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Research Progress on the Effectiveness Evaluation of Digital Transformation in Manufacturing Enterprises

Chenming Zhang

Henan Polytechnic University, Jiaozuo 454150, Henan, China

Abstract: Under the macro context of the Industry 4.0 wave and the "Made in China 2025" strategy, digital transformation has become an imperative path for the high-quality development of manufacturing enterprises. Focusing on the core issue of evaluating the effectiveness of digital transformation in manufacturing enterprises, this paper first elucidates the connotation and theoretical basis of digital transformation. Subsequently, it analyzes four major transformation paths: production digitaliza tion, management digitalization, business model innovation, and organizational capability building. Based on this, a comprehensive effectiveness evaluation framework covering four dimensions—strategy, technology, organization, and benefit—is constructed. It is proposed that the effectiveness evaluation of digital transformation in manufacturing enterprises should adhere to systems thinking, emphasize the organic integration of process and results, and account for dynamic evolution characteristics. The findings of this study can provide a theoretical foundation and decision-making reference for manufacturing enterprises to implement effectiveness evaluation of digital transformation.

Keywords: Manufacturing; Digital Transformation; Effectiveness Evaluation; Transformation Paths.

1. Introduction

Under the macro context of the rapid development of the digital economy, digital transformation has become a core strategic initiative for manufacturing enterprises to break through development bottlenecks and reshape competitive advantages. However, empirical evidence suggests that many enterprises face the dilemma of high input but low return, where problems such as hindered system integration and scarcity of data elements occur frequently, making how to scientifically evaluate the transformation effectiveness a key practical issue that enterprises urgently need to solve.

Reviewing existing research, the evaluation system regarding the effectiveness of digital transformation in manufacturing enterprises is still weak; existing results are mostly limited to a single dimension, difficult to fully match the industry characteristics of complex production processes and asset intensity in manufacturing. In view of this, this paper is based on the core issue of effectiveness evaluation of digital transformation in manufacturing enterprises, systematically combs through its theoretical context and practical paths, constructs a multi-dimensional evaluation framework integrating strategy, technology, organization, and benefit, aiming to provide theoretical basis and practical guidance for the digital transformation practice of manufacturing enterprises.

2. Theoretical Basis of Digital Transformation in Manufacturing Enterprises

2.1. Related Theories of Enterprise Digital Transformation

The theoretical connotation of digital transformation has been increasingly deepened in academic research. Early studies mostly were based on the technical perspective. The Development Research Center of the State Council defined it as constructing a data closed-loop through new-generation information technology to break down barriers between different levels and industries [1]. By 2021, the China Electronics Standardization Institute further highlighted the core role of data elements, arguing that the essence of digital transformation is achieving digital connectivity across the full business chain using technologies such as big data and cloud computing [2]. Meanwhile, some scholars focused on organizational-level changes. Mitra [3] et al. proposed that digital transformation should cover three dimensions: technology application, organizational restructuring, and management innovation. Baiyere [4] et al. pointed out that this process involves systematic upgrades in multiple aspects such as enterprise management and infrastructure.

With the deepening of research, the concept of Digital Intelligence Transformation gradually entered the academic horizon. The Peking University Research Group first proposed this concept, defining it as the integration of digital wisdom and intelligent digitalization [5]. Subsequently, the academic community interpreted it from multiple perspectives. Annarelli [6] et al. believed that digital transformation is a process where enterprises achieve transformation in multiple dimensions such as strategy, culture, and processes. Qi Yudong et al. emphasized that it is the integration of digitalization and intelligence. Fu Jianhua explored the impact of new-generation information technology on enterprise operations from a financial perspective.

Synthesizing the above research, this paper argues that the concept of Digital Intelligence and transformation practice are inherently consistent. It can be comprehensively defined as: enterprises systematically apply technologies such as IoT, cloud computing, and artificial intelligence to promote collaborative changes in elements such as strategy, structure, and culture, ultimately achieving reconstruction of operational processes, upgrading of decision-making systems, and innovation of value networks. From an internal perspective, this transformation helps enterprises optimize resource allocation, reduce operating costs, and improve management efficiency. From an external perspective, it

enables enterprises to respond to market changes more quickly and build differentiated competitive advantages. Under the strategic background of Industry 4.0 and "Made in China 2025", this transformation has become an important path for manufacturing enterprises to enhance core competitiveness and achieve high-quality development.

2.2. Methodological Basis for Effectiveness Evaluation of Digital Transformation

The methodological research on Effectiveness Evaluation of Digital Transformation focuses on elucidating two key issues: "Evaluation Content" and "Evaluation Methods". Regarding evaluation content, the effectiveness of digital transformation has significant multi-dimensional characteristics. It is not only manifested in the improvement of financial indicators but also penetrates into implicit dimensions such as operational efficiency, innovation capability, and organizational vitality. This requires the evaluation system to possess a high degree of comprehensiveness and inclusiveness. Regarding evaluation paths, it mainly covers two paradigms: quantitative and qualitative. Quantitative evaluation relies on indicator systems and data analysis, providing a relatively objective measurement scale, but is often constrained by data availability and completeness. Qualitative evaluation reveals the practical logic of transformation through field surveys and in-depth interviews, helping to capture deep motivations behind the data, but is susceptible to subjective factors [7]. Empirical evidence suggests that the two are not mutually exclusive but complementary and symbiotic. Only through collaborative application can the one-sidedness of evaluation results be avoided. Examining from a time dimension, effectiveness evaluation should also distinguish between Outcome Evaluation and Process Evaluation. The former focuses on the final output brought by the transformation, while the latter concerns the dynamic evolution during the transformation process, such as the actual application depth of the system and the acceptance level of employees. Together, they constitute a complete picture of transformation effectiveness [8]. In addition, relevant policy documents such as the "Evaluation Indicators for Digitalization Level of SMEs" issued by the Ministry of Industry and Information Technology, and empirical studies by scholars such as Kane and Vial, also provide an important basis for the construction of the evaluation framework, highlighting the synergistic effect between strategic leadership, technical support, and organizational guarantee [9, 10]. In conclusion, the methodological basis for Effectiveness Evaluation of Digital Transformation is established precisely in this cross-integration of multi-dimensions and multi-perspectives.

3. Research on Digital Transformation Paths in Manufacturing Enterprises

Existing research universally indicates that digital transformation in manufacturing enterprises is a gradual and dynamic evolutionary process. The stage model constructed by Matt [11] et al. points out that transformation typically commences with enterprises leveraging technological innovation to enhance operational efficiency. Accompanied by comprehensive innovations in management paradigms and product-service offerings, enterprises enter the maturity stage of transformation. The optimization stage is particularly critical, wherein enterprises must continuously refine their technology architecture, organizational forms, and strategic planning to ensure the sustainable development of digitalization. Meanwhile, the external market competition environment profoundly shapes the transformation process. Nguyen [12] et al. noted that while digital transformation requires continuous resource investment, intense competition often compresses profit margins, thereby exacerbating the difficulty of transformation. Henriette [13] et al. further emphasized that enterprises need to maintain a dynamic balance among strategy, organization, and technology. In summary, relevant foreign research exhibits the overall characteristics of "progressiveness-dynamism-equilibrium".

3.1. Four Major Paths of Digital Transformation in Manufacturing

Empirical evidence suggests that, influenced by the heterogeneity of scale, industry attributes, and resource endowments, manufacturing enterprises often form differentiated transformation paths, which can be primarily summarized into the following four categories [14].

Production Intelligence constitutes the core component of digital transformation in manufacturing, focusing on the production process. By deploying automated equipment and information systems, it achieves digitalization, networking, and intelligence in production processes, ultimately realizing the goals of flexible production and intelligent manufacturing.

Management Digitalization emphasizes enterprise management activities, aiming to enhance management efficiency and decision-making quality through information systems. It encompasses domains such as finance, supply chain, human resources, and office collaboration, with the key objective being to break down information barriers and achieve efficient data circulation and sharing.

Business Model Innovation represents the deepening stage of digital transformation. Leveraging digital technologies, it reshapes the value relationships between enterprises and their customers or partners, expanding new value growth points in areas such as marketing models, service models, value creation, and ecosystem construction.

Organizational Capability Building focuses on constructing talent systems and organizational cultures adaptable to the digital era. It encompasses the cultivation of interdisciplinary talents, enhancement of employees' digital skills, shaping of digital culture, and optimization of organizational structures.

3.2. Internal Correlations and Collaborative Promotion of Each Path

The aforementioned four paths do not exist in isolation but are mutually coupled and co-evolutionary. Production Intelligence and Management Digitalization constitute the cornerstone of transformation, empowering Business Model Innovation. Conversely, Business Model Innovation reciprocally drives the upgrading of production and management systems. Organizational Capability Building permeates the entire transformation process, providing talent reserves and cultural support for the implementation of other paths. Manufacturing enterprises should base themselves on their own endowments, select appropriate path combinations, maintain dynamic balance among various elements, and steadily advance digital transformation.

4. Evaluation Framework for Digital Transformation Effectiveness

This paper constructs a Digital Transformation Effectiveness Evaluation Framework for Manufacturing Enterprises encompassing four dimensions: Strategy, Technology, Organization, and Benefit.

The Strategy Dimension focuses on assessing the degree of integration between the transformation strategy and the enterprise's overall development plan. Specifically, it evaluates whether digital transformation is incorporated into the enterprise's overall strategic system, whether it possesses a clear vision and actionable implementation plan; the matching degree between resource input and transformation goals; the perfection of coordination mechanisms and assessment incentives, as well as the timeliness of problem-solving mechanisms. This dimension essentially reflects the enterprise's degree of attention to transformation and strategic execution capability [15].

The Technology Dimension aims to evaluate the maturity of digital infrastructure and system applications. Specific indicators include industrial network coverage, equipment connectivity, and data acquisition capability levels; the coverage scope and application depth of key systems such as ERP and MES for core businesses; the interconnectivity of data between systems, and whether information silos are eliminated; the degree of release of data element value, and whether it can effectively support decision-making. This dimension embodies the enterprise's digital foundational capability.

The Organization Dimension focuses on the adaptability of the talent system and cultural atmosphere to the transformation process. It covers the sufficiency of digital talent reserves, the soundness of interdisciplinary talent cultivation mechanisms, employees' acceptance of the system and operational competence, the atmosphere of organizational innovation culture, as well as inter-departmental collaboration efficiency and the elimination of barriers. This dimension aims to measure the organizational soft power that drives the continuous deepening of the transformation.

The Benefit Dimension quantifies the actual output generated by the transformation. For example, the improvement of operational indicators such as production efficiency, equipment utilization, and inventory turnover; cost control status, the magnitude of profitability improvement; market share and customer satisfaction performance; breakthroughs in new product development and business model innovation. This dimension ultimately responds to: the input-output effectiveness of the transformation [16].

The above four dimensions are logically coupled and collaboratively support each other. The Strategy Dimension establishes direction, the Technology Dimension consolidates the foundation, the Organization Dimension provides impetus, and the Benefit Dimension verifies results [17]. In the specific implementation of evaluation, qualitative analysis and quantitative analysis should be integrated, paying attention to both objective data and subjective perception; focusing on both short-term output and long-term potential; valuing both result indicators and process performance. Through multi-dimensional and multi-perspective comprehensive evaluation, the comprehensive effectiveness of digital transformation in Manufacturing Enterprises is comprehensively assessed.

5. Conclusion

This study focuses on the core issue of Effectiveness Evaluation of Digital Transformation in Manufacturing Enterprises, carrying out systematic research from three levels: theoretical basis, transformation paths, and evaluation framework [18]. Research conclusions indicate that digital transformation in manufacturing is a complex systematic engineering involving multi-dimensions, which necessitates constructing a logically coupled evaluation system from the four dimensions of Strategy, Technology, Organization, and Benefit, to comprehensively characterize transformation effectiveness [19]. In the process of advancing transformation, enterprises should base themselves on their own endowments, select and combine among paths such as Production Intelligence, Management Digitalization, Business Model Innovation, and Organizational Capability Building, and strengthen the collaborative advancement of each path [20]. Simultaneously, Effectiveness Evaluation should adhere to the principle of combining Process and Outcome, paying attention to both the final output brought by transformation and the dynamic performance during the transformation process, so as to identify problems and adjust direction in a timely manner. In addition, evaluation itself is also a dynamic evolutionary process, requiring adjustment of evaluation focus according to differences in enterprise transformation stages, and establishing a normalized assessment mechanism to provide a decision-making basis for continuous improvement. The evaluation framework constructed by this study can provide a theoretical basis and practical guidance for Manufacturing Enterprises to carry out Effectiveness Evaluation of Digital Transformation; future research can further explore the differentiated characteristics of different types of enterprises in evaluation practice.

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