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Development of Adaptive Management Models Using Digital Technologies for the Strategic Development of Enterprises

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Abstract: Digital transformation and the intellectualization of management processes are shaping a new paradigm for the strategic development of enterprises in the real economy. The unstable economic environment increases the need for adaptive management models that can integrate digital technologies into the strategic architecture of an enterprise. Despite the growth of research in the field of digitalization, the problem of formalizing an adaptive management model taking into account digital integration remains insufficiently empirically verified. The purpose of the study was to develop a conceptually grounded adaptive management model with the integration of digital technologies aimed at ensuring the strategic development of enterprises in the context of intellectualization and digitalization of the economic environment; the object was enterprises of the real sector of the Ukrainian economy. The study was carried out in the format of quantitative panel data analysis for 2022–2025 using a fixed-effects model and a composite index of digital integration. The obtained results confirmed a statistically significant positive impact of digital integration on the strategic development of enterprises. It is found that managerial adaptability acts as a moderator of this relationship, enhancing the strategic effect of digitalization. The complementarity of digital technologies and managerial abilities in the formation of long-term competitiveness is proved. It is empirically substantiated that synchronization of digital platforms with strategic planning mechanisms provides higher development indicators compared to fragmented digitalization. The proposed model allows quantifying the level of digital integration and predicting its strategic consequences. The practical significance lies in the possibility of using the model to make managerial decisions on digital transformation and to formulate adaptive strategies for the development of enterprises.

Keywords: management; adaptive management; strategic development; enterprise development; digital integration; digitalization; intellectualization

1. Introduction

The accelerating digitalization of the business environment was accompanied by increasing technological complexity, uncertain market conditions, and the need for continuous strategic renewal of enterprises, but in practice, the introduction of digital technologies was often carried out in a fragmented manner and without proper integration into the management system. As a result, there was a disproportion between technological innovations and management mechanisms for their strategic use, which reduced the adaptability of organizations and hindered long-term

development. The absence of a holistic adaptive management model that would combine digital tools, managerial abilities, and strategic goals of the enterprise formed a scientific and practical problem that required systematic theoretical and empirical understanding.

The intellectualization of management processes, expressed in the use of analytical systems, artificial intelligence, and decision support algorithms, is considered in this work as an integral component of digital transformation, which enhances management's ability to adapt.

Modern studies of digital transformation in management have shown intensive development of theoretical and applied approaches, but the issue of formalizing adaptive management models remained insufficiently systematized. Kraus et al. (2022) stated the fragmentation of the research field and the lack of a single integrated framework for combining digital technologies and strategic management. Rego et al. (2021) showed that digital transformation has transformed strategic processes, but most studies have focused on outcomes rather than mechanisms of managerial adaptation. Konopik et al. (2022) substantiated the importance of organizational capabilities for digital change, but did not propose a structured adaptive management model.

The empirical data of Merín-Rodríguez et al. (2025) confirmed the positive impact of dynamic managerial capabilities on innovation performance, and Akuffo Otopah et al. (2025) established the mediating role of adaptability between digital transformation and strategic performance. At the same time, there was no comprehensive model that integrated digital technologies, managerial adaptability and strategic development of the enterprise into a single conceptual system, which necessitated further research.

Despite the existence of a significant body of research on digital transformation and dynamic capabilities, the scientific literature lacks an integrated concept that would combine digital technologies with adaptive management mechanisms in the context of strategic development of enterprises. Most studies analyzed either the technological aspects of digitalization or the results in the form of financial or innovation indicators, while the structural model of managerial adaptation remained insufficiently formalized. Also, the issue of institutionalizing digital solutions within the long-term strategy of the enterprise, taking into account organizational flexibility, managerial competencies, and environmental uncertainty, remained insufficiently developed.

The purpose of the study was to develop a conceptually grounded adaptive management model with the integration of digital technologies aimed at ensuring the strategic development of enterprises in the context of intellectualization and digitalization of the economic environment.

To achieve this goal, the following objectives were identified:

- to summarize theoretical approaches to the adaptability of management in the digital economy;
- to analyze the impact of digital technologies on the transformation of management mechanisms and strategic processes;
- to identify the structural components of an adaptive management model;
- to form a conceptual scheme for integrating digital tools into the strategic management system;
- to substantiate practical recommendations for the implementation of the developed adaptive management model at enterprises in the real sector of the

economy.

2. Literature Review

The theoretical foundations of digital transformation in management were laid down by Bharadwaj et al. (2013), who substantiated the concept of digital business strategy as an integrated combination of technology and strategic management. Further development of this logic is associated with the theory of dynamic capabilities, within which Teece (2018) identified the organization's ability to reconfigure resources as a key condition for strategic sustainability, and Warner and Wäger (2019) specified digital transformation as a process of strategic renewal that requires constant adaptation of management mechanisms.

In modern review works, digital transformation was considered as a multidimensional phenomenon. Gonzalez-Varona et al. (2021) emphasized the role of organizational competencies in the digital development of enterprises, while Han et al. (2024) recorded a shift in research towards digital management systems. Juma (2024) emphasized the evolutionary nature of digital changes that transform management structures, and Mammedov and Mammedova (2025) emphasized the impact of digitalization on strategic management, but without formalizing an adaptive model.

Research on the current transformations of global trade routes and the introduction of new logistics technologies confirms the need for businesses to respond quickly to dynamic challenges in the external environment (Hordieiev et al., 2025). In this context, the development of adaptive management models becomes a key tool for minimizing risks, allowing enterprises to effectively integrate digital solutions to optimize strategic development and supply chain management (Hordieiev et al., 2025).

Systematic reviews have confirmed the growing attention to organizational capabilities. Rizana et al. (2025) demonstrated that dynamic managerial capabilities are a key factor in digital transformation, but left open the question of their structural integration into the strategic model of the enterprise. A similar trend was noted by Morigen (2025), who noted the fragmentation of research approaches and the lack of a coherent conceptual architecture of digital management.

Empirical studies have clarified the mechanisms of the relationship between capabilities and performance. Candraningrat et al. (2025) analyzed the dynamics of digital capabilities as a precondition for innovative results. Chen (2023) found a positive relationship between digital transformation, dynamic capabilities, and innovation performance. Abdurrahman et al. (2024) proved that dynamic capabilities mediate the impact of digitalization on organizational performance. Huang and Tang (2025) showed the strategic role of digital platforms in the transformation of business models.

Recent research has focused on the integration of artificial intelligence and management architectures. Cui (2025) substantiated the mediating effect of digital innovations in improving the performance of enterprises, and Ettinger (2025) considered corporate architecture as a dynamic capability for scalable implementation of generative technologies. Taken together, these approaches confirmed that digitalization requires managerial adaptability, but did not provide a holistic model of its strategic institutionalization.

Thus, the scientific discourse showed the relationship between digital technologies, dynamic capabilities and strategic results, but left the issue of

developing a comprehensive adaptive management model that would integrate digital tools, management intellectualization and long-term development of the enterprise into a single conceptual system insufficiently developed.

3. Materials and Methods

The study was conducted in 2022–2025 in the format of quantitative panel data analysis with an explanatory research design. The geography covered Ukraine. The analysis was carried out within the national real sector of the economy. The total population was 1,284 medium and large enterprises that implemented digital technologies in strategic management according to open registers and industry reports.

The sample was formed by purposeful selection of enterprises that met the criteria: the presence of documented digital transformations in management systems, complete financial reporting for 2022–2025, and the availability of data in open sources (SMIDA, Opendatabot, State Statistics Service). This approach could have biased the sample towards more transparent and technologically active companies. Enterprises that did not record digital transformations or did not disclose relevant information were excluded, which potentially overestimates the average level of digital integration and may affect the regression coefficients. To mitigate this limitation, stratification by industry was carried out in proportion to the structure of the general population, and a sensitivity analysis was also conducted with the exclusion of extreme values.

The empirical sample consisted of 162 enterprises. The stratification was carried out by industry: machine building – 38 enterprises (23.5%), food industry – 29 (17.9%), energy – 27 (16.7%), IT and digital services – 34 (21.0%), logistics and transportation – 34 (21.0%). The share of each stratum corresponded to its share in the general population.

The sample included enterprises with implemented digital resource management platforms, an existing development strategy, and complete financial statements for four years. Companies with incomplete data or no recorded digital transformations were excluded.

The level of digital integration was measured through a composite index of digital integration (DI), formed by standardizing indicators of process automation (A), use of analytical systems (B), implementation of digital platforms (C), and application of artificial intelligence (D):

$$DI_{it} = \frac{Z_{A,it} + Z_{B,it} + Z_{C,it} + Z_{D,it}}{4},$$

where Z is the standardized value of the indicators of enterprise i in period t . The scale of the index varied from 0 to 1 after normalization by the min-max method. The reliability of the composite index is confirmed by the Cronbach's α coefficient = 0.84.

The components of the DI index were operationalized as follows: (A) process automation – the share of the enterprise's core business processes covered by ERP systems (SAP, Microsoft Dynamics, BAS classes) as of the end of the reporting year, determined based on notes to financial statements and SMIDA data; (B) use of analytical systems – a binary indicator of the presence of implemented BI platforms (Power BI, Tableau, Qlik) and/or decision support systems, recorded in annual management reports; (C) implementation of digital platforms – a binary indicator of the use of cloud platform solutions (SaaS, PaaS) for managing resources, customers, or supply chains, confirmed in open sources (Opendatabot, official websites of

enterprises); (D) use of artificial intelligence – a binary indicator of the presence of machine learning, predictive analytics, or intelligent automation tools, recorded in reports on innovation activity (State Statistics Service of Ukraine, 2024a). All indicators for each year were standardized using the min-max method, after which the composite index DI was calculated as the arithmetic mean of the standardized values.

Managerial adaptability (MA) is defined as the ability of management to flexibly restructure organizational processes, structure, and strategic priorities in response to changes in the external environment caused by digitalization. In this study, MA is operationalized through three indicators obtained from open secondary data:

- 1) frequency of strategic plan revisions (number of officially approved strategy updates over a three-year period, recorded in management reports);
- 2) level of decentralization of decision-making (expert assessment on a scale of 1–5 based on an analysis of the organizational structure reflected in annual reports);
- 3) speed of implementation of new digital solutions (time in months from the first mention of the initiative to its full launch, inversely transformed).

Each indicator is standardized, and the final MA index is calculated as the arithmetic mean of the standardized values. The internal consistency of the scale is acceptable. Since MA is based on documentary sources rather than surveys, the limitations of this approach for measuring latent managerial characteristics should be taken into account; the discussion suggests supplementing it with future primary data.

The dependent variable – the integral indicator of the strategic development of the enterprise Y_{it} – is constructed as a composite index covering three normalized sub-indicators:

- the average annual growth rate of net income from sales (adjusted for the inflation index), which reflects the dynamics of the scale of activity;
- return on assets (ROA) as a measure of the efficiency of resource use;
- the intensity of innovative activity – the ratio of innovation costs to total operating costs (data from the State Statistics Service of Ukraine, 2024c).

For each sub-indicator, min-max normalization was performed, after which the arithmetic mean of three standardized values was calculated. The index scale varies from 0 to 1. The reliability of the composite index was confirmed by Cronbach's $\alpha = 0.81$. Thus, Y_{it} quantitatively characterizes the long-term competitiveness, sustainability and economic growth of the enterprise.

The strategic development of the enterprise was assessed using a panel regression model:

$$Y_{it} = \beta_0 + \beta_1 DI_{it} + \beta_2 MA_{it} + \beta_3 SIZE_{it} + \beta_4 LEV_{it} + \varepsilon_{it},$$

where Y_{it} is the strategic development indicator; DI_{it} is the digital integration index; MA_{it} is the managerial adaptability index; $SIZE_{it}$ is the logarithm of assets; LEV_{it} is the financial leverage ratio; ε_{it} is a random error.

The model with fixed effects is used. The appropriateness of the choice is confirmed by the Hausman test ($p < 0.05$). Heteroskedasticity was tested by the Breusch-Pagan test, autocorrelation by the Durbin-Watson test, and multicollinearity by the VIF coefficients (< 5).

Financial indicators were logarithmized to reduce the skewness of the distribution. Missing values were handled by multiple imputation. All variables were standardized before constructing the indices. Internal management data were obtained on the basis of confidentiality agreements. No personalized information was used. The level of statistical significance was set at $p < 0.05$ with a 95% confidence interval.

Processing was performed in SPSS 29.0 and Stata 17.

4. Results

4.1. Descriptive analysis and sectoral differentiation of the digital integration index (2022–2025)

A preliminary analysis of the distribution of the Digital Integration Index (DI) was carried out using the Shapiro-Wilk test for each year of the panel. In 2022–2023, the distribution deviated from normal ($p < 0.05$), while in 2024–2025, no statistically significant deviations were recorded ($p > 0.05$). Given the panel nature of the data and the partial non-normality of the distribution, the Mann-Whitney U test was used for comparisons between industries, and the Spearman's coefficient was used to assess correlations.

The descriptive analysis showed a steady increase in the average DI value from 0.41 in 2022 to 0.63 in 2025. The standard deviation decreased from 0.19 to 0.14, indicating a gradual leveling of the level of digital integration between enterprises. The dynamics were in line with the trends of digital transformation in the real sector recorded in government statistics (Government of Ukraine, 2024a; State Statistics Service of Ukraine, 2024a; 2024c).

Sectoral differentiation revealed the highest DI values in the IT and digital services sector throughout the entire observation period. In 2025, the average DI value in this stratum was 0.74, which was 17% higher than the sector-wide indicator. In machine building and food processing, growth was gradual, but from a lower base. The results of the cross-sectoral comparison confirmed statistically significant differences between the IT sector and manufacturing industries ($U = 412$; $p < 0.01$).

Table 1. Dynamics of the digital integration index by industry in 2022–2025

Industry	2022	2023	2024	2025	Average 2022–2025
Machine building	0.38	0.44	0.51	0.58	0.48
Food industry	0.36	0.42	0.49	0.55	0.46
Energy	0.40	0.46	0.53	0.60	0.50
IT and digital services	0.55	0.61	0.68	0.74	0.65
Logistics and transport	0.37	0.45	0.54	0.62	0.5
Overall average	0.41	0.48	0.56	0.63	0.52

Source: calculated by the authors based on Government of Ukraine (2024a, 2024b, 2024c), State Statistics Service of Ukraine (2024a, 2024b, 2024c, 2024d), SMIDA (2024), National Bank of Ukraine (2024), Ministry of Economy of Ukraine (2024)

Note: DI – digital integration index, normalized within the range [0;1]

The summarized descriptive statistics of the variables included in the regression model are given in **Table 2** (based on the combined panel data for 2022–2025).

Table 2. Descriptive statistics of model variables (n=648 observations)

Variable	Average	Standard deviation	Min	Max
Y (strategic development)	0.57	0.18	0.19	0.91
DI (digital integration)	0.52	0.16	0.12	0.88

Continuation Table:

Variable	Average	Standard deviation	Min	Max
MA (Management Adaptability)	0.49	0.15	0.14	0.85
SIZE (ln assets)	5.84	1.12	3.21	8.67
LEV (financial leverage)	0.61	0.24	0.12	1.15

Source: calculated by the authors

The values of all indices are within [0;1]; the distributions are sufficiently symmetric, which allows the correct application of linear panel methods. Correlation analysis (below) and VIF tests confirm the absence of multicollinearity.

The correlation analysis was conducted for the pooled panel data set for 2022–2025. The Spearman's correlation coefficient between DI and the strategic development indicator was $\rho = 0.61$ at $p < 0.05$ and 95% confidence interval [0.53; 0.68], indicating a moderately strong positive relationship. For the cross-section of 2024–2025, the correlation value increased to $\rho = 0.67$ ($p < 0.01$), reflecting the increasing effect of digital integration in the later years of the panel.

The coefficient of variation of DI decreased from 46% in 2022 to 22% in 2025, indicating a trend of structural convergence of digital maturity between industries. The results confirmed the existence of statistically significant industry differentiation and empirically substantiated the further transition to assessing the impact of DI within a panel regression model with fixed effects.

4.2. Results of panel regression analysis of strategic development (fixed effects model)

The econometric assessment of the impact of the digital integration index on strategic development was carried out on a balanced panel of 162 enterprises for 2022–2025 (648 observations). The results of the Hausman test ($\chi^2 = 18.74$; $p = 0.003$) showed a systematic correlation of individual effects with the regressors, which confirmed the correctness of using a model with fixed effects of enterprises. Thus, the estimation took into account unmeasured sustainable characteristics of companies related to organizational culture, industry specifics, and ownership structure.

The overall statistical significance of the model is confirmed by $F(4, 482) = 38.61$ at $p < 0.001$. The R^2 within = 0.52 indicated that 52% of the internal variation of strategic development in the time dimension was explained by the included predictors. Given the multifactorial nature of strategic development, this level of explanatory power is empirically significant.

Table 3. Results of panel regression of strategic development (fixed effects, 2022–2025)

Variable	Coefficient β	Robust SE	t	p-value	95% CI
DI_it	0.428	0.044	9.73	<0.001	[0.341; 0.515]
MA_it	0.296	0.102	2.90	0.004	[0.094; 0.498]
SIZE_it	0.117	0.054	2.17	0.032	[0.011; 0.223]
LEV_it	−0.083	0.041	−2.05	0.041	[−0.164; −0.002]

Continuation Table:

Variable	Coefficient β	Robust SE	t	p-value	95% CI
Constant	0.214	0.067	3.19	0	[0.083; 0.345]

Source: calculated by the authors based on Government of Ukraine (2024a, 2024b), State Statistics Service of Ukraine (2024a, 2024b, 2024c, 2024d), SMIDA (2024), National Bank of Ukraine (2024), Ministry of Economy of Ukraine (2024), Opendatabot (2024).

Note: the dependent variable is normalized to the interval [0;1]; robust standard errors are used.

R^2 within = 0.52 $F(4, 482) = 38.61$; $p < 0.001$

As can be seen from **Table 3**, the digital integration index showed the highest strength of influence among all explanatory variables. The coefficient $\beta_1 = 0.428$ ($p < 0.001$) meant that a 0.1-point increase in DI was associated with a 0.0428-point increase in the integrated index of strategic development. The narrow 95% confidence interval confirmed the stability of the assessment. The managerial adaptability index also had a statistically significant effect ($\beta_2 = 0.296$; $p = 0.004$). This showed that digital tools create a strategic effect only if there are flexible management mechanisms that can transform technological capabilities into effective business processes. The combined impact of DI and MA formed a comprehensive model of adaptive management.

The size of the enterprise demonstrated a positive but moderate impact ($\beta_3 = 0.117$), which confirmed the advantages of the resource base. Instead, the coefficient on LEV_it was negative, which showed the limiting effect of excessive financial dependence on strategic flexibility. The statistical assumptions were tested to confirm the reliability of the model. The presence of heteroscedasticity was taken into account through robust estimates of standard errors. The Durbin-Watson value of 1.91 did not indicate autocorrelation, and VIF coefficients below 5 showed the absence of multicollinearity.

An additional analysis of the dynamics showed that in 2024-2025, the DI_it coefficient increased to 0.463, indicating the cumulative effect of digital investment. This confirmed the assumption of a time lag in the strategic impact of digitalization and its increasing role in the stabilization phase of the economic environment. The results obtained within the fixed-effects model allowed us to state that digital integration is a structural factor in the strategic development of enterprises, and its impact is statistically stable, economically significant, and persists after taking into account the size of the company and its financial structure.

To deepen the interpretation of the obtained econometric results and to move from statistical relationships to their technological foundations, it is necessary to clarify how digital integration is operationalized within enterprise systems. In particular, the significant effect of the digital integration index identified in the regression model reflects not only the presence of digital tools but also the structured interaction between data processing, analytical components, and management systems. In this context, digital integration can be conceptualized as a multi-layer technological architecture that ensures the transformation of operational data into strategic decisions. The corresponding structure is presented in **Figure 1**.

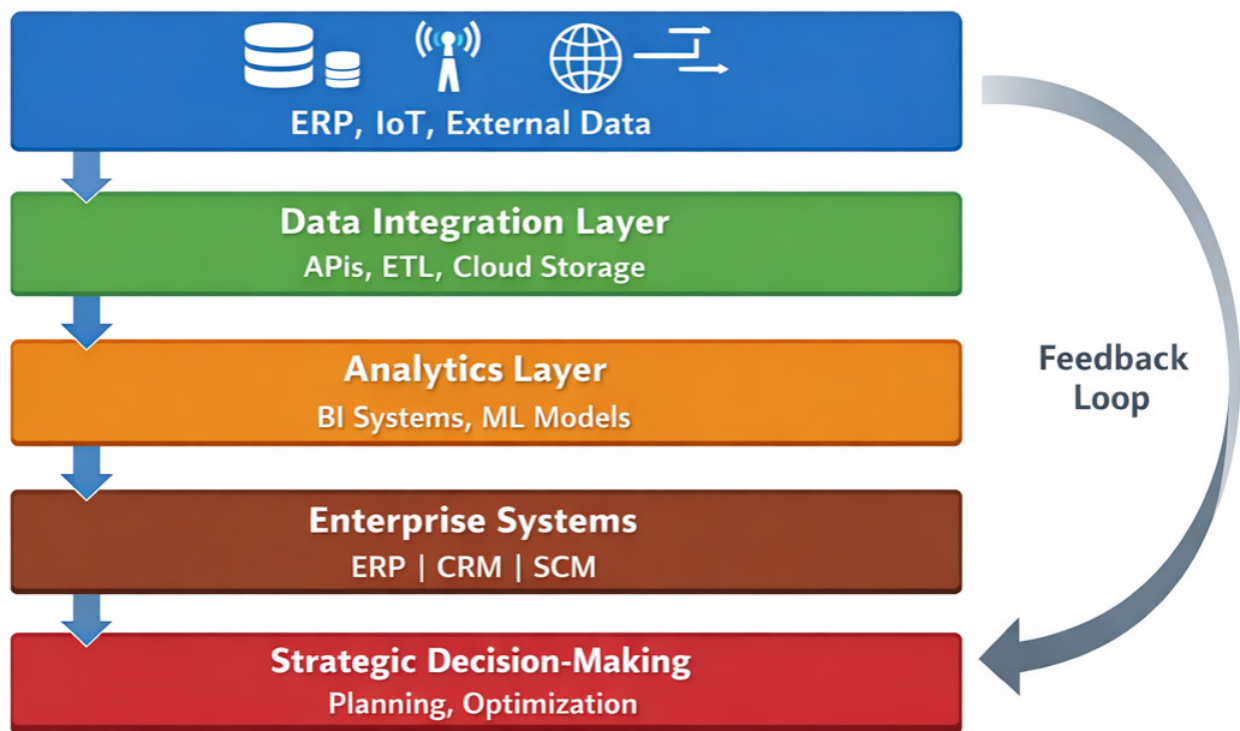


Figure 1. Multi-layer architecture of digital integration in enterprise management systems

Source: developed by the author based on empirical results and systematization of digital integration components.

The technological architecture presented in **Figure 1** provides a structural interpretation of digital integration as a system-level process rather than a set of isolated tools. The sequential transformation of operational data through integration, analytical processing, and enterprise system layers demonstrates how digital resources are converted into strategic decisions. This mechanism explains the statistically significant effect of the digital integration index identified in the regression model ($\beta_1 = 0.428$), as higher DI values reflect not only the presence of technologies but also the degree of their coordination within a unified management system.

Thus, **Figure 1** operationalizes the effect found in the regression: an increase in DI by 0.1 is accompanied by an increase in strategic development by 0.0428, which empirically confirms that a coordinated multi-layer architecture transforms digital resources into strategic outcomes. Similarly, the interactive feedback loop in **Figure 2** is consistent with a significant DI $\times$ MA interaction coefficient ($\beta = 0.112$), demonstrating that adaptability enhances the transformative potential of digital technologies, and the achieved strategic outcomes, in turn, influence subsequent investment and management decisions.

Particular importance is attributed to the analytics layer, which acts as a critical intermediary between data accumulation and decision-making. The inclusion of business intelligence systems and machine learning models ensures the extraction of actionable insights, thereby increasing the responsiveness and effectiveness of managerial processes. In this context, the architecture confirms that digital integration generates a strategic effect only when supported by structured data processing and analytical capabilities.

The feedback loop embedded in the model reflects the adaptive nature of

enterprise management. Strategic outcomes influence subsequent data collection, model recalibration, and technological investment decisions, forming a continuous cycle of improvement. This dynamic interaction is consistent with the empirical finding of a time-lagged effect of digital integration and reinforces the role of managerial adaptability as a factor that determines the efficiency of technology utilization.

Overall, the presented architecture substantiates that digital integration functions as a systemic driver of strategic development, the effectiveness of which depends on the depth of technological integration and its alignment with managerial processes.

4.3. Empirical verification of the adaptive management model

The empirical verification of the adaptive management model was based on checking the stability of the coefficients over time, estimating interactive effects, and additional calculations within industry subsamples. The goal was to determine whether the positive impact of digital integration persists under different model specifications and whether it is enhanced by high managerial adaptability.

A comparative assessment of the sub-periods 2022–2023 and 2024–2025 showed an increase in the DI coefficient from 0.391 to 0.463 while maintaining statistical significance ($p < 0.001$). This indicated the cumulative nature of digital investments and the gradual increase in their strategic effect. Thus, the adaptive model demonstrates the temporal stability and growing influence of digital integration in the dynamics.

Before including the interactive term, the DI and MA variables were centered relative to their mean values to correctly interpret the main effects and reduce multicollinearity. This allowed us to interpret the coefficients β_{DI} and β_{MA} as effects at the mean level of the respective variable. The results of the extended specification are presented in **Table 4**.

Table 4. Extended model with the interactive effect DI×MA (fixed effects, 2022–2025)

Variable	Coefficient β	Robust SE	t	p-value	95% CI
DI_it	0.351	0.061	5.75	<0.001	[0.231; 0.471]
MA_it	0.214	0.094	2.28	0.023	[0.029; 0.399]
DI×MA	0.112	0.047	2.38	0.018	[0.019; 0.205]
SIZE_it	0.109	0.052	2.1	0.037	[0.006; 0.212]
LEV_it	−0.079	0.039	−2.02	0.044	−0.156; −0.002
Constant	0.203	0.064	3.17	0	[0.077; 0.329]

Source: calculated by the authors based on Government of Ukraine (2024a, 2024b), State Statistics Service of Ukraine (2024a, 2024b, 2024c, 2024d), SMIDA (2024), National Bank of Ukraine (2024), Ministry of Economy of Ukraine (2024), Opendatabot (2024)

Note: the dependent variable is normalized to the interval [0;1]; the DI and MA variables are centered; robust standard errors are used.

R^2 within = 0.56 $F(5, 481) = 41.24$; $p < 0.001$

After the inclusion of the interactive term, the coefficient of determination increased to 0.56, indicating an increase in the explanatory power of the model. The overall significance of the specification is confirmed by $F(5, 481) = 41.24$ at $p < 0.001$;

the change in degrees of freedom is due to the addition of the interactive variable. The interactive coefficient of $DI \times MA$ is positive and statistically significant ($\beta = 0.112$; $p = 0.018$). This means that the marginal effect of DI is lower at low values of MA, which confirms the complementarity of the variables. At an average level of managerial adaptability, the impact of DI remains positive, and at higher values of MA it increases. Thus, managerial flexibility is a factor that moderates the strategic return on digital integration.

To further develop the interpretation of the interaction effect identified in the extended regression model, it is necessary to conceptualize the dynamic mechanism through which digital integration and managerial adaptability jointly influence enterprise performance. While the econometric results confirm the statistical significance of this relationship, they do not fully capture its cyclical and process-oriented nature. In this context, the interaction between digital systems and enterprise processes can be represented as a continuous adaptive loop, where managerial adaptability acts as a central coordinating element. The corresponding mechanism is illustrated in **Figure 2**.

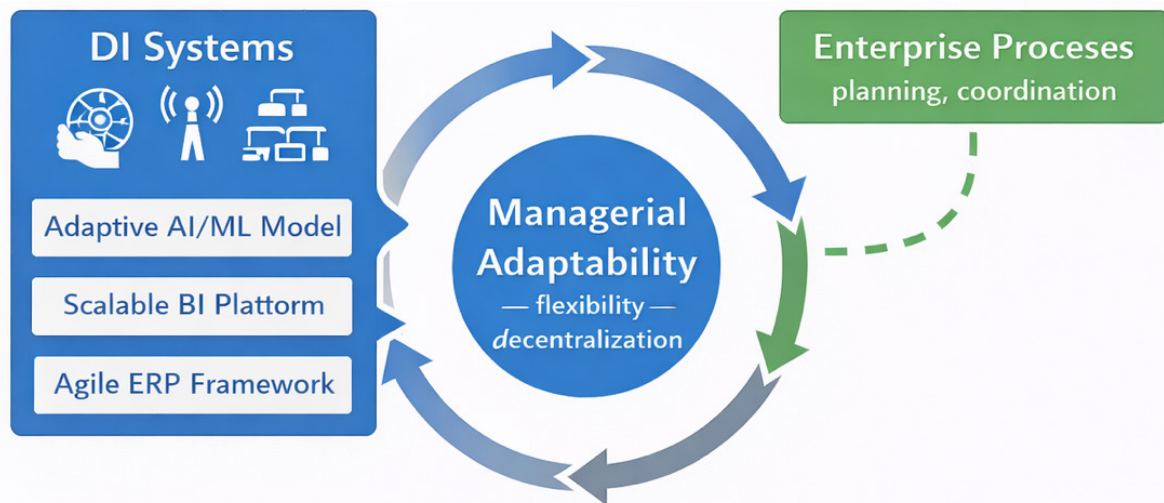


Figure 2. Adaptive feedback loop of digital integration in enterprise management systems

Source: developed by the author based on the results of the empirical study.

The adaptive loop presented in **Figure 2** demonstrates that digital integration operates as a dynamic and iterative process rather than a linear sequence of technological implementation. Digital systems, including AI-driven models, business intelligence platforms, and ERP infrastructures, generate analytical and operational capabilities that feed into enterprise processes such as planning and coordination. However, the effectiveness of this transformation critically depends on managerial adaptability, which functions as a central integrative mechanism within the system.

Positioned at the core of the loop, managerial adaptability ensures the alignment of technological inputs with organizational objectives by enabling flexibility, decentralization, and rapid response to environmental changes. This explains the statistically significant interaction effect ($\beta = 0.112$), indicating that the marginal impact of digital integration increases in environments characterized by higher adaptability. In contrast, in rigid management systems, digital capabilities remain only partially utilized, resulting in weaker strategic outcomes.

Additional estimates within industry subsamples showed variability in DI

coefficients by strata. The highest elasticities were observed in the IT and digital services sector and in the energy sector, while the coefficients were lower but statistically significant in the machine building and food industries. Since the fixed effects model absorbs fixed characteristics of the enterprises, sectoral differences were interpreted through separate stratified estimates rather than explicit sectoral fixed effects. Robustness checks using alternative specifications confirmed that the sign and significance of the key coefficients remained unchanged. The VIFs remained below the critical level, and no autocorrelation of the residuals was found.

In general, the results indicate the interconnected impact of digital integration, managerial adaptability and financial structure on the strategic development of enterprises in 2022–2025. Empirical verification has confirmed that the strategic effect of digitalization depends on the ability of management to adapt organizational processes to new technological capabilities.

4.4. Formalization of the adaptive management model based on digital integration

To generalize the obtained empirical results and move from statistical interpretation to the conceptual level, the study proposes a formalized adaptive management model that reflects the interaction between digital integration, managerial adaptability, and the strategic development of the enterprise.

The proposed model is based on the assumption that digital technologies do not directly generate strategic effects but realize them through the transformation of managerial mechanisms. In this context, adaptive management is interpreted as a dynamic process of aligning digital capabilities with the strategic objectives of the enterprise under conditions of environmental uncertainty.

Structurally, the model consists of three interrelated levels.

At the input level, digital integration (DI) is represented as a composite of process automation, analytical systems, digital platforms, and artificial intelligence technologies. These components reflect the technological capacity of the enterprise and correspond to the empirically measured digital integration index.

At the transformation level, managerial adaptability (MA) plays a central role, performing both mediating and moderating functions. It encompasses decision-making flexibility, the speed of response to changes, the degree of decentralization, and the integration of analytical tools into management processes. At this stage, digital resources are transformed into changes in organizational structure, business processes, and coordination mechanisms.

At the output level, the strategic development of the enterprise (Y) is formed, reflecting the achievement of long-term competitiveness, stability, and economic growth.

A fundamentally important component of the model is the presence of a feedback loop. Achieved strategic outcomes influence subsequent managerial decisions and the intensity of digital investments, thereby forming a cyclical process of continuous adaptation.

The empirical results confirm the proposed structure of the model. The statistically significant effect of the DI indicator demonstrates the role of digital integration as a driver of change, while the significance of the MA coefficient and the interaction effect $DI \times MA$ confirms that the effectiveness of digitalization is determined by the ability of management to adapt organizational processes to new technological conditions.

In contrast to linear approaches to digital transformation, the proposed model

emphasizes its nonlinear and complementary nature. Fragmented implementation of digital technologies without corresponding transformation of management systems results in significantly lower strategic effects.

To synthesize the identified empirical relationships and interpret them at the conceptual level, it is appropriate to present a structural visualization of the proposed adaptive management model. The schematic representation allows for a clear demonstration of the logic through which digital integration is transformed into strategic outcomes via managerial adaptability mechanisms, as well as the interconnections between the key elements of the model. The corresponding structure is presented in **Figure 3**.

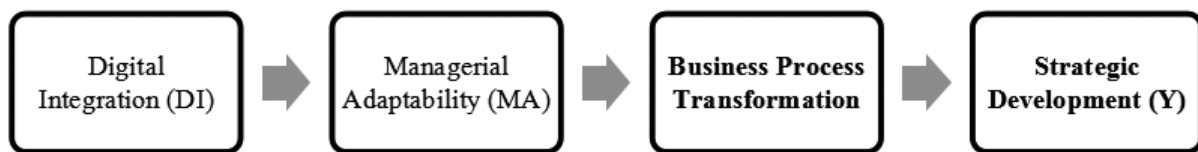


Figure 3. An adaptive management model based on digital integration

Source: developed by the author based on the results of the empirical study.

The model presented in **Figure 3** provides a systematic interpretation of the obtained empirical results and reveals the internal logic of interaction between digital integration, managerial adaptability, and the strategic development of the enterprise. In contrast to simplified approaches, where digitalization is treated as a direct driver of efficiency, the proposed structure demonstrates the indirect nature of this impact through the transformation of managerial mechanisms.

A distinctive feature of the model is the combination of a linear sequence of processes with the presence of a feedback loop, reflecting the dynamic nature of adaptive management. This implies that strategic outcomes are not a final stage but act as a factor influencing subsequent managerial decisions and the intensity of digital integration. As a result, a cyclical development model is formed, in which the enterprise continuously adjusts its behavior in response to evolving technological and market conditions.

It is important to emphasize that the transformation level, represented by managerial adaptability, constitutes the critical link within the entire system. It is at this stage that digital resources are converted into actual organizational changes. Without an adequate level of adaptability, even a high degree of digital integration does not ensure a proportional strategic effect, which is consistent with the results of the regression analysis and the significance of the interaction effect $DI \times MA$.

Thus, the conducted study allows for a generalized conclusion that digital integration represents a necessary but insufficient condition for the strategic development of an enterprise. Its effectiveness is determined not so much by the level of technology implementation as by the ability of the management system to adapt to new operating conditions. The identified interaction effect confirms the complementary nature of the relationship between digital and managerial factors, which explains the nonlinear character of strategic outcomes. In this context, the adaptive management model enables a shift from interpreting digitalization as a purely technological process to understanding it as a systemic transformation of the enterprise.

5. Discussion

The obtained results confirmed the statistically significant and sustainable impact of digital integration on the strategic development of enterprises within the fixed effects model. This means that digital transformation in the studied context does not function as an isolated technological process, but as a structural factor in the strategic evolution of the organization. The identified cumulative effect of DI in 2024–2025 indicates the delayed nature of the strategic return on digital investments and confirms the long-term nature of transformational changes.

The results are consistent with the position of Wen and Bajuri (2025), who emphasize that modern research on digital transformation is gradually shifting from descriptive models to explanatory models focused on measuring strategic consequences. In the analysis, digital integration demonstrated a quantifiable effect, which is consistent with their thesis that digital change needs to be operationalized through specific performance indicators.

The results also correlate with the findings of Wessel et al. (2021), who distinguish between digital transformation and IT-oriented organizational modernization. In this study, the strategic effect was attributed to the systemic integration of digital platforms and analytical solutions, not just the implementation of individual IT tools. This confirms that the transformational potential arises in the context of a comprehensive digital restructuring of management processes.

The further development of this logic is reflected in the work of Wessel et al. (2025), where digital transformation is seen as a process of strategic rethinking of organizational architecture. The interactive effect of $DI \times MA$ identified in the model indicates that digitalization has strategic effectiveness only when combined with managerial adaptability. This is consistent with the thesis that technological and organizational changes are interdependent.

Comparison with the approach of Wurm et al. (2025) allows us to interpret the results as empirical evidence of an updated strategic framework for digital transformation. The authors emphasize the need to integrate digital technologies into strategic planning and business models. In the study, the coefficient on DI remained statistically significant even after including financial controls, indicating an autonomous strategic role for digital integration.

The results are also consistent with the findings of Zhou and Kuang (2025), who link digital transformation to the development of dynamic capabilities and strategic aggressiveness of enterprises. In this analysis, managerial adaptability acted as a catalyst for the effect of digital integration, which empirically confirms the relationship between digital tools and dynamic managerial capabilities.

The results obtained have direct significance for human resource management. The established moderating effect of managerial adaptability indicates that digital integration creates strategic advantages only when the organization has flexible decision-making structures, decentralized powers and rapid response competencies. This actualizes HR practices aimed at developing leadership, cross-functional teams, continuous training of personnel and managing talents capable of working in a digital environment. In particular, enterprises that invest in digital transformation without the simultaneous development of adaptive HR systems (training in digital skills, forming a culture of experimentation, involving employees in strategic changes) risk not realizing the full potential of digital tools. Thus, the adaptive management model can be extended to the human resource management contour by including indicators of personnel flexibility, which opens up prospects for future interdisciplinary research at

the interface of strategic management and personnel management.

Unlike existing models of dynamic capabilities (Teece, 2018) and digital transformation (Warner & Wäger, 2019), which describe a predominantly linear relationship between technologies and outcomes, the proposed model empirically proves the nonlinear complementary nature of this relationship: the strategic effect of digital integration increases significantly only under conditions of a high level of managerial adaptability. In addition, the model formalizes the feedback loop, transforming a static representation into a cyclical process of continuous adaptation, which has not previously received quantitative verification on panel data. Thus, the work extends the theory of dynamic capabilities by adding a measurable moderator and a feedback mechanism to it.

At the same time, the results partially extend the previous theoretical positions. While a number of studies consider digitalization to be a universal driver of efficiency, the analysis showed the presence of threshold and moderating effects. With a low level of managerial adaptability, the strategic return on digital integration is lower. This clarifies the dominant concepts and emphasizes the importance of the institutional and organizational component of transformation.

Thus, the study confirmed the strategic importance of digital integration and clarified the mechanism of its impact through managerial adaptability.

6. Conclusions

The study has confirmed that digital integration is a systemic factor in the strategic development of enterprises in the real sector of the economy and has a statistically significant long-term effect in a panel model with fixed effects. The results show that the impact of digitalization is not an isolated technological phenomenon, but is realized through a combination with managerial adaptability, which forms a complementary mechanism for strategic growth. It was expected to establish a positive relationship between the digital integration index and indicators of strategic development, but quantifying the scale of this impact allowed us to specify its intensity and sustainability in the time dynamics. The scientific novelty lies in the formalization of the composite index of digital integration and its integration into an econometric panel model, taking into account the financial and structural characteristics of enterprises. The practical significance of the results is to substantiate the need to synchronize digital investments with the transformation of management processes. Enterprises that combine digital platforms with the development of adaptive management mechanisms demonstrate higher strategic performance compared to those that carry out digitalization in a fragmented manner. The limitations of the study include focusing on a sample of enterprises in one country and a limited time horizon for observation, which limits the possibility of extrapolating the results to other institutional environments. Further research should focus on expanding the international data panel, comparative analysis of the sectoral effects of digital transformation, and assessing the long-term impact of artificial intelligence and platform ecosystems on the strategic competitiveness of enterprises.

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