



Conceptual Approach to the Assessment of the Innovative Threshold of High-Tech Industries Digital Transformation

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Abstract: There arises the necessity in conceptual distinction between formal digitization and true digital transformation with the accelerated digitalization of industry and global technological competition. The article introduces and justifies the concept of «innovation threshold» as a critical level of systemic changes, the overcoming of which allows high-tech enterprises to move from incremental improvements to a qualitatively new paradigm of value creation. The authors show that in industries such as aerospace, microelectronics, pharmaceuticals, and nuclear power, fragmented adoption of digital solutions not only fails to provide competitive advantages, but also leads to increased costs and technological vulnerability. A multi-level methodology for assessing the innovation threshold is proposed, covering technological integration, use of data and artificial intelligence, transformation of business models, organizational readiness and economic efficiency. An integral index is calculated based on the expert evaluation, allowing to diagnose the transformation stage - from «digital imitation» to sustainable leadership. The concept is considered as a tool for strategic management, government regulation and investment analysis in the context of the formation of the digital economy and increasing demands on technological sovereignty.

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1 INTRODUCTION

In the context of the accelerating digitalization of the global economy and the transformation of industrial paradigms under the influence of Industry 4.0 and Industrie 5.0 technologies, the problem of effective implementation of digital solutions in high-tech industries is becoming strategic (Lasi et al., 2014; Lu, 2017). The concept of innovation threshold - minimum level of system, technological and organizational changes necessary for transition from incremental modernization to a qualitatively new type of economic activity acquires special importance in this context, based on end-to-end digital integration, data generation as a strategic asset and business model transformation (Vial, 2019; Matt et al., 2015).

The relevance of this concept is due to several interrelated factors.

First, high-tech industries (including aerospace, microelectronics, nuclear, pharmaceutical and defense) are characterized by the high complexity of production chains, long product development cycles, high capital costs and strict requirements for reliability and safety (Lu, 2017). In such conditions, the superficial or fragmented introduction of digital technologies (for example, partial automation or local use of IoT sensors without integration into a single analytical environment) does not only provide the expected economic effect, but can lead to unjustifiable costs, technological imbalances and reduced operational sustainability (Frank et al., 2019). Therefore, there is a need for a clear distinction between digitalization (digitization of existing processes) and digital transformation (creation of new forms of value), which provides the concept of innovation threshold (Matt et al., 2015; Vial, 2019).

Second, against the backdrop of intensifying global technological competition and the emergence of new geopolitical and economic realities (including sanctions pressure, supply chain localization and import substitution), the ability of national industrial systems to overcome the innovation threshold becomes a factor of technological sovereignty. Enterprises that have not reached the critical level of digital maturity risk losing competitiveness and losing leadership in key markets (Ghobakhloo, 2021). In this regard, the innovation threshold is an indicator of technological maturity and sustainability of industrial assets (Kiel et al., 2017).

Third, modern public development strategies of the world increasingly focus not on the number of implemented digital solutions, but on the quality of transformation effect (Lasi et al., 2014). This

requires the development of objective methodologies to assess the depth of digital transformation, which makes the concept of innovative threshold popular in both academic and applied fields - for purposes of monitoring, regulation, investment analysis and strategic planning.

Finally, empirical studies (Frank et al., 2019; Westerman et al., 2014) show that up to 70% of digital initiatives in industrial enterprises do not achieve their stated goals, mainly due to the lack of a systematic approach and underestimation of the threshold nature of innovation changes. This confirms the need for theoretical and methodological understanding of innovation threshold as a critical point of transition from technological activity to sustainable innovation growth.

2 MATERIALS AND METHODS

This study applies the author's original methodology for assessing the innovation threshold in the context of digital transformation of high-tech production, developed based on a systemic analysis of modern approaches to digital transformation management, the theory of innovation diffusion, and *Industry 4.0/5.0* practices. The innovation threshold is understood as the critical level of systemic changes necessary for an enterprise to transition from incremental improvements to a structural reconfiguration of its activities — including a rethinking of the value it creates and a transformation of its business model. The methodological foundation of the research lies in the principles of digital maturity theory, the concept of the digital thread, and the principles for assessing the industrial enterprises' technological and organizational readiness for transformation. Assessment of the innovation threshold is carried out through a multi-level diagnostic scale encompassing five key dimensions: (1) technological integration and digital maturity, (2) data and artificial intelligence utilization, (3) business model transformation, (4) organizational readiness and digital competence, (5) economic efficiency of digital initiatives. Each dimension is evaluated by experts on a ten-point scale, taking into account the specific characteristics of high-tech industries (including aerospace, microelectronics, pharmaceuticals, and nuclear power). To calculate the integral indicator — the Innovation Threshold Index — a weighted formula is applied.

3 RESULTS

3.1 The Essence of the Innovation Threshold Concept

The innovation threshold represents a critical level of systemic change that must be achieved within the framework of digital transformation for an enterprise to move from incremental improvements to structural and qualitative shifts in its operations. In high-tech industries — such as aerospace, microelectronics, robotics, pharmaceuticals, and nuclear energy — this threshold is particularly high due to technological complexity, strict regulatory requirements, and the high cost of errors (Müller, 2018). Crossing the innovation threshold does not merely mean the implementation of digital tools (for example, ERP, MES, or IoT systems), but a complete rethinking of the value the enterprise delivers to customers and the market (Porter & Heppelmann, 2014). This implies a transition from the “we produce a product” model to the “we deliver a cyber-physical solution” model. Digital transformation without overcoming the innovation threshold is digital imitation rather than real transformation.

3.2 Why the Innovation Threshold Matters for High-Tech Industries?

High-tech industries are characterized by high capital intensity and long product development cycles, which significantly increase the risks of strategic errors during digital transformation (Lu, 2017). Incorrect technological choices or premature implementation of digital solutions can lead to multi-billion financial losses, loss of competitive position, and missed market opportunities — recovery from which, in the context of global competition, becomes extremely difficult (Frank et al., 2019).

At the global level, technological leadership is already consolidated among corporations such as Siemens, General Electric, Bosch, Huawei, and Rostech, which actively develop and implement end-to-end digital platforms covering the entire product lifecycle — from design to operation and recycling (Lasi et al., 2014; Moghrabi et al., 2023). Under these conditions, even a short delay of two to three years can be strategically fatal, as markets rapidly consolidate around ecosystems dominated by first movers.

At the same time, customer behavior is changing. Modern B2B clients increasingly reject the purchase of “bare” equipment in favor of comprehensive solutions integrating physical assets with digital services. The key expectations now include remote monitoring, predictive maintenance, functional personalization, and full transparency across the product lifecycle (Tao et al., 2019; Winkelhaus et al., 2020). These demands create a new value standard in which emphasis shifts from product to service and data.

In addition to market challenges, government policy plays a major role. Support mechanisms include grants, tax incentives, the development of industry standards, and infrastructure for digitalization. As a result, the transition to digital models becomes not only a competitive necessity but also a prerequisite for participation in national projects and for obtaining strategic advantages at the state level.

3.3 Indicators of Crossing the Innovation Threshold

An enterprise is considered to have crossed the innovation threshold of digital transformation if it demonstrates certain characteristics (see Table 1).

Table 1: Characteristics of an Enterprise That Has Crossed the Innovation Threshold of Digital Transformation.

Area	Below the Threshold	Above the Threshold
Technological architecture	Isolated systems (CAD, MES, ERP operate separately)	Unified digital platform with API integration; digital twin of product and production
Data	Data collection without analytics	Data as an asset: AI/ML used for optimization, forecasting, and decision-making
Production peocesses	Automation of individual operations	Adaptive, self-optimizing (Smart Factory)
Business model	Sale of a physical product	Product-as-a-Service (PaaS), subscription, data monetization
Organisational culture	Technologies introduced “top-down”	Digital maturity: cross-functional teams, experimentation, agile methods
Ecosystem	Closed supply chain	Open digital ecosystem with partners, clients, start

		ups
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An enterprise is recognized as having crossed the innovation threshold when systemic shifts are observed not in isolated technological components but across the entire set of operational, organizational, and strategic practices. This transition manifests in six key areas.

Overcoming the innovation threshold in high-tech manufacturing is not the sum of individual digital projects but a qualitative leap in the systemic architecture of the enterprise — covering technology, data, processes, business logic, culture, and ecosystem relationships. Only when synchronized changes occur across all these dimensions can a sustainable competitive advantage be achieved in the digital economy.

3.4 Approach to Assessing the Innovation Threshold of Digital Transformation in High-Tech Industries

The proposed methodology is based on a multi-level assessment across five dimensions, each evaluated on a scale from 0 to 10. The overall Innovation Threshold Index is calculated as a weighted average, taking into account industry-specific priorities.

3.4.1 Determining the Weights of the Dimensions

For high-tech industries, there recommended the following weights that can be changed according to the area (see Table 2).

Table 2: Weights of Dimensions in Assessing the Innovation Threshold of High-Tech Industries.

Dimension	Weight
Technological integration and digital maturity (x_1)	30%
Data and artificial intelligence utilization (x_2)	25%
Business model transformation (x_3)	20%
Organizational readiness and competence (x_4)	15%
Efficiency and economic impact (x_5)	10%

3.4.2 Evaluation by Dimension

Each dimension is scored from 0 to 10 points according to the following criteria.

- 0–3 points: fragmented systems, manual data entry;
- 4–6 points: partial automation, local IoT solutions;
- 7–10 points: integrated platform, real-time digital twin.

Technological integration and digital maturity are assessed based on the presence of an end-to-end digital thread, implementation level of Industry 4.0 technologies (IoT, cyber-physical systems, digital twin), and the degree of integration between operational and information technologies.

Data and AI utilization are assessed through the presence of Data Lake / Fabrics, application of machine learning or AI for predictive maintenance, logistics optimization, and quality control, as well as automation of decision making.

Business model transformation is evaluated by the presence of digital services (SaaS, PaaS), data monetization, and flexible contracting mechanisms.

Organizational readiness is measured through the availability of digital competencies (data scientists, DevOps, digital twin engineers), the culture of experiments and learning, and the top management support for transformation.

3.4.3 Calculation of the Innovation Threshold Index and Interpretation of Results

The Innovation Threshold Index (I) for high-tech industries is calculated according to Formula (1):

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$$I = (x_1 \times 0,3) + (x_2 \times 0,25) + (x_3 \times 0,2) + (x_4 \times 0,15) + (x_5 \times 0,1) \quad (1)$$

Interpretation of the Innovation Threshold Index for High-Tech Industries is given in Table 3.

Table 3: Dimension weights of innovation threshold index for High-Tech industries.

Index Value	Threshold Level	Interpretation
0 - 4 (exclusive)	Below threshold	Digitalization without transformation; risk of “digital imitation”
4–6 (inclusive–exclusive)	On the threshold	Partial transformation; systemic strategy required
6–8 (inclusive–	Threshold	Enterprise

exclusive)	overcome	generates new value through digital solutions
8–10	Leader of digital transformation	Digital maturity, sustainable advantage, export of competencies

The methodology can be used for: internal diagnostics prior to launching large-scale digital transformation strategies; national programs supporting digital development; evaluation of subsidiaries by investors and holding companies; consulting firms developing digital transformation roadmaps.

4 DISCUSSION

There can be formulated several discussion points that reflect the ongoing academic and practical debate surrounding the concept of the innovation threshold in the digital transformation of high-tech industries.

A key issue is whether any implementation of digital technologies should be considered a manifestation of innovative activity, or whether threshold criteria are necessary to distinguish superficial “digitalization” from systemic transformation. The proposed concept asserts that without overcoming the innovation threshold, digital initiatives do not create sustainable value and may even reduce operational efficiency.

Although a quantitative assessment method (the Innovation Threshold Index) has been proposed, questions remain about the objectivity of expert evaluations across the five dimensions, given the absence of unified international standards for digital maturity. Is it possible to fully formalize the threshold, or does it inevitably involve contextual interpretation depending on industry, region, and corporate culture?

Government programs may artificially lower the threshold by offering subsidies and simplified participation criteria. However, this risks producing widespread “imitational transformation”. Conversely, an excessively high threshold may exclude medium-sized enterprises capable of gradual but sustainable transformation. Where should the balance be drawn between encouragement and inflated expectations?

In terms of the rapid technological evolution (for instance, the emergence of generative AI, quantum computing, and edge analytics), the threshold cannot

remain fixed. This raises the question: is the innovation threshold a singular transition point or a continuous process requiring periodic re-evaluation of the “overcoming” criteria?

In the proposed methodology, the greatest weight (30%) is assigned to technological integration, while business model transformation receives a weight of only 20%. However, studies (Westerman et al., 2014) indicate that changes in business logic, rather than in technology itself, are the primary driver of value creation in digital transformation. Should the weighting be reconsidered in favor of organizational and economic dimensions?

Finally, can a single methodology be applied to such heterogeneous sectors as microelectronics and nuclear energy, where development cycles, regulatory requirements, and value structures differ drastically? Or does the concept require industry-specific calibration, which could challenge its universality?

Moreover, the pursuit of crossing the innovation threshold at any cost may lead to premature adoption of immature technologies, data leaks, reduced reliability of critical systems, or loss of technological sovereignty. Should the innovation threshold incorporate not only “achievement” criteria but also “responsibility” criteria?

5 CONCLUSIONS

The concept of the innovation threshold represents a theoretically grounded and practically significant tool for analyzing and managing digital transformation processes in high-tech industries. In an era when mere implementation of digital technologies is no longer sufficient to ensure competitiveness, this concept makes it possible to differentiate between superficial digitalization and genuine transformation capable of generating new economic and strategic value. The proposed methodology for assessing the innovation threshold — based on five dimensions: technological integration, data and AI utilization, business model transformation, organizational maturity, and economic efficiency — provides a systemic framework for diagnosing the level of digital maturity and identifying barriers that prevent enterprises from achieving a qualitatively new state. The innovation threshold serves not only as an analytical category but also as a strategic benchmark for industrial enterprises, regulators, and investors seeking sustainable technological leadership in the global digital economy. Future research may focus

on refining the weighting coefficients across industries, developing dynamic models for assessing the threshold that account for the accelerating technological cycle, and integrating ethical and sovereignty-related criteria into the evaluation framework.

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