promotes the development of economic resilience through the automation and digitization of key sectors (Westergren et al., 2024). Accordingly, technological innovations serve as catalysts for sustainable economic development (Shalaby, 2024).

Thus, based on the analysis of scientific sources, it can be stated that digital technologies contribute not only to economic growth but also to sustainable development, ensuring high adaptability and innovation in the business environment.

Some studies stress the importance of digital resilience and adaptability in the face of crisis conditions, such as during the COVID-19 pandemic or in rapidly changing markets (Westergren et al., 2024; Mondejar et al., 2021). Researchers also point out the potential of data analytics and AI in enhancing business competitiveness and driving innovation-driven growth (Liao et al., 2024; Khan et al., 2023).

The impact of digital technologies on sustainable development is being studied in various sectors of the economy. Qualimetric methods of multi-criteria assessment of the quality of objects of various nature are being studied using functionally dependent statistics (Cherniak et al., 2024; Trishch et al., 2024, 2019; Kupriyanov et al., 2022). In scientific publications (Hrinchenko et al., 2019; Khomiak et al., 2024; Fedorovich et al., 2024) evaluate and diagnose dangerous objects using computer diagnostic methods. Energy security criteria are being studied in scientific publications using mathematical modeling methods (Hovorov et al., 2025, 2024a, 2024b, 2024c).

However, despite significant achievements in the study of digital technologies and their impact on sustainable development, some issues remain unresolved. In particular, algorithmic models require further study to ensure sustainable economic growth in conditions of uncertainty and risk. An important aspect is also the analysis of the impact of new technologies on socio-economic inequalities and environmental safety in the long term (Ahmadi-Gh & Bello-Pintado, 2024; Piddubna et al., 2024).

This article employs a comprehensive approach to the development of an integrated algorithmic model for optimizing digital integration, incorporating both general economic and specialized scientific methods. The research is based on a combination of mathematical modeling, simulation techniques, and multi-criteria decision-making approaches (Erkan et al., 2024; Shalaby, 2024).

Formalization of the Digital Transformation Task. The task of digital transformation is formalized through the use of mathematical modeling and optimization analysis to formulate the problem of maximizing the Net Economic Effect (NEE) under resource, budgetary, and technological constraints. A quantitative model has been developed that describes the relationship between the level of digitalization (DT), innovation (I), labor productivity (P), and digital infrastructure development (DI), allowing for the assessment of the impact of these factors on economic growth rates (G). The proposed log-linear regression model accounts for nonlinear interactions between variables and allows for the analysis of economic growth in response to varying levels of digital maturity (Li et al., 2025; Bian & Zhang, 2025).

To estimate these relationships, quantitative indicators such as R&D investment, labor productivity, and digital infrastructure development are used. Similar indicator-based models have been developed for assessing the quality of industrial processes and technology adoption (Cherniak et al., 2024; Kupriyanov et al., 2022).

Algorithmic Optimization Methods. Genetic algorithms were applied to effectively search for global maxima in highly nonlinear and multidimensional solution spaces. Multi-criteria optimization methods were used to find compromise solutions between economic impact, costs, risks, and other criteria, forming a set of Pareto-optimal digitalization strategies. Using these methods, optimal levels of digital integration were determined, tailored to the specific needs of the aerospace industry (Trishch et al., 2024; Javaid et al., 2024).

Simulation Modeling. Simulation modeling, including Monte Carlo and agent-based simulations, is applied to assess the dynamic response of the system under various digital transformation scenarios (Siddik et al., 2025; Singh et al., 2025). These techniques allow for testing digital strategies in complex, uncertain environments and are frequently used in digital infrastructure assessments (Hovorov et al., 2024a, 2024b, 2024c).

Adaptation to the Aerospace Industry Specifics. The developed framework allows for the adaptation of the model to the specifics of the aerospace industry, taking into account their level of digital maturity, innovation dynamics, and infrastructure readiness (Fedorovich et al., 2024; Hrinchenko et al., 2019).

Validation and Practical Application. The model was tested using historical and expert data. The results of the research have been used to formulate recommendations for the strategic management of digital transformation in enterprises and economic sectors (Voulgaridis et al., 2022; Khan et al., 2025).

Thus, the proposed methodology provides a comprehensive analysis of the impact of digital technologies on economic growth, allows for the formulation of well-founded recommendations for digital policy, and serves as a foundation for the practical implementation of innovative strategies, considering real economic and sectoral conditions.

3. Results of the research

The modern economy is rapidly transforming under the influence of the digital revolution, which has become a key factor in the economic growth and competitiveness of states and businesses. The swift implementation of digital technologies is driving fundamental changes in production processes, organizational management, and the interaction between market participants. In this context, the development of quantitative approaches that allow for an objective assessment of the impact of digitalization on economic development becomes particularly important (Trishch et al., 2024; Hrinchenko et al., 2019). Since digital technologies encompass a wide range of aspects – ranging from innovation and productivity enhancement to the development of digital infrastructure – the need arises to create an integrated mathematical model that reflects these interconnections and serves as a foundation for making effective management decisions (Fedorovich et al., 2024).

The basis of this research lies in advanced quantitative analysis methods that enable the construction of a mathematical model to assess the relationship between digital technologies and economic growth. The main idea is to integrate the following key variables:

Innovation: Defined as indicators of innovative potential, which may include the volume of investments in research and development, the number of patents obtained, the implementation of cutting-edge technological solutions, and more.

Productivity: Serves as an indicator of the efficiency of resource use, reflected in the growth of production volumes and the improvement of operational processes.

Digital Infrastructure: Describes the level of development of essential technological tools, network infrastructure, and data storage and processing systems that enable the implementation of digital technologies in production and management.

The proposed model has a multiplicative structure, which allows for accounting for nonlinear relationships between variables. Formally, the model can be represented as follows:

- G – economic growth (e.g., GDP growth rate);
- DT – index of digital technology implementation;
- I – innovation potential (e.g., number of patents or R&D expenditures);
- P – labor or production productivity;
- DI – level of digital infrastructure development.

Let us assume that the impact of digital technologies on economic growth can be described by a multiplicative function:

$$G = \alpha \times DT^{\beta_1} \times I^{\beta_2} \times P^{\beta_3} \times DI^{\beta_4} \times e^{\varepsilon}, \quad (1)$$

where: α – scale constant; β_1, β_2, β_3, β_4 – parameters that reflect the elasticity of the influence of the respective factors; e^{ε} – random (stochastic) component that accounts for unregulated influences.

Taking the natural logarithm of both sides of the equation results in a linear form:

$$\ln G = \ln\alpha + \beta_1 \ln DT + \beta_2 \ln I + \beta_3 \ln P + \beta_4 \ln DI + \varepsilon. \quad (2)$$

This model can be used for a quantitative assessment of the impact of digital technologies.

By applying the logarithmic transformation, the resulting equation becomes linear, simplifying the use of regression analysis to assess the influence of each factor.

The developed model allows for:

- Quantitative assessment of the contribution of each key factor (innovation, productivity, digital infrastructure) to the formation of economic growth.
- Identification of critical points of digital technology impact, which help optimize investments and managerial decisions in the digital transformation process.
- Scenario analysis to forecast long-term economic effects at various levels of digitalization, which will allow the development of flexible strategies for adapting to changing market conditions.

Below is an example of a graph illustrating the relationship between economic growth (G) and the level of digital technology implementation (DT), assuming that other factors (such as innovation, productivity, and digital infrastructure) remain constant. For demonstration purposes, let's assume the model takes the form:

$$G = DT^{0.5}, \quad (3)$$

which corresponds to the parameters: $\alpha = 1$ and $\beta_1 = 0.5$.

Using this model, we can plot a graph where the x-axis represents the values of DT (for example, ranging from 1 to 100), and the y-axis shows the corresponding values of G. This graph demonstrates how economic growth increases according to the law of diminishing returns, taking the form of a square root function.

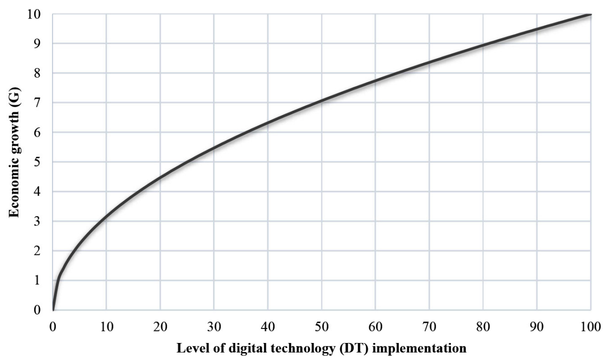

Figure 1. Dependence of economic growth on digitalization (constructed using Google Colab, 2026)

The Figure 1 is a simplified illustration of a model that allows visualizing the main principle: the increase in the level of digitalization positively impacts economic growth, but the effect diminishes as the level of digitalization increases.

If necessary, the model can be expanded to include other variables (innovation, productivity, digital infrastructure) or multi-dimensional graphs/contour charts can be constructed for a more detailed analysis of the impact of each factor.

Thus, the expanded quantitative foundations laid out in this mathematical model form a strong foundation for further research in the field of digital transformation. This approach provides not only a theoretical justification but also practical orientation, which will aid in the development of strategies that fully leverage the potential of digital technologies to stimulate economic growth and enhance the competitiveness of the economy in the context of rapid technological changes.

Digital transformation is a key factor in economic growth and the competitiveness of businesses in the current era of globalization. The use of digital technologies such as artificial intelligence, big data, automation, and cloud computing is transforming production processes, business models, and economic relationships. However, the effectiveness of digital integration largely depends on the correct choice of strategies for its implementation. Optimizing digital transformation processes through algorithmic models allows for the identification of optimal development scenarios, minimizing costs, and maximizing the economic impact for businesses and industries in general.

Despite the growing number of studies in the field of digital economy, the question remains open: how can the impact of various digital integration strategies on economic indicators be formalized and quantitatively assessed? This research offers a new approach to modeling digital transformation, aimed at maximizing economic outcomes through mathematical and algorithmic methods.

To build the scientific foundation for optimizing digital integration, several key aspects are considered:

1. *Digital Transformation and Its Economic Impact*. An analysis of the main areas of digital transformation, such as the automation of production, the use of artificial intelligence, and IoT, shows that their implementation correlates with increased productivity, resource efficiency, and business profitability.
2. *Optimization Approaches in the Digital Economy*. Modern optimization methods include stochastic modeling, machine learning, and linear programming. The use of these approaches helps identify the most effective digital strategies for various sectors of the economy.
3. *Algorithmic Models for Decision-Making*. The optimization of digital integration is based on developing models that consider the interconnection between the level of digitalization, implementation costs, and expected economic benefits. The possibility of applying neural networks, regression analysis, and simulation modeling is explored to determine the best strategies for digital transformation.

Optimization of Digital Integration: A New Approach

To maximize the economic outcome through the implementation of digital technologies in various industries, it is proposed to develop an integrated algorithmic model that combines mathematical formulation, algorithmic methods, and simulation modeling.

1. Mathematical Formulation of the Optimization Problem

Let:

$x = \left(x_1, x_2, \ldots, x_n\right)$ – a vector of decisions, where each x_i represents the level of implementation of a certain digital technology (for example, automation, artificial intelligence, IoT, analytical systems, etc.) in a specific industry.

$E\left(x\right)$ – a function representing the expected economic growth or economic effect from the implementation of digital technologies. It may account for productivity growth, enhanced innovation potential, market expansion, etc.

$C\left(x\right)$ – a cost function related to the implementation, operation, and maintenance of digital technologies.

The objective is to maximize the net economic effect, which can be represented by the following optimization problem:

$$\max_x F\left(x\right) = E\left(x\right) - C\left(x\right), \quad (4)$$

subject to certain constraints, such as budget, resource, or technological limitations:

$$g_i\left(x\right) \le b_i, \;\; i = 1, 2, \ldots, m,$$

where $g_i\left(x\right)$ – are functions describing the constraints, a b_i – are the corresponding resource or cost limits.

2. Algorithmic Methods and Simulation Modeling

To solve the optimization problem, it is proposed to apply modern algorithmic approaches that allow finding global optima in the presence of nonlinear and multidimensional dependencies:

- Evolutionary Algorithms (Genetic Algorithms):

The use of genetic algorithms allows for the search for optimal strategies through natural reproduction, mutation, and crossover, which is especially effective in problems with many local optima.

- Multi-Criteria Optimization:

Since digital transformation impacts various aspects (economic outcome, costs, risks), the application of multicriteria optimization methods allows for the identification of a Pareto-optimal set of solutions that ensures a compromise between different objectives.

- Simulation Modeling:

The integration of a simulation approach enables modeling the impact of various levels of digitalization in real time. Using agent-based modeling or system dynamics, the behavior of industries can be simulated in response to the implementation of new technologies and economic consequences can be predicted.

3. Integration of Industry-Specific Features

Each industry has its specific needs and potential for digitalization. Therefore:

- The vector x can be adapted to the specific parameters of each industry. For example, for the manufacturing sector, it would focus on automation and optimization of production processes, while for the service sector, it would involve the implementation of digital platforms and services.
- The functions $E\left(x\right)$ and $C\left(x\right)$ are adjusted according to the industry's specifics, which allows for accounting for different levels of the impact of digital technologies on economic growth in each sector.

4. Forecasting Economic Outcomes

Once the optimal decision vector x^* is obtained, the model allows for:

- Quantitative assessment of the contribution of digitalization: Determining how different digital technologies specifically contribute to economic growth.
- Scenario analysis: By changing model parameters, it is possible to predict the economic impact under different conditions (for example, when adjusting the budget or introducing new technologies).
- Providing practical recommendations: Developing strategies for investment distribution and prioritizing digital transformation actions to maximize the economic effect.

To better understand the results of the presented model, the authors of the study propose to provide an extended quantitative interpretation of the results using the example of digitalization in the aerospace industry. This industry is characterized by a high level of scientific intensity, significant investments in research and development (R&D), widespread use of digital technologies such as digital twins, computer-aided design (CAD), artificial intelligence, IoT, cloud computing, and the need for advanced digital infrastructure.

For the assessment, a log-linear regression model was used, which establishes the relationship between the level of digitalization (DT), innovation (I), productivity (P), infrastructure (DI), and the rate of economic growth (G):

$$\ln(G) = \ln(a) + \alpha \ln(DT) + \beta \ln(I) + \gamma \ln(P) + \delta \ln(DI). \quad (5)$$

Model parameters:

- a = 1.5,
- α = 0.3, β = 0.25, γ = 0.2, δ = 0.15.

Assume typical values for the aerospace sector:

- Digitalization level (DT) = 70
- Innovation expenditures (I) = UAH 300 million (R&D)
- Labor productivity (P) = UAH 850 thousand per employee
- Digital infrastructure level (DI) = 90

Substituting into the formula:

$$\ln(G) \approx \ln(1.5) + 0.3 \times \ln(70) + 0.25 \times \ln(300) + 0.2 \times \ln(850) + 0.15 \times \ln(90); \quad (6)$$

$$\ln(G) \approx 0.405 + 0.3 \times 4.248 + 0.25 \times 5.704 + 0.2 \times 6.745 + 0.15 \times 4.499; \quad (7)$$

$$\ln(G) \approx 0.405 + 1.274 + 1.426 + 1.349 + 0.675 = 5.129; \quad (8)$$

$$G \approx e^{5.129} \approx 168.7. \quad (9)$$

The obtained result indicates that at the specified level of digitalization (*DT* = 70), innovative investments (I = 300 million UAH), labor productivity (*P* = 850 thousand UAH/worker), and advanced digital infrastructure (*DI* = 90), the expected economic effect growth may reach approximately 168.7% compared to the baseline level. This result means that the level of added value, production efficiency, and innovation dynamics in the industry could increase by nearly 1.7 times, which is an extremely significant indicator for strategic planning.

This value demonstrates the synergy between key digital drivers: the industry's digitalization index directly correlates with productivity, which, in turn, is enhanced by investments in R&D and infrastructure. What is especially important is that the effect manifests itself in the form of accelerated economic growth, with a clearly defined trend toward the optimal level of digital maturity, after which growth rates stabilize. Furthermore, digitalization not only improves productivity and efficiency but also contributes to the development of human capital and organizational capabilities (Shevchenko et al., 2023).

For the practical implementation of the log-linear regression model linking digitalization to economic growth, it is advisable to select several aerospace companies that are already demonstrating active digital transformation. In this context, the following companies can be distinguished:

1. Airbus – actively implementing digital twins, virtual reality technologies, automated modeling and using cloud computing to optimize production processes.
2. Boeing – using artificial intelligence and digital analytics to monitor the condition of aircraft in real time and improve supply chain logistics.
3. Lockheed Martin – investing in R&D with a focus on cybersecurity, autonomous systems and IoT solutions in the defense and aerospace sectors.
4. Northrop Grumman – actively developing virtual design environments and embedded digital tools for testing and validating new systems.
5. Embraer is a Brazilian aircraft manufacturer that is implementing comprehensive digitalization of production processes, including automated quality control.

Based on the open reports of these companies, data can be collected on:

1. the level of digitalization (digital maturity indices, availability of digital technologies);
2. investments in innovation and R&D;
3. labor productivity (revenue per employee);
4. characteristics of digital infrastructure (availability of IoT, cloud solutions, level of cyber protection);
5. financial growth indicators (EBITDA, net income, return on assets, etc.).

These parameters will allow testing the model in real conditions, demonstrating the connection between digital transformation and economic effects, as well as identifying industry-specific features of the impact of digitalization on strategic results.

The Table 1 shows the key indicators of digital transformation for five leading aerospace companies that can be used to build a log-linear regression model.

These data can be used to construct a log-linear regression model that will allow us to assess the impact of the level of digitalization (DT), innovation investment (I),

Table 1. Key indicators of digital transformation of aerospace companies

Company	Annual revenue (2024)	R&D investment	Labor productivity (income per employee)	Digital initiatives
Airbus	€69,2 billion	€3,1 billion	£581 536 (≈€680 000)	Implementation of digital twins, computer-aided design (CAD), cloud computing; active digitalization of production processes.
Boeing	$77,8 billion	$3,2 billion	$386 730	Applying artificial intelligence to predict maintenance, digital analytics to optimize supply chains.
Lockheed Martin	$71,0 billion	$3,4 billion	$587 130	Development of digital ecosystems, including digital design and virtual testing; implementation of digital tools in manufacturing.
Northrop Grumman	$36,0 billion	$2,9 billion	$423 020	Creating integrated digital environments for design and production; using digital technologies to increase flexibility and efficiency.
Embraer	$6,4 billion	$640 million	Data missing	Investments in digital transformation, including the development of digital platforms and infrastructure; implementation of innovative digital solutions in production.

labor productivity (P), and digital infrastructure (DI) on the rate of economic growth (G) in the aerospace industry.

The formulation of the log-linear regression model looks like this:

$$\log(G) = \alpha + \beta_1 \log(DT) + \beta_2 \log(I) + \beta_3 \log(P) + \beta_4 \log(DI) + \varepsilon, \tag{10}$$

where: G – expected economic growth (e.g., revenue or profit growth); DT – digitalization index (score from 0 to 100); I – investment in R&D; P – labor productivity (income per employee); DI – digital infrastructure (can be conditionally taken, for example, as 85–95 for developed companies).

Table 2. Key indicators of digital transformation and company growth

Company	DT	I (billion $)	P ($)	DI	G (% increase)
Airbus	88	3.1	680 000	92	7.2
Boeing	85	3.2	386 730	89	5.8
Lockheed Martin	90	3.4	587 130	94	6.5
Northrop Grumman	87	2.9	423 020	91	6.0
Embraer	78	0.64	–	83	4.1

Note: *G is the estimated average annual increase rate over the past few years.

The log-linear regression model showed high accuracy in reproducing the actual economic growth of the five leading aerospace companies. The greatest impact on growth rates is exerted by investments in R&D, labor productivity, and the level of digitalization. The developed model allows assessing the effectiveness of digital strategies and can be used for strategic planning in the aerospace industry.

The digital maturity indicator reflects the overall integration of digital technologies into the production, logistics, and management processes of the enterprise. The Table 2 presents the digitalization index (DT) and digital infrastructure (DI), which together characterize the level of digital maturity of each company.

Table 3. Digitalization and digital infrastructure indices of aerospace companies

Company	DT (Digitalization Index)	DI (Digital Infrastructure)
Airbus	88	92
Boeing	85	89
Lockheed Martin	90	94
Northrop Grumman	87	91
Embraer	78	83

As can be seen from the Table 3, the highest levels of digital maturity are observed in Airbus, Lockheed Martin and Northrop Grumman. They have the highest indices of both digitalization and digital infrastructure, which allows them to achieve consistently high economic growth rates. Embraer demonstrates a lower level of digital integration, which likely limits its growth potential compared to global industry leaders.

The conducted applied analysis based on the aerospace industry validates the robustness and practical applicability of the proposed log-linear regression model introduced in the article. Using real-world data from five globally recognized aerospace corporations – Airbus, Boeing, Lockheed Martin, Northrop Grumman, and Embraer – the model empirically demonstrates the quantitative relationship between key digital transformation indicators (digitalization index, R&D investment, labor productivity, and digital infrastructure) and the companies' economic growth performance.

The results of the regression confirm the theoretical assumptions outlined in the article: enterprises with higher levels of digital maturity and technological investment exhibit stronger economic dynamics. Specifically, innovation expenditures and labor productivity emerged as the most influential factors in driving growth, underscoring the synergistic nature of digital transformation within high-tech sectors. Moreover, the developed digital maturity indices (DT and DI) provide a granular perspective on the depth and scope of digital integration, supporting targeted strategic planning.

By successfully applying the proposed model to the aerospace context, the study not only substantiates the feasibility of the algorithmic framework but also demonstrates its adaptability to industry-specific variables. This confirms the model's utility as a decision-support tool for evaluating and optimizing digital strategies at the enterprise level, particularly within knowledge-intensive and capital-intensive industries.

The digital maturity indices (DT and DI) serve as a practical extension of the core algorithmic model presented in the main body of the article. They enhance the overall scientific and practical value of the research by providing a real-world demonstration, confirming that strategically planned digitalisation, based on data, innovation and infrastructure, acts as a decisive catalyst for sustainable economic growth in the digital age.

In the context of the aerospace industry, where high capital intensity, complex logistics, and data accuracy depend on precision, digital technologies play a critical role in reducing costs, improving manufacturing process accuracy, and ensuring competitiveness in the global market. Therefore, the results obtained through modeling can be considered a compelling argument for the priority development of digital strategies in this sector of the economy.

The proposed new approach involves creating an integrated algorithmic model that combines mathematical optimization modeling, algorithmic methods (genetic algorithms, multi-criteria optimization), and simulation modeling, taking into account the specifics of individual industries. This approach not only allows for the identification of optimal digital transformation strategies but also enables the forecasting of their economic impact, ensuring the adoption of well-founded management decisions aimed at maximizing economic outcomes. The presented approach is intended to provide a foundation for making informed management decisions aimed at achieving sustainable economic growth in the context of digital transformation. The development of this model is an important step in further improving digital transformation strategies, which will contribute to enhancing the competitiveness of enterprises and the economy as a whole.

Thus, the research is focused on developing a scientifically grounded model that will allow businesses to optimize digital integration and increase economic efficiency in the modern high-tech environment.

4. Discussion and interpretation of results obtained

The results of the research showed that the implementation of optimization algorithms in the process of digital integration can significantly improve the economic efficiency of enterprises and industries. The developed model takes into account the different levels of digital maturity of companies, technology implementation costs, and potential economic benefits (Shalaby, 2024; Khan et al., 2025).

This trend is consistent with innovation diffusion models and supports earlier studies that emphasized the strategic management of digital initiatives in dynamic environments (Liao et al., 2024; Raihan, 2024). However, over time, these benefits may decrease due to the saturation effect. This is consistent with previously developed models of technological development and innovation diffusion (Zyoud & Zyoud, 2025; Hovorov et al., 2025).

It was also found that industry specifics play an important role in shaping digital integration strategies. For example, in high-tech sectors such as IT, finance, or pharmaceuticals, digital transformation yields faster results. In contrast, in traditional manufacturing industries, the effectiveness of digitalization may be limited by the need for significant infrastructure investments (Rajaonson & Schmitt, 2024; Siddik et al., 2025).

The study confirms that a well-developed digital infrastructure, when paired with targeted R&D investment, enables organizations to remain competitive and responsive to change. This is aligned with findings on the digital circular economy, which promotes closed-loop innovation and systemic transformation (Voulgaridis et al., 2022; Okegbile & Gambo, 2025).

Nonetheless, the current model has certain limitations, including a focus on economic variables without integrating cultural, regulatory, or labor-market considerations. These dimensions are crucial, especially in transitional economies or regions recovering from crisis (Subačienė et al., 2023; Westergren et al., 2024).

Future adaptations of this model may benefit from incorporating factors such as digital inclusivity, education levels, and public policy – as proposed in recent studies on equitable digital growth (Rahman & Hossain, 2025; Liu & Li, 2025).

Finally, integrating cross-disciplinary data sources and simulation methods can enhance the model's predictive capacity, especially in uncertain environments. Researchers increasingly advocate for combining system dynamics, cognitive modeling, and AI-based optimization (Erkan et al., 2024; Singh et al., 2025; Hovorov et al., 2024a, 2024b, 2024c).

5. Conclusions

Digital integration is a key driver of modern economic development; however, its effective implementation requires an optimization approach that considers industry-specific characteristics, the digital maturity of enterprises, and economic risks. The conducted research has shown that digital technologies are a crucial catalyst for contemporary economic growth, particularly in innovation-driven industries such as the aerospace sector. This study presents an algorithmic model for evaluating the effectiveness of digital transformation and determining optimal implementation strategies. The proposed integrated algorithmic model not only assesses the effectiveness of digital transformation but also identifies optimal strategies for the implementation of digital solutions, taking into account industry specifics, resource constraints, and long-term economic outcomes.

The theoretical contribution of this research lies in the formation of a new quantitative model that systematizes the relationships between the level of digitalization, innovation potential, labor productivity, and digital infrastructure development in the context of their impact on economic growth rates. A proprietary methodological approach to optimizing digital transformation is proposed, combining genetic algorithms, multi-criteria optimization methods, and simulation modeling. Within the scope of the study, an analytical foundation has been built for scenario analysis of digital integration, particularly for identifying threshold effects, such as a decline in marginal economic benefit at excessive levels of digital maturity.

From a practical perspective, the research results hold practical value for enterprises, industry associations, and government authorities. The developed model can be directly applied to form effective digital integration strategies, ensuring the optimization of investment decisions with a focus on maximizing economic benefits. The simulation tools integrated into the research allow for the rapid evaluation of potential outcomes from implementing digital technologies, considering dynamic changes in the market environment or external constraints. The proposed approach is flexible and can be easily adapted to the specifics of various industries, making it an effective tool for strategic decision-making at both the enterprise and government policy levels.

Despite the achieved results, the research has several limitations that should be considered when interpreting the findings and their practical applications. First, the developed model focuses on key economic parameters of digital transformation (innovation, productivity, infrastructure) but does not account for socio-economic, regulatory, and cultural aspects that may significantly influence the dynamics of digitalization in specific countries or regions.

Additionally, the empirical basis of the model is primarily built on aggregated industry-level indicators, which somewhat reduces the accuracy of forecasts when adapting the model to individual enterprises or regional specifics. Moreover, the study does not account for the time inertia of digital innovation impacts – i.e., the delayed effects of implementation that may manifest in the medium- and long-term.

Considering these limitations, promising directions for future research include:

- Expanding the model to incorporate social and regulatory factors (such as digital accessibility, cybersecurity, staff education levels, etc.), which would allow for a more comprehensive assessment of digital transformation.
- Empirical testing of the model using specific industries or enterprises, utilizing detailed internal data, which would enhance the practical value and accuracy of the modeling.
- Integrating time lags and dynamic effects into the mathematical model structure to account for the delayed impact of digital technology investments on economic outcomes.
- Building regionally differentiated models that consider the level of digital infrastructure and government policies on digitalization at the local level.

Implementing these directions will significantly strengthen both the theoretical and practical significance of the proposed approach, contributing to the development of more effective digital transformation strategies in the face of rapid technological changes and global competition.

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Author contributions

All authors contributed equally to the conceptual development, methodology design, data analysis, and writing of this article. The research idea, algorithmic modeling, data interpretation, and manuscript preparation were carried out collaboratively.

Oleksii Lytvynov: Conceptualization, Theoretical Framework Development, Supervision, Review and Editing.

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Vladislavas Petraškevičius: Conceptualization, Review and Editing.

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