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ORIGINAL

Exploration of Digital Transformation Paths of Different Enterprises Based on Federal Learning from the Perspective of Business Model

Exploración de diferentes caminos de transformación digital empresarial basados en el aprendizaje federal desde la perspectiva del modelo de negocio

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ABSTRACT

Digital transformation and upgrading have emerged as central theories for integrating digital consumption with enterprise transformation. This shift is essential for enterprises to meet evolving development needs and establish sustainable interest models. However, practical challenges and a lack of experience often hinder successful transformation, raising doubts about whether digital transformation can genuinely enhance performance. The theoretical exploration of this relationship remains in its early stages, with differing scholarly views on how digitalization affects performance.

Objective: this paper aims to explore the mechanisms through which digital transformation impacts enterprise performance. It seeks to address the existing gaps in understanding and to investigate the channels through which digital transformation influences performance, utilizing various theoretical perspectives.

Method: to address high communication costs and data heterogeneity in federated learning, this study introduces local update and gradient compression techniques in optimization algorithms. Additionally, it incorporates gradient tracking to manage data heterogeneity. The paper employs a combination of resource-based theory, empowerment theory, and contingency theory, along with empirical analysis and experimental detection methods, to enrich the research content and depth.

Results: the experimental results demonstrate that the optimized NG Boost model is effective in examining enterprises undergoing digital transformation from a dynamic capabilities perspective. This approach proves useful for studying how digital transformation leads to performance enhancement.

Conclusion: the study confirms that integrating local updates, gradient compression, and gradient tracking into optimization algorithms can address key challenges in federated learning. The findings highlight the significance of digital transformation in improving enterprise performance, emphasizing the value of dynamic capabilities in achieving performance upgrades.

Keywords: Business Model; Federal Learning; Digital Transformation of Enterprises; NG Boost Model Optimization.

RESUMEN

La transformación digital y la actualización se han consolidado como teorías centrales para integrar el consumo digital con la transformación empresarial. Este cambio es esencial para que las empresas satisfagan las necesidades de desarrollo en evolución y establezcan modelos de interés sostenibles. Sin embargo, los desafíos prácticos y la falta de experiencia a menudo dificultan una transformación exitosa, generando dudas sobre si la transformación digital puede realmente mejorar el rendimiento. La exploración teórica de esta relación aún se encuentra en sus primeras etapas, con diversas opiniones académicas sobre cómo la digitalización afecta el rendimiento.

Objetivo: este artículo tiene como objetivo explorar los mecanismos a través de los cuales la transformación digital impacta el rendimiento empresarial. Busca abordar las lagunas existentes en la comprensión y examinar los canales a través de los cuales la transformación digital influye en el rendimiento, utilizando diversas perspectivas teóricas.
Método: para abordar los altos costos de comunicación y la heterogeneidad de datos en el aprendizaje federado, este estudio introduce técnicas de actualización local y compresión de gradientes en los algoritmos de optimización. Además, incorpora el seguimiento de gradientes para gestionar la heterogeneidad de datos. El artículo emplea una combinación de teoría basada en recursos, teoría del empoderamiento y teoría de contingencia, junto con métodos de análisis empírico y detección experimental, para enriquecer el contenido y la profundidad de la investigación.
Resultados: los resultados experimentales demuestran que el modelo NG Boost optimizado es efectivo para examinar empresas en proceso de transformación digital desde una perspectiva de capacidades dinámicas. Este enfoque resulta útil para estudiar cómo la transformación digital conduce a la mejora del rendimiento.
Conclusión: el estudio confirma que integrar actualizaciones locales, compresión de gradientes y seguimiento de gradientes en los algoritmos de optimización puede abordar desafíos clave en el aprendizaje federado. Los hallazgos destacan la importancia de la transformación digital en la mejora del rendimiento empresarial, enfatizando el valor de las capacidades dinámicas para lograr mejoras en el rendimiento.

Palabras clave: Modelo de Negocio; Aprendizaje Federal; Transformación Digital de las Empresas; Optimización del Modelo de Impulso NG.

INTRODUCTION

Digital transformation refers to the innovation of business model and value creation model by traditional enterprises through deep integration with digital economy to form a new digital and intelligent enterprise supported by digital technology. The business model is a value creation system based on the overall resource capacity of the enterprise and the internal and external stakeholders. Therefore, the model has surpassed the price or function advantages in traditional competition, and formed a competitive advantage with value superiority, heterogeneity, difficulty in imitation, transferability, and difficulty in substitution. Major companies that have implemented digital transformation or digital reform usually have invested huge human and material costs and have implemented digital transformation on information technology equipment and information systems. Among the major companies in China's digital transformation, only 16 % of them can achieve significant improvement in their operating income and net business income, which has improved compared with the past, but the overall performance of enterprises in digital transformation is not ideal. It can be seen from this that although many companies are currently committed to promoting the digital transformation, there are still many problems to be solved, with the significant growth of enterprise revenue and profits as the standard for successful transformation.[1,2]

In the complex and volatile international environment and in the historical position of the new era, China needs to take innovation as the driving force, rely on scientific and technological forces, consider the domestic and international markets, and build a new development pattern in which the two promote each other. They have become the embryonic form of digital industry with a certain scale and an important part of the national industrial layout. In important documents such as the 13th Five Year Plan and the 14th Five Year Plan, it has been mentioned many times to accelerate the development of digital industry and actively promote the in digital industry.[3,4,5]

Moreover, the existing research mainly emphasizes the necessity of digital transformation from a macro perspective and the business priorities that transformation should pay attention to, and lacks more universal research conclusions on transformation strategies, paths, etc. It can be said that the research in this field is still. In the current economic environment and market development trend, independent innovation and in-depth application of digital technology can reduce the restrictions on traditional manufacturing. Digital transformation has become the main means of upgrading, innovation, cost reduction and gain of manufacturing industries, and in improving the core competitiveness of high-end equipment manufacturing and building international brands. This paper selects Hangfa Power as a case company to analyze in detail the in-depth application of digital transformation and the internal transmission path of digital transformation to enterprise performance, to provide reference for the transformation and upgrading of other high-end equipment manufacturing industries.[6,7]

To sum up, this paper explores new ideas and methods of enterprise digital transformation in the form of model optimization, which is of forward-looking significance.

Ng boost model optimization

NG Boost model is a new type of supervised machine learning algorithm. It introduces natural gradient

into the traditional gradient lifting algorithm and has the ability of probability prediction while retaining the advantages of high accuracy of gradient lifting algorithm in small-scale datasets. Since the noise of observation points causes errors in this formula, this paper can sum and minimize the errors by constructing the least squares problem, as shown in equation (1):

$$\xi^* = \arg\min_{\xi} \frac{1}{2}\sum_{i=1}^{n}\left\| u_i - \frac{1}{s_i} K \exp\left(\xi^n\right) P_i \right\|_2^2 \quad (1)$$

In visual SLAM, it is usually a nonlinear function. Because its form is generally complex, we usually use iterative method to solve it, so the objective function can be expressed as, as shown in equation (2):

$$\min_x F\left(x_k + \Delta x_k\right) = \left\| f\left(x_k + \Delta x_k\right)\right\|^2 \quad (2)$$

An appropriate scoring rule must be able to accurately evaluate the difference between the predicted distribution and the true value and can enable the true probability distribution to obtain the best score. We can use the mathematical formula to express it as, as shown in equation (3):

$$\mathrm{E}_{y\sim\mathrm{Q}}[S(Q,y)] << \mathrm{E}_{y\sim\mathrm{Q}}[S(P,y)] \quad \forall P,Q, \quad (3)$$

The first order expansion function has the minimum value under the condition that the function is derived, as shown in equation (4):

$$\frac{\partial\left\| f\left(x_k\right) + J\left(x_k\right)^T \Delta x_k \right\|^2}{\partial \Delta x_k} = 0 \quad (4)$$

Further solution can be obtained, as shown in equation (5):

$$J\left(x_k\right) J\left(x_k\right)^T \Delta x_k = -J\left(x_k\right) f\left(x_k\right) \quad (5)$$

The extra score on the right side of the equation is the divergence induced by the scoring rule. It is nonnegative and can be used to measure the difference between distribution Q and distribution P. It is defined as, as shown in equation (6):

$$D_S(Q\| P) = \mathrm{E}_{y\sim\mathrm{Q}}[S(P,y)] - \mathrm{E}_{y\sim\mathrm{Q}}[S(Q,y)] \quad (6)$$

We can derive KL divergence from MLE scoring rules, as shown in equation (7):

$$D_{\mathrm{L}}(Q\| P) = \mathrm{E}_{y\sim\mathrm{Q}}[\mathrm{L}(P,y)] - \mathrm{E}_{y\sim\mathrm{Q}}[\mathrm{L}(Q,y)] = D_{KL}(Q\| P) \quad (7)$$

METHOD

Data selection

This paper focuses on SMEs and studies their digital transformation. Most of the previous scholars' relevant research focused on analyzing the necessity and reasons of transformation and studied the strategic choice of SME transformation. Their research conclusions did not adapt to the digital direction of SME transformation.

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Therefore, this paper attempts SMEs, so that the transformation of SMEs can meet the requirements of the construction of "Digital China". A typical federated network framework is shown in figure 1.

The problem of vertical federated NG Boost in mobile edge computing is expressed as follows: the primary node has the ID, some features and labels of the sample, and the secondary node has the ID and some features of the sample. The primary and secondary nodes complete the establishment and training of the NG Boost model without disclosing their own data to each other. The purpose of image classification task is to distinguish different types of images according to the characteristics reflected by the images. The general training process is shown in figure 2.

As shown in figure 3, for the pinhole camera model, this paper introduces three coordinate systems to describe the camera imaging process:

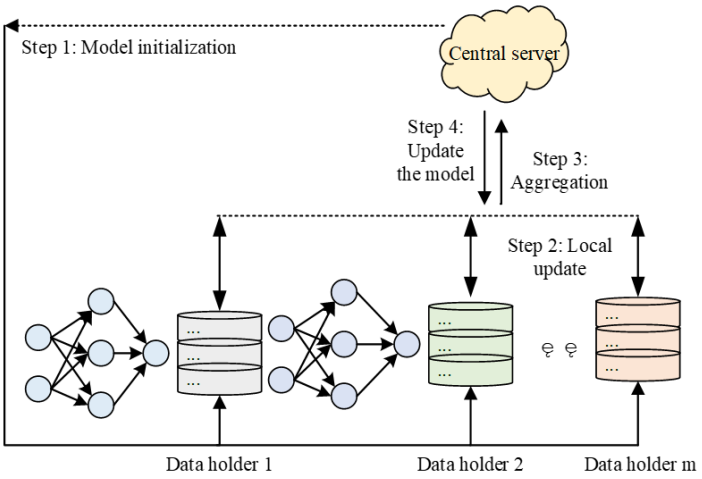

Figure 1. Federal Learning Process

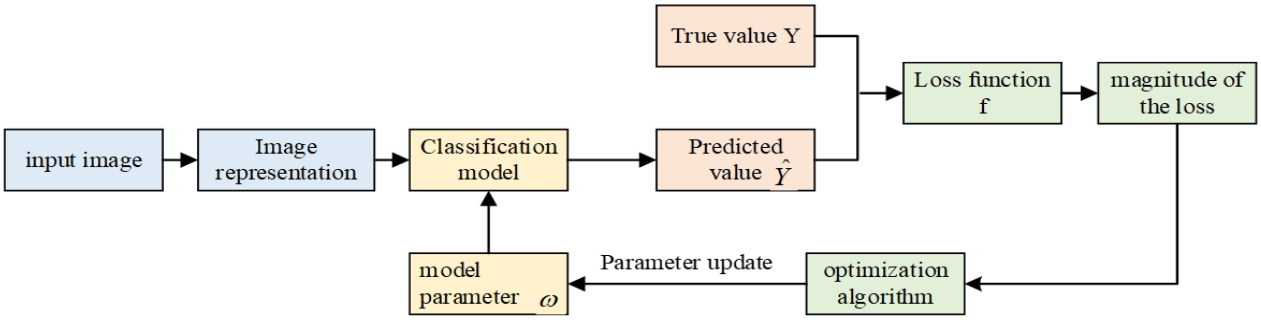

Figure 2. Image Classification Process Optimization

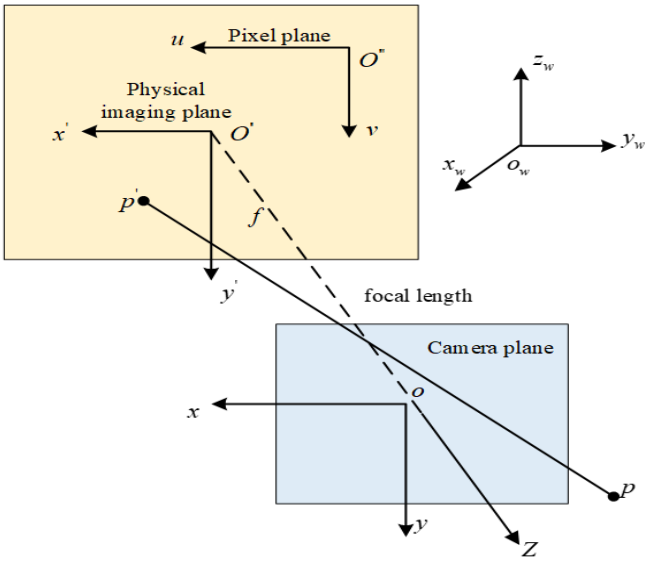

Figure 3 Pinhole Camera Model

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Figure 4 shows various federated learning architectures for two party scenarios. When the features of data sets among participants overlap more and the samples overlap less, horizontal federated learning is adopted; When feature overlap is small and sample overlap is large, longitudinal federated learning is adopted; When the features and samples overlap little, the migrating federation learning is adopted.

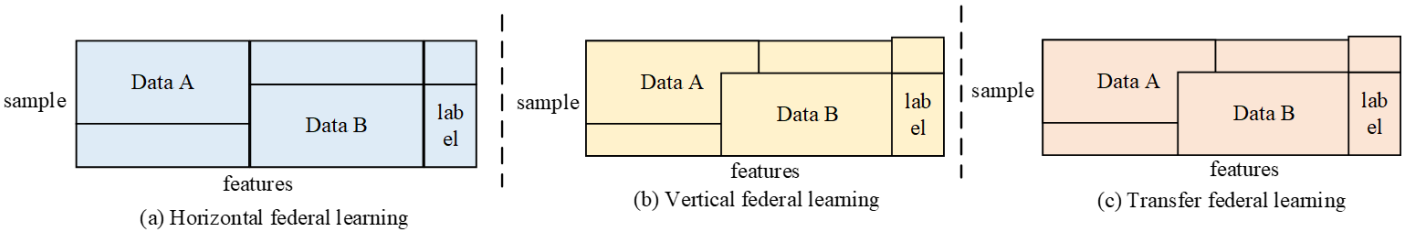

Figure 4. Federal Learning Architecture

Statistical analysis

Federated learning aims to solve the problem of interactive training of global functions between multiple devices and a central server. Specifically, the form of optimization problem solved by federated learning is shown in equation (8):

$$\min_{\omega \in R^d} \left\{ f(\omega) := \frac{1}{m} \sum_{j=1}^{m} f_j(\omega) \right\} \quad (8)$$

Digital transformation is a dynamic process in which relevant entities apply 5G, in relevant fields as required. The process of digital transformation requires very high innovation. On the one hand, digital technology continues to innovate based on the development trend of digital economy to promote the upgrading of technology itself; On the other hand, enterprises should innovate the entry points, scenarios and tools of relevant digital technology applications according to their own development characteristics. At the same time, due to the close relationship between business model and value chain, business model innovation is also of great significance for building the competitive advantage of enterprises.

At present, the digital transformation of Chinese enterprises is still in its infancy. According to the survey, only 11 % of enterprises will achieve significant results in digital transformation in 2020. Many enterprises have only conducted single point experiments or partial promotion of digital construction. Many enterprises have problems such as inadequate understanding, unclear goals, lack of top-level design, and are facing transformation difficulties. Figure 5 shows the current situation of digital transformation of enterprises in China. Large enterprises are the main force in the construction of digital economy in China. The larger the enterprises are, the more they can realize the importance of digital transformation and start digital transformation earlier. Among these enterprises, there are many “leading enterprises” in some industries, which can provide a good demonstration for enterprises in transformation difficulties (figure 5).

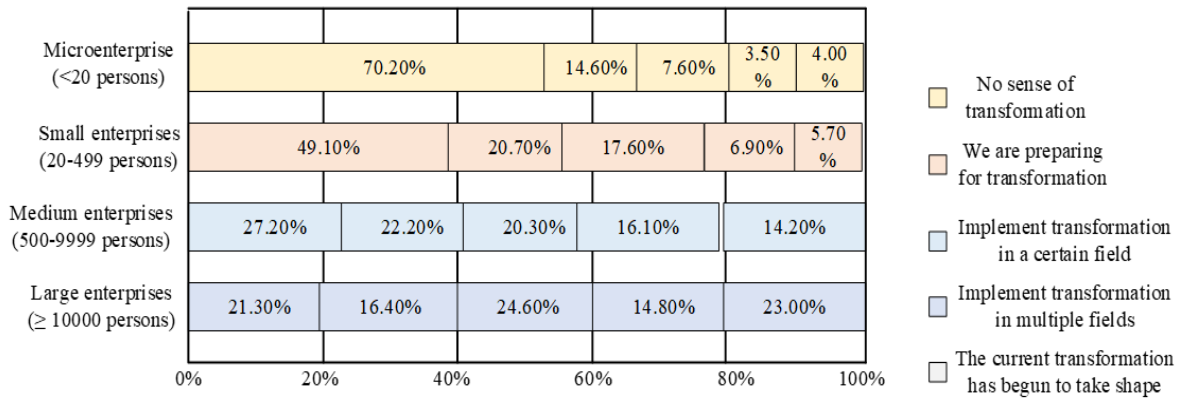

Figure 5. Current Situation of Digital Transformation of Chinese Enterprises

To sum up, digital transformation is a series of reforms adopted by enterprises to adapt to the market, seize market share, and make enterprise development more stable and progressive. Enterprise performance is a straightforward manifestation of enterprise reform.

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RESULTS

Mechanism analysis of enterprise digital transformation power

For enterprises preparing for digital transformation, they should first clarify the reasons why their organizations want to carry out digital transformation, that is, "Why should my organization implement digitalization?", Whether it is active transformation or passive transformation, enterprises need huge investment in human resources, capital resources and material resources in the process, and bear huge risks of transformation failure. There are at least 10 factors driving enterprises' digital transformation, as shown in table 1.

Table 1. Drivers of enterprise digital transformation

Driving force type	Drive
Requirements for inherent characteristics of products or services	Electronic transmission
	Available information strength
	Customer customization
	Realize integration effect
The need for interaction between the company and customers	Reduce search costs
	Real time interaction
	Reduce contract risk
Delivery needs of the company with partners and competitors	Realize network effect
	Leveraging the benefits of standardization
	Ability to make up for deficiencies

Summary of Digital Transformation Path

Descriptive statistics of relevant variables within the sample interval are shown in table 2. The sample size is about 9 296, among the alternative variables of enterprise performance, the level of return on assets (ROA) is in the range of - 19,6 %~20,6 %, with an average of 4,1 %; Return on equity (ROE) ranges from - 42,9 % to 33,9 %, with an average of 6,4 %, indicating that the performance levels of different manufacturing enterprises are uneven and significantly different; The average of the degree of digital transformation of enterprises (the result of logarithmic processing of the frequency of the relevant characteristic words of digital transformation) is 1 278, the minimum value is 0, and the maximum value is 4 949. This indicates that the degree of digital transformation of manufacturing enterprises is quite different, and some enterprises may not have started digital transformation.

Table 2. Descriptive Statistical Results of Enterprise Digital Transformation

Variable name	sample size	mean value	standard deviation	minimum value	p25	median	p75	Maximum
ROA	9 296	0,042	0,058	-0,197	0,014	0,038	0,069	0,207
ROE	9 296	0,065	0,105	-0,429	0,026	0,064	0,113	0,339
Digital Trans	9 296	1,279	1,233	0	0	1,099	2,079	4,949
Age	9 296	2,681	0,365	2,198	2,399	2,566	3,046	3,368
Size	9 296	7,924	1,146	4,935	7,143	7,849	8,632	11,334
Leverage	9 296	0,403	0,186	0,059	0,255	0,398	0,543	0,866
Indirect	9 296	0,386	0,075	0,251	0,334	0,376	0,429	0,601
Shareholder	9 296	0,328	0,139	0,085	0,219	0,305	0,417	0,741
Duality	9 296	0,239	0,427	0	0	0	0	1
Audit	9 296	0,981	0,143	0	1	1	1	1
SOE	9 296	0,327	0,469	0	0	0	1	1

To improve the effectiveness of empirical research, this paper uses the method of adjusting the caliber of variable measurement to conduct a robustness test. First, replace the measurement indicators of the enterprise performance of the explained variable, and retest after replacing the return on ROA with the return on ROE. The second is to change the measurement method of the enterprise's digital transformation of explanatory variables, rebuild the digital transformation indicators according to the "degree of digital transformation of listed companies" in the Gustavian Digital Economy Database, and construct the 0-1 virtual

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variable according, so as to realize the replacement of explanatory variables. The benchmark test results after variable replacement are shown in table 3.

The scale of China's digital economy has also been developing at a high speed. In five years, the scale of China's digital economy has increased by 110,7 %, as shown in figure 6.

Table 3. Robustness test: substitution variable method

Variable	I ROE	II ROA	III ROE	IV ROA	V ROE
Digital Trans	0,0048*** (0,001)	-	-	-	-
Digital Trans._1		0,0013** (0,001)	0,0029*** (0,001)	-	-
Digital Trans._ Dum	-	-	-	0,0039*** (0,001)	0,0098*** (0,002)
Age	0,00253*** (0,004)	0,0114*** (0,002)	0,0255*** (0,004)	0,0112*** (0,002)	0,0250*** (0,004)
Size	0,0272*** (0,001)	0,0152*** (0,001)	0,0274*** (0,001)	0,0153*** (0,001)	0,0273*** (0,001)
Leverage	-0,1546*** (0,009)	-0,1351*** (0,004)	-0,1550*** (0,009)	-0,1349*** (0,004)	-0,1545*** (0,009)

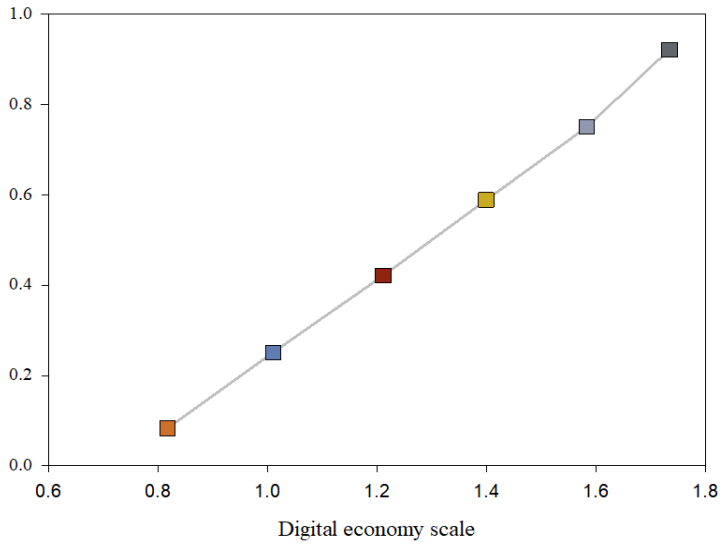

Figure 6. China's Digital Economy Market Size from 2015 to 2020 (Unit: trillion yuan)

Table 4. Dynamic Capability of Midea Group in Digital Transformation Process

Dimension	Specific performance	keywords
Environmental awareness	Establish digital transformation strategy: establish standardized information system and apply the latest	Strategic transformation
	ICT technology; Actively cooperate with relevant enterprises	
Resource integration capability	Realize resource standardization, data and co creation and sharing;	Unique resources
	Establish joint ventures and acquire leading companies in the industry	
Knowledge learning ability	The knowledge is visualized and easy to transmit;	Knowledge system construction
	Set up an intelligent manufacturing research institute	
	Absorb internal external knowledge and expand knowledge database	
Management and operation capability	Organizational change; Flat management; T+3 production and marketing mode	Operation mode transformation
	Build a symbiotic system of stakeholders	

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Among the external environmental factors followed by industrial digital platform construction, digital development of supply chain, business environment optimization and other factors. From the above analysis, the key for enterprises to implement digital transformation strategy in a dynamic environment is to have dynamic capabilities that match the dynamic environment, and to intentionally improve the dynamic capabilities of the organization when taking specific relevant measures, as shown in table 4 and table 5.

Table 5. Digital transformation measurement scale

Number	Item
1	Our company adopts digital technology to upgrade existing products, services, and processes
2	Our company fully promotes digital design, manufacturing, and management
3	Our company develops digital products and services

DISCUSSION

To promote the digital transformation of SMEs, it is necessary to focus on increasing the external environment's financial, technical and policy support.[8,9,10] From the perspective of the government, we should build institutional mechanisms for digital transformation, do a good job in the top-level design of digital strategy, and introduce a series of support policies for the digital transformation of SMEs as appropriate; From the market level, we should promote the digital development of the supply chain, optimize the business environment for the development of SMEs, and build a suitable digital ecosystem for them.[11,12] The government should cooperate with the market to form a virtuous circle mechanism, smooth the flow of capital, technology, and policy, provide corresponding guarantee, and build a strong external support mechanism for SMEs to carry out digital transformation.[13]

To sum up, the digital transformation of enterprises is a process of digital empowerment and value reshaping of the industrial chain with digital information technology as the support and data as the production factor. The path of industrial digital transformation is that SMEs rely on digital industries, coordinate with the process of industrial digital transformation, and promote enterprises to achieve digital transformation[14,15] It is a transformation path of "from surface to point".

CONCLUSION

In the critical period of digital strategy and SME development and transformation, how to find a more matching production relationship and operation management mode has become a hot topic of SME development, which means that digital quality and digital breadth are constantly extended. This research takes the business development model in the network economy era as the breakthrough point. On the basis of a deep understanding of the components of the business model, it clarifies the business operation mechanism, and then seeks the shortest path through algorithm optimization. Through experimental verification and value chain analysis, the optimization model has profound significance for enterprise development, and the model coupling and accuracy have been significantly improved, with the accuracy rising to 87 %.

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CONFLICT OF INTEREST

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Research: Yalin Gong.
Methodology: Yalin Gong.
Project management: Yalin Gong.
Resources: Yalin Gong.
Software: Yalin Gong.
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Validation: Yalin Gong.
Display: Yalin Gong.
Drafting - original draft: Yalin Gong.
Writing - proofreading and editing: Yalin Gong.