УДК 005.511:004.9; 338.45; 005.334; JEL classification M11, O32, M15, D81
DOI: https://doi.org/10.36887/2415-8453-2025-4-24

Селезньова Галина Олександрівна[1], к.е.н., доцент, доцент кафедри економіки підприємства та організації бізнесу

Хвостіков Андрій Ігоревич[1], доктор філософії (PhD) з економіки, викладач кафедри економіки підприємства та організації бізнесу
[1]*Харківський національний економічний університет імені Семена Кузнеця*

Seleznova Halyna[1], Candidate of Science (in Economics), Associate Professor, Associate Professor of Enterprise Economics and Business Organization Department, https://orcid.org/0000-0003-1942-923X
Khvostikov Andrii[1], PhD in Economics, Lecturer, https://orcid.org/0000-0003-1177-9761

[1]*Simon Kuznets Kharkiv National University of Economics, Kharkiv*

МЕТОДИ ПЛАНУВАННЯ НА ПІДПРИЄМСТВІ В УМОВАХ ЦИФРОВІЗАЦІЇ: ТРАНСФОРМАЦІЯ ПАРАДИГМ, ІНСТРУМЕНТАРІЙ ТА ПРАКТИКА
PLANNING METHODS IN AN ENTERPRISE IN THE CONDITIONS OF DIGITALIZATION: TRANSFORMATION OF PARADIGMS, TOOLS, AND PRACTICE

Селезньова Г. О., Хвостіков А. І. Методи планування на підприємстві в умовах цифровізації: трансформація парадигм, інструментарій та практика. *Український журнал прикладної економіки та техніки*. 2025. Том 10. № 4. С. 126 – 131.

Seleznova H., Khvostikov A. Planning methods in an enterprise in the conditions of digitalization: transformation of paradigms, tools, and practice. *Ukrainian Journal of Applied Economics and Technology*. 2025. Volume 10. № 4, pp. 126 – 131.

The article is devoted to the transformation of enterprise planning systems under the influence of Industry 4.0. Under conditions of VUCA and BANI, traditional deterministic methods become less efficient and are outperformed by intelligent systems. For Ukrainian businesses during the war, modernization of planning is a strategic tool for ensuring resilience. The purpose of the work is to theoretically substantiate and analyze the practical aspects of the transition to digital planning models based on predictive analytics and Data-Driven approaches. The study uses system analysis to examine the architecture of ERP systems; comparative analysis to compare the approaches of Industry 3.0 and 4.0; case studies of market leaders (Kernel, Metinvest, DTEK); and the method of logical generalization to identify barriers to digitalization. It has been proven that the digital transformation of planning is based on three shifts: the transition to Rolling Forecasting, the introduction of probabilistic modeling, and the use of artificial intelligence. The industry 4.0 toolkit is analyzed: integrated business planning (IBP), DDMRP methodology, deep learning algorithms (LSTM), and digital twins (Digital Twins). The synergy of these technologies enables risk-free testing of what-if scenarios. The experience of leading companies confirms that implementing these tools delivers measurable economic benefits – EBITDA growth and working capital optimization, even in crisis conditions. The digitalization of planning is imperative for integrating domestic businesses into global value chains. The main barriers to implementation are a lack of digital competencies, an outdated culture, and investment risks. It is recommended to focus on business process reengineering and cloud infrastructure development. The study's results can be used by management to develop adaptive management strategies.
Keywords: *digital planning, artificial intelligence, IBP, DDMRP, digital twins, VUCA world, strategic resilience.*

Стаття присвячена трансформації систем планування підприємств під впливом Індустрії 4.0. В умовах концепцій VUCA та BANI традиційні детерміновані методи втрачають ефективність, поступаючись інтелектуальним системам. Для українського бізнесу в умовах війни модернізація планування є стратегічним інструментом забезпечення резильєнтності. Метою роботи є теоретичне обґрунтування та аналіз практичних аспектів переходу до цифрових моделей планування на основі предиктивної аналітики та Data-Driven підходів. У дослідженні використано системний аналіз для вивчення архітектури ERP-систем; порівняльний аналіз — для зіставлення підходів Індустрії 3.0 та 4.0; кейс-стаді лідерів ринку («Кернел», «Метінвест», ДТЕК) та метод логічного узагальнення для визначення бар'єрів цифровізації. Доведено, що цифрова трансформація планування базується на трьох зсувах: переході до ковзного прогнозування (Rolling Forecast), впровадженні ймовірнісного моделювання та використанні штучного інтелекту. Проаналізовано інструментарій Industry 4.0: інтегроване бізнес-планування (IBP), методологію DDMRP, алгоритми глибокого навчання (LSTM) та цифрові двійники (Digital Twins). Синергія цих технологій створює умови для безризикового тестування сценаріїв «що-якщо». Досвід провідних компаній підтверджує, що впровадження цих інструментів забезпечує вимірний економічний ефект — зростання EBITDA та оптимізацію оборотного капіталу навіть у кризових умовах.
Цифровізація планування є імперативом для інтеграції вітчизняного бізнесу в глобальні ланцюги вартості. Основними бар'єрами імплементації визначено дефіцит цифрових компетенцій, застарілу культуру та інвестиційні ризики. Рекомендовано фокусуватися на реінжинірингу бізнес-процесів та розбудові хмарної інфраструктури. Результати дослідження можуть бути використані менеджментом для розробки стратегій адаптивного управління.
Ключові слова: *цифрове планування, штучний інтелект, IBP, DDMRP, цифрові двійники, VUCA-світ, стратегічна резильєнтність.*

Statement of the problem

The current stage of global economic development is characterized by fundamental tectonic shifts driven by the transition to the Fourth Industrial Revolution (Industry 4.0). This transition is not just the introduction of new technologies, but a change in the very ontology of production and management processes. The central place in this transformation is occupied by the enterprise activity planning system, which serves as the "nervous system" of the organization, coordinating resources, synchronizing processes, and adapting to changes in the external environment. In the conditions that modern management science characterizes as VUCA (Volatile, Uncertain, Complex, Ambiguous) or BANI (Brittle, Anxious, Non-linear, Incomprehensible), traditional deterministic planning methods developed in the era of stability and mass production fail. Rigid five-year strategies and static annual budgets, which were the standard of corporate governance yesterday, are now becoming a brake on development, preventing businesses from responding quickly to market turbulence, disruptions in global supply chains, and technological disruptions.

For Ukrainian enterprises, the problem of modernization of planning systems acquires existential importance. Functioning in the conditions of a full-scale war, permanent threats to the physical security of assets, energy instability, and logistical blockade requires domestic management not only to increase efficiency, but to ensure resilience — the ability of the system to withstand shocks, adapt, and recover. Digitalization in this context goes beyond the fashion trend and becomes a key tool for survival. The introduction of artificial intelligence (AI), machine learning (ML), big data (Big Data), and digital twin

technologies allows you to move from reactive "extinguishing fires" to proactive scenario planning based on risk anticipation and real-time resource optimization.

The relevance of the topic is enhanced by the fact that the digital transformation of planning is not only a technological but also a deep organizational challenge. It requires revising the decision-making architecture, changing personnel role models, and forming a new data culture. The abandonment of intuitive management in favor of Data-Driven Decision Making is becoming imperative for integrating Ukrainian businesses into the European economic space and global value chains.

The problem of transforming the planning methodology under the influence of digital technologies is in the focus of both global and domestic scientific thought. Analysis of the source base enables us to identify several key areas of research that underpin this article.

The fundamental principles of business management in the era of digitalization are thoroughly developed in the works of the Ukrainian scientific school. A team of authors led by A. P. Grinko, in the monograph "Methodology of Business Management in the Context of Digitalization" (2022) [1], formulated a holistic concept of digital transformation as a systemic process. Scientists argue that digital strategy cannot exist autonomously; It should be derived from the overall business strategy and implemented through a mechanism of cascading goals. Attention is paid in their work to knowledge management as a critical resource for innovative development, as well as to the transformation of business models, where digitalization acts as a catalyst for the creation of new value propositions.

The study of strategic planning and financial sustainability is devoted to the work of A. Mytianska [2]. The author emphasizes a shift in strategic planning towards customer focus and flexibility. Her research emphasizes that in the digital economy, the financial stability of an enterprise is inextricably linked to its digital maturity - the ability to innovate and adapt business processes quickly.

The impact of the Fourth Industrial Revolution on Ukraine's industrial landscape is analyzed in detail in the works of G. V. Zadorozhnyi, N. G. Duna, and their co-authors [3]. Scientists consider Industry 4.0 as a complex of cyber-physical systems (CPS) that integrate production facilities with the digital space. In their scientific reviews, they find a correlation between the introduction of Industry 4.0 technologies and the transition to a circular economy, which opens new prospects for resource-saving planning. This area of research is critically important for understanding the macroeconomic prerequisites for modernizing the Ukrainian industry.

A significant layer of foreign research is devoted to the development and validation of specific mathematical models for digital planning. Papers investigating the application of artificial intelligence in supply chain management [4] convincingly demonstrate the advantages of Deep Learning methods over classical statistical approaches. Studies of the efficiency of recurrent neural networks, such as LSTM (Long Short-Term Memory), demonstrate their strong ability to forecast demand under nonlinear trends and seasonality, whereas traditional ARIMA (AutoRegressive Integrated Moving Average) models exhibit significant errors. Scientists are also exploring integrating Monte Carlo methods with machine learning algorithms to assess risks and improve the accuracy of financial forecasting [5].

The practical aspects of implementing enterprise resource planning (ERP) systems and the evolution to integrated business planning (IBP) are covered in research by leading consulting companies and industry experts. McKinsey and Deloitte analysts point out that IBP is not just a technological upgrade but a change in the management paradigm that allows you to synchronize strategic goals with operational execution. In the domestic context, the works of V. Blokhina and other researchers [6, 7] analyze the specifics of the ERP market in Ukraine, noting the tendency to replace Russian software with Western and Ukrainian analogues, which creates both technological challenges and opportunities for reengineering planning processes.

The role of Digital Twins technology in production planning is revealed through the analysis of cases and theoretical models in works [8, 9] The researchers focus on the possibility of using digital twins for risk-free testing of management decisions (what-if scenarios) and dynamic optimization of production schedules, which is the pinnacle of the evolution of planning systems from MRP to intelligent adaptive systems.

Socio-economic aspects of digitalization, in particular the readiness of personnel and organizational structures, are studied in the works of N. Shvets, G. Shevtsova [10], O. Roeva [11] The authors identify key barriers to the path of Ukrainian enterprises: the deficit of digital competencies, resistance to change and insufficient investment provision, which is an essential context for understanding the real pace of implementation of the latest planning methods.

The purpose of the research

The article is aimed at theoretical substantiation and practical study of the transformation of methodological approaches to planning the activities of enterprises under the influence of technologies of the Fourth Industrial Revolution (Industry 4.0), as well as in determining strategic tools for ensuring the resilience and financial sustainability of business in the conditions of extreme uncertainty (VUCA/BANI environment) and military challenges in Ukraine.

Presentation of the primary research material

Historically, the system of production planning, originating in the principles of scientific management of F. Taylor and G. Ford, was based on the postulates of stability, predictability, and process linearity. The main tools were tight budgets and long-term calendar plans (a year, five years). In such a paradigm, any deviation from the plan was interpreted as an anomaly or a performer's mistake. However, in the digital economy, where the rate of change in the external environment exceeds the reaction rate of traditional hierarchical structures, this approach becomes a dangerous anachronism.

Digitalization leads to the transition to a new paradigm of planning (Figure 1), which three fundamental shifts can characterize:

1. From discreteness to continuity (continuity). The traditional "once a year" budgeting cycle is being replaced by the concept of Rolling Forecast. This is a dynamic process in which the planning horizon shifts forward (usually by 12–18 months), and forecasts are updated monthly or even weekly as new data arrive [12]. This approach allows the enterprise to avoid being a hostage to outdated budget assumptions made a year ago and to promptly redistribute resources in accordance with the current market situation.
2. From determinism to probability. Classical planning operates with "single-point estimates" — for example, "the sales volume will be 1000 units." Digital planning recognizes the stochastic nature of reality. Instead of a single digit, probability ranges and confidence intervals are used. The use of simulation modeling methods, such as the Monte Carlo method, allows management to see the full range of possible scenarios and assess the probability of achieving goals (for example, "with a

probability of 85%, the profit will be in the X–Y range") [5]. This fundamentally changes the approach to risk management, integrating it directly into the planning process.

3. From reactivity to predictiveness and prescriptivity. Traditional controlling systems record deviations after the fact (lagging indicators). Digital tools powered by AI/ML enable you to move to leading indicators, predicting problems before they occur. Moreover, the development of prescriptive analytics allows systems not only to predict the future, but also to automatically generate recommendations for optimal actions to achieve the desired result [13].

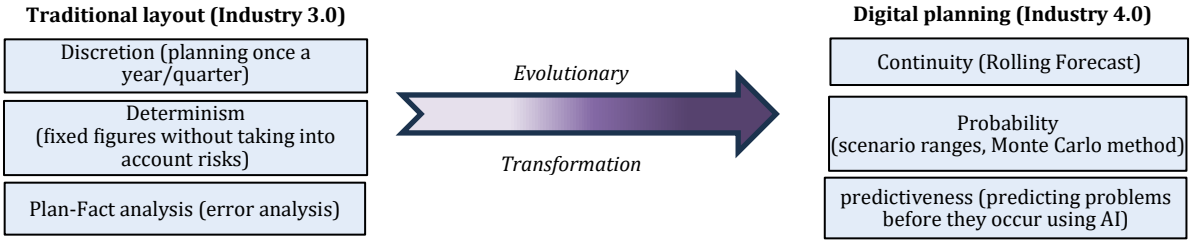

Fig. 1. Evolutionary transformation of the planning paradigm in the context of Industry 4.0

Source: compiled by the author.

The modern architecture of planning systems is based on the integration of heterogeneous technologies, each of which solves specific tasks (Table 1), which together form a single ecosystem for enterprise management.

Table 1. Matrix of the impact of digital technologies on planning performance indicators

Technology / Methodology	Key change in the process	Impact on financial and economic indicators	Sphere of greatest efficiency
IBP (Integrated Business Planning)	Real-time synchronization of financial and operational plans.	Increase in sales margins, shortening the planning cycle.	Agricultural holdings, multi-level corporations.
DDMRP (Demand Driven MRP)	Moving from predictive to streaming inventory management.	Reducing the level of excess stocks by 30-45%, eliminating the deficit.	Production with a wide range (SKU).
AI / LSTM (Neural Networks)	Identification of non-linear trends and hidden patterns.	Increase in the accuracy of demand forecasting by 15-25%.	Retail, Energy, FMCG.
Digital Twins	Risk-free simulation of What-if scenarios.	Reduction of maintenance costs (repairs), optimization of production capacities.	Mining and metallurgical complex, energy.

Source: compiled by the author.

Enterprise Resource Planning (ERP) systems have gone from simple accounting systems to powerful digitalization platforms. However, classic ERPs often suffer from a gap between strategic vision and operational execution. The answer to this challenge was Integrated Business Planning (IBP).

IBP is not just a software module but a management process that integrates sales, marketing, production, procurement, logistics, and finance planning into a single loop [14]. Unlike traditional S&OP (Sales and Operations Planning), which primarily focuses on balancing supply and demand indicators, IBP provides full financial integration. Any change in the operational plan (for example, a delay in the delivery of raw materials or a surge in demand for a specific SKU) is instantly translated by the system into financial metrics: forecast P&L (income statement), Cash Flow (cash flow), and balance sheet. This allows management to make decisions with a clear understanding of their impact on the company's financial results ("monetization" of operational decisions).

In volatile demand conditions, traditional MRP (Material Requirements Planning) systems, which operate on a "push" principle based on forecasts, can generate the so-called "bullwhip effect". Minor errors in demand estimates for final products lead to significant fluctuations in orders for raw materials and components, resulting in either warehouse overstocking or shortages.

The Demand Driven MRP (DDMRP) methodology offers a revolutionary approach to managing material flow [15]. It combines elements of MRP, Lean (lean manufacturing), and constraint theory (TOC). The key idea of DDMRP is to strategically decouple the supply chain by placing inventory buffers at critical points. Unlike static safety stocks, DDMRP buffers are dynamic: their size is automatically recalculated daily by the system based on average daily consumption (ADU) and variability factors [16]. Replenishment planning is carried out according to the principle of "pulling" only when there is a real need (when the stock level in the buffer falls below a specific limit) and not based on an unreliable forecast. This allows you to reduce the inventory level by 30–45% while increasing the Service Level to 98–99% [15].

The use of AI in planning allows you to go beyond the capabilities of the human brain in processing multidimensional data. Recurrent neural networks (RNNs), in particular the Long Short-Term Memory (LSTM) architecture, are particularly effective.

Unlike standard neural networks, LSTM has a "memory" that allows it to retain information about the system's previous states for a long time. This is critical for predicting time series (sales, energy consumption), where the current value depends on events that occurred much earlier (seasonality, cyclical trends). LSTM networks can learn from historical data, identifying nonlinear dependencies that classical regression formulas cannot capture. Studies show that hybrid models combining LSTM with ensemble learning methods (e.g., Random Forest) achieve significantly higher prediction accuracy in "noisy" data conditions [4].

Monte Carlo modeling is the standard for probabilistic planning. The algorithm generates thousands of iterations of the financial model calculation, each time randomly selecting values for the input variables (exchange rate, gas price, crop volume) from their respective distributions. The result is a histogram of the probability distribution of a key indicator (e.g. NPV or EBITDA), which allows management to estimate, for example, Value at Risk (VaR) — the maximum number of losses with a certain probability [5].

A digital twin (Digital Twins) is a virtual dynamic model of a physical asset, process, or system that is synchronized with the original through real-time (IoT) data streams [17]. In the context of planning, digital twins act as a "sandbox" for hypothesis testing.

Management can simulate What-If scenarios without risk to real production:

– What happens to order fulfilment if the main press fails?
– How will the cost change when switching to an alternative supplier of raw materials with a longer delivery time?

– What is the optimal repair schedule that will ensure maximum availability of equipment during the peak season?

The integration of the digital twin with the ERP system enables a closed control loop: data from the shop floor enters the twin, AI algorithms calculate the optimal action plan, and corrective commands are transmitted back to the production system.

To visually demonstrate the depth of the transformation, it is advisable to compare the key characteristics of traditional and digital planning approaches (Table 2).

Table 2. Comparative characteristics of traditional and digital planning methods

Characteristics	Traditional Planning (Industry 3.0)	Digital planning (Industry 4.0/5.0)
Horizon and frequency	Annual static budgets, quarterly actualization. Discrete process.	Rolling Forecasts, Continuous Updating (Real-time). Continuous process.
The basis of decisions	Historical data, expert opinion, and extrapolation of the past.	Predictive analytics (AI/ML), Big Data, scenario modelling.
Data architecture	Scattered Excel spreadsheets, information "wells" (silos), and manual consolidation.	Single Source of Truth, cloud platforms, and Data Lakes.
Inventory Management	MRP (Push): production per warehouse according to forecast.	DDMRP (Pull): output on demand, dynamic buffers.
Analysis focus	Analysis of deviations "Plan-Fact" (postmortem analysis).	Scenario modelling, "What-If", risk assessment, prescriptive analytics.
The role of finance	Controller, cost recorder.	Strategic Business Partner, Value Driver.
Interaction	Consistent, hierarchical transfer of plans.	Collaborative, simultaneous operation of all functions in a single space.

Source: developed by the author based on [18].

Despite the harsh conditions of the war, the flagships of the Ukrainian economy demonstrate a high level of digital maturity, using advanced planning technologies to ensure business resilience.

Kernel Agricultural Holding is a pioneer of digitalization in the agricultural sector of Eastern Europe. The company implemented a large-scale project DigitalAgriBusiness, which transformed approaches to agrarian production planning [19]:

– Technological core: The use of RTK signals (Real Time Kinematic) for autopiloting equipment with an accuracy of 2 cm, satellite monitoring of fields, analysis of big data on the state of soils and weather.

– Differentiated planning: The system allows you to create task maps for machinery using the Variable Rate Application technology — fertilizers and seeds are applied in exactly the amount that is needed for a particular area of the field, which optimizes costs and maximizes yields.

– Performance: According to the company's reports, digital innovations generate additional EBITDA (about $25 million in fiscal year 2019), increasing economic efficiency by $45 per hectare. The integration of data into a single platform enabled the transition to the OpenAgribusiness ecosystem model, giving farming partners access to digital planning tools and agronomic consulting.

Metinvest Group implements digital tools to manage complex production chains from ore mining to steel smelting [19]:

– Integrated planning: Centralized planning and analysis functions have been created, allowing you to consolidate the needs of all assets and optimize the supply chain. This has become a critical factor in resilience amid disruptions to logistics due to hostilities.

– Digital GOK (Digital Quarry): The use of drones for surveying allows you to create highly accurate digital 3D models of quarries. This is the basis for operational planning of mining operations, calculation of production volumes, and traffic management.

– AI in manufacturing: Implementation of AI-based systems to manage the technological parameters of ore beneficiation (iron content control) and predictive equipment maintenance. The transition to AI-predicted "condition" repairs rather than scheduled preventive repairs can significantly reduce downtime and maintenance costs.

DTEK Energy Holding uses digital technologies to balance the power system and manage assets.

– Digital twins: The creation of digital twins of power grids and fields allows you to simulate equipment operating modes, plan load distribution and optimize resource extraction [21].

– Renewable Energy Forecasting: The use of AI for high-precision forecasting of solar and wind power plant generation allows you to efficiently plan trading operations in the electricity market and balance the power system, which is critical in the face of capacity shortages.

Despite the presence of successful cases, the mass introduction of digital planning methods in the Ukrainian business environment encounters systemic obstacles [22]:

– Personnel and competence gap. The labor market is experiencing an acute shortage of "new wave" specialists — business analysts, data scientists, and digital system architects who understand the specifics of production planning. At the same time, existing staff often resist change for fear of losing their jobs or misunderstanding new technologies.

– Outdated organizational culture. Many businesses are trying to implement new digital tools (such as ERP) on top of outdated, inefficient business processes. This leads to a phenomenon known as "chaos digitalization," in which automation only speeds up the spread of erroneous decisions.

– Financial constraints and investment risks. The introduction of full-fledged IBP systems and digital twins requires significant investments. In the face of high military risks and limited access to credit, many companies, especially SMEs, are forced to postpone strategic IT projects and focus on short-term survival.

– Security and infrastructure challenges. Cyber threats from the aggressor country, physical destruction of server equipment, and power outages are forcing businesses to migrate to cloud environments, which requires additional efforts to ensure data protection and business continuity.

Conclusions and prospects for further research

The study allows us to assert that the digitalization of planning methods is an irreversible evolutionary process that determines the future competitiveness of enterprises. In the context of the Ukrainian reality, burdened by war and economic uncertainty, the introduction of digital tools is being transformed from a growth strategy into a survival and resilience strategy.

1. Paradigm shift. There is a fundamental shift from discrete, deterministic planning to continuous, probabilistic and scenario modeling. Planning ceases to be an administrative function and becomes a tool for dynamic risk management.

2. Technology stack. The effectiveness of a modern planning system depends on the synergy of technologies: IBP ensures organizational unity, DDMRP provides demand adaptability, AI/LSTM improves forecast accuracy, and Digital Twins ensure experiment safety.

3. Strategic imperative. The successful cases of Kernel, Metinvest, and DTEK demonstrate that digital transformation of planning delivers measurable economic benefits (EBITDA growth, inventory reduction, cost optimization) even in crisis conditions.

4. Recommendations. For a successful transformation, Ukrainian enterprises need to focus not only on the purchase of software, but also on reengineering business processes, investing in the development of digital competencies of personnel, and building a data culture. It is critical to move to cloud-based solutions to ensure data security and infrastructure flexibility.

The digitalization of planning is the way to create a "smart enterprise" that can not only respond to challenges, but also stay ahead of them, turning uncertainty into opportunities for development.

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Стаття надійшла до редакції / Received 18.10.2025 Прийнята до друку / Accepted 02.11.2025