Path and Effect Analysis of Digital Transformation for Small and Medium-sized Manufacturing Enterprises

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Abstract: *Small and medium-sized enterprises are generally resource-poor, do not have high-tech foundations, are labour-intensive, and thus the development and impact of digitalisation on such enterprises will be studied in this paper. This paper will examine in detail the micro-foundations, path differentiation and effect generation mechanisms of the reform at home. Digital mapping provides the basis for change, and the efficiency of resource utilisation depends on the ambidextrous nature and resource organisation system of the organisation; thus, digital technology can promote the collaborative resilience of production networks. The three kinds of transformation paths are as follows: gradual integration based on modularisation of the production process, value chain extension of the product-service system, and niche transition through platform collaboration. Changes in the Structure of Operational Efficiency, Endogenous Growth of Innovation Effectiveness and Heterogeneity with Non-linear Characteristics in Economic Performance. The organisation of this paper will provide some theoretical support for understanding the internal reasons why small and medium-sized manufacturing enterprises are going digital.*

Keywords: *Small and Medium-sized Manufacturing Enterprises, Digital Transformation, Paths to Transformation, Operational Efficiency, Effectiveness of Innovation, Economic Performance.*

Introduction

The problem of digitalisation in manufacturing is now a subject that research on industrial organisation and enterprise management should pay attention to. As the smallest units in the industrial system, small and medium-sized manufacturing enterprises have their own change logic and do not operate in the same way as large enterprises. Small and medium-sized manufacturing enterprises have fewer resources than large enterprises, so they are limited in terms of capital, talent and absorption capacity during the digitalisation process, and the generation of transformation paths and effects is more contingent and context-dependent. Most of the existing research is at the level of technology or large-scale industry, and little attention has been paid to the internal relationship structure of a company's internal capabilities, resource orchestration mechanisms and various transformation paths. In the section on intrinsic ability, this paper will investigate the micro-foundation, path of differentiation and mechanism of effect generation for this ability to find the basic logic by which enterprises can achieve digital breakthroughs under conditions of limited resources. It can offer a theoretical support for understanding the heterogeneity and processuality of digital transformation in small and medium-sized manufacturing enterprises, provide analytical tools and decision-making support, help these enterprises choose their own paths for transformation.

1. The Internal Logic of Digital Transformation and the Reconstruction of Core Elements

1.1 The Micro-foundations and Value Drivers of Digitalisation in Manufacturing Enterprises

The first step in the digitalisation of small and medium-sized manufacturing enterprises is to build a digital map of the production area. At the bottom of the above process is an exact description and computable representation of manufacturing resources, process parameters and operating workflows; therefore, it is necessary to standardise data interfaces at the equipment level, deploy sensor network nodes and integrate data from the manufacturing execution system. Organize the physical process of production as an organized stream of material flow and equipment status data, build a bidirectional mapping link between the digital world and the real world for the enterprise, and thus provide an information carrier foundation for optimisation decisions. At this time, the degree of digitalisation will determine how much improvement can be achieved in terms of process optimisation, quality control and cost management, and set the upper limit for the extent of transformation[1].

Based on the above micro-foundations, the driving force of digital technology in the value creation of manufacturing enterprises can be seen in the restructuring of coupling relationships among all links in the value chain. In the past, Design, Process, Production and Delivery were all separate links in traditional manufacturing; now, with the integration of data, they have been connected to form a single, continuous and traceable flow of information to solve the problems of inefficiency and information distortion at the links among these areas. Add data elements to change the time and place of value creation, and thus the company can complete the entire closed-loop process of order collection and product delivery in less time. At the same time, constantly monitor the operating environment and issue early warnings of any problems; thus, fluctuations in production can be avoided, the company's self-correction ability in response to changes in production will be strengthened, and timely technical support will be provided to ensure the stable production of high-quality products.

1.2 Organisational Ambidexitai and Digital Resource Orchestration

Small and medium-sized manufacturing enterprises are in a bad way because of limited resources and the increasing complexity of change in the process of digitalisation, so organisational ambidexterity should be introduced to solve this problem. The ability to explore is the capacity to proactively explore and learn about new digital technologies, innovative business models, new organisational forms for production in a company, etc.; it is based on building a technology-adoption system that supports trial-and-error and rapid iteration. Exploitation ability, on the other hand, refers to how fully and efficiently a company can make full use of its existing production facilities, process knowledge and management experience to achieve the best integration of digital technology and company-specific knowledge in the current production system. The division of the two abilities is not due to a lack of resources; rather, it is an evolution of organisational ability that changes with different stages of development and various degrees of technology integration.

The Digital Resource Orchestration Mechanism will make full use of its limited resources in the process of transformation to achieve good results in the transformation. Most small and medium-sized manufacturing enterprises do not have the funds for large-scale organised digital investment, and their transformation paths are generally bottom-up and modular. That is to say, the goal is to achieve digitalisation of the foundation of the production process, build independently operating digital units, and then realise system integration of these units through resource orchestration. At this time, the company should find the main processes or bottlenecks in its operation that can improve the overall efficiency with a relatively small investment, and then concentrate its digital resources on these areas to achieve local optimisation and enhance the system. To ensure the good operation of resource orchestration, it is necessary to have not only the right direction for technological investment but also an organisation and utilisation of digital assets in conjunction with tacit resources, such as process knowledge and operational experience, by the enterprise. Given the above, the small and medium-sized manufacturing enterprise will be able to achieve the transformation at a relatively low cost.

1.3 Enhance the Resilience of the Production Network through the Integration of Digital Technology

The production activities of small and medium-sized manufacturing enterprises are closely linked to upstream and downstream collaboration networks, and with the introduction of digital technology, the way information is transmitted and coordinated among the nodes of the network has been changing. The old model of linear cooperation has been limited by orders and buffered by inventory, and now it is developing into a network of cooperation based on real-time data sharing. Digital technology can spread the status information, capacity information and constraint information of all links in the supply chain openly, and at the same time, production plans and resource allocation of upstream and downstream enterprises can be jointly planned through a single digital platform. Close coordination of information at the level of information can reduce the bullwhip effect caused by information asymmetry and improve the adaptability of the production network to changes in demand and supply[2].

The other kind of resilience is how quickly one can respond to and adapt the production network in the face of changes caused by digital technology. To improve the speed of response, real-time data collection and edge computing can help the company find production problems and supply chain disorders early on, thus reducing the time from the occurrence of a problem to the start of countermeasures. Digital production resource management and capacity-matching mechanisms can be employed to adjust the scale of rearrangement capacity, modify the company's internal production capacity, promptly change suppliers or revise production plans in light of any sudden changes, etc. Small and medium-sized manufacturing enterprises at the edge of the network no longer need to keep inventory or have spare capacity for resilience; instead, they have digitally cooperated with other nodes in the network to build a distributed risk-sharing mechanism. With the help of digital-connected collaborative resilience, small and medium-sized manufacturing enterprises will be able to continue normal production and operation in the face of changes in the market and disruptions to the supply chain by utilizing the adaptability of the whole-network.

2. Path Differentiation Characteristics and Evolution Mechanisms of Transformation

2.1 Gradual Embedding Path Based on Modularization of the Production Process

Modularity of the production process is gradually being introduced in the digitalisation of small and medium-sized manufacturing enterprises. The first is that the entire production system will be divided into several relatively independent and clearly defined parts for digitalisation; each part should have its own functions, be internally consistent, meet standard interface requirements, and the start of digitalisation can be based on a single process, a specific piece of equipment or a particular production area. Given the company's current resources and technology absorption capacity, the first subject of digitalisation in the production link will be one that improves the overall efficiency of operations or has lower transformation costs. Based on the previous experience of technology and organisation, start with local development, then gradually expand this development to the upstream and downstream ends, and finally, after a series of breakthroughs, achieve linear integration and then area-wide coverage.

The way the modular path is developed is to gradually increase the coupling degree of the digital units. At the beginning of the change, most of the digital units operate independently, and the optimisation result is only an increase in the production efficiency of a single unit. Standardisation of the interfaces among the units and the construction of data-exchange mechanisms have started to connect the previously isolated digital units, forming an interconnected digital network, and the production process has been changed from fragmented operation to continuous and cooperative operation. The development process is not only the addition of some digital units; rather, by coordinating the production rhythm and integrating the flow of information, the inter-process buffer inventory has been reduced in an organised manner, abnormal information among units has been promptly communicated, and thus the overall efficiency of the system has been improved while maintaining production flexibility.

2.2 The Value Extension Path Based on the Product-Service System

The construction of a product-service system is a change in how small and medium-sized manufacturing enterprises deliver; it is no longer about selling products. The main reason for this is that the actual goods will be used to carry the value. Add sensing, computation and communication functions to the product to continuously collect data on the operating conditions and environment of the product while it is being used. With the help of this data stream, the company will gain a deeper understanding of how the product is actually used by customers at home, and it can turn the original single-transaction relationship into a long-term interactive relationship throughout the life of the product. In this way, by changing the form of value, the company can increase its total value through the addition of services such as preventive maintenance, operational optimisation and pay-for-performance; thus, a virtuous cycle will be formed in which products and services support each other[3].

The first reason for the development of the value chain is that the company can make full use of its data resources. The data obtained from product use do not have inherent value; instead, the company should build a technical chain to collect, transmit, store and analyse this data, and then turn the results of the analysis into specific services for customers to enjoy. At the same time, the company should also gradually strengthen its data processing capabilities, develop knowledge-based services, add value to the original manufacturing business, and so on. As more and more data and analysis models have been accumulated, the company has gained a better understanding of the operating characteristics of its products and, accordingly, changed its service model from passive fault response to active fault prevention. At the same time, with the expansion of the scope of services, new demands for products have arisen; based on actual use data, modifications can be made to the structure and parameters of these products, thus forming a virtuous cycle that promotes the joint development of manufacturing and services.

2.3 The Niche Transition Path Based on Platform Cooperation

Along the path of platform-based cooperation, small and medium-sized manufacturing enterprises have increased their own strength and expanded the scale of the market by joining industrial platforms. At this time, the company will no longer limit the scope of its digital construction to the transformation of its own production system but will actively use the industrial Internet platform, the vertical platform for industries and the platform for supply chain collaboration set up by leading enterprises to publish standardised interfaces of its manufacturing capabilities, process expertise and production capacity resources on these platforms. Through the intermediary and integration functions of the platform, the enterprise is no longer restricted to the fixed position in the original division of labour of the industrial chain; it can match its own strengths with the demand of the entire market and gain new value creation opportunities outside of its original business scope. Platform cooperation can help small and medium-sized enterprises that were originally at the lower or supporting end of the industrial chain join the system of high-value-added production and make full use of their own excellent manufacturing capabilities.

The form of the change in niche can be seen in the case of a company that has developed from a single-value network participant to a multi-network node. In the traditional structure of the industrial chain, most small and medium-sized manufacturing enterprises are supported by a few core enterprises, and the development of their business and market risks is highly dependent on a single customer. A company can join many value chains and take various positions in them via platforms. It can be a specialised producer of a certain industry, carry out custom orders, provide production capacity in a distributed manufacturing network, offer technical services to other enterprises based on process knowledge, and so on. A person connected to many networks will not be reliant on a single channel and can expand their market. At the same time, transaction records, performance evaluations and the technical reputation the company has built through participation in the platform are also transferable digital assets; they can provide verifiable proof of the company's progress in the industrial division system and form an incremental mechanism for gradual niche upgrading.

3. Multidimensional Measurement of Transformation Effects and the Mechanisms of Efficiency Generation

3.1 Structural Optimisation of Operational Efficiency and Optimisation of Factor Allocation

Digitalisation has been used to improve the operating efficiency and organise the structure of the production system more reasonably. In the traditional manufacturing model, there is information time lag and transmission distortion in the planning, supply, operation and inspection links; as a result, the proportion of non-value-added waiting time in the production cycle is too high, and equipment utilisation is limited by the empirical judgment of manual scheduling. Digital technology can be employed to show the present conditions of the production site in the management window, and based on the type of schedule, it will switch from fixed-period production planning to dynamic scheduling. At the operating level, the general equipment efficiency, production cycle time and work-in-progress inventory have all been declining gradually, and there has been a structural improvement in production efficiency[4].

Optimisation of factor allocation is the reason for the increase in operating efficiency. Small and medium-sized manufacturing enterprises have limited resources in terms of labour, equipment capacity and capital, so their production is restricted by the efficiency of resource utilisation. Based on the collection and analysis of data for the digital system, we have learned how the factor inputs affect the actual outputs; we can find bottlenecks in the system that reduce efficiency, and limited factors can be reallocated to areas with higher marginal returns. A digital system can accurately calculate the amount of material, energy and equipment that will be lost; it can provide an objective basis for factor substitution, and thus, by making small adjustments to various combinations of factors, a high level of output can be achieved without increasing the total quantity of resource input.

3.2 Endogenous Growth of Innovation Efficacy and the Mechanism of Knowledge Accumulation

Digitalisation will continue to promote the development of innovation in all areas. Traditional innovation activities are based on the empirical judgment of R&D personnel and physical experiments, have a long cycle, are high in cost, and are very uncertain. Digital technology has combined the Design, production and testing of products in one platform, and now innovation is being carried out in parallel and iteratively. A virtual environment will be constructed at the company to simulate the process conditions and analyse the quality prediction for the feasibility study of production; thus, we will need to reduce the number of physical trials and errors. A short innovation cycle and low trial-and-error costs will increase the number of innovation attempts in a given period and promote the general effect of innovation accumulation.

At the base of the knowledge accumulation mechanism is the development of innovation efficiency. The process knowledge and operating experience of small and medium-sized manufacturing enterprises are mainly in a tacit form and reside in the cognition of technical experts; thus, there are serious obstacles to their inheritance and reuse. The digital system will organise and link the parameter-setting information, anomaly-handling records and improvement records of the production process to turn tacit knowledge into retrievable and reusable explicit knowledge and build enterprise-level knowledge assets. Long-term trend analysis of the accumulated data can help the company find correlations among all its links and other quality factors that have gone unnoticed by traditional experience; thus, new knowledge will be obtained outside the previous limits of knowledge, and innovation activities will change from being based on experience to being data-driven.

3.3 Heterogeneous Features and Nonlinear Development of Economic Performance

Digitalisation has had many kinds of effects on the economy. The particular sub-industry the company belongs to, the degree of technological intensity, the scale of its market, and the foundation of its current management will all affect how and to what extent digital investment shows good financial results. By building a digital system for the main business of high-tech manufacturing, both the efficiency and quality of the products will be improved, and the company will gain a competitive advantage in the market. Labour-intensive manufacturing enterprises will be judged on the reduction of labour costs and the improvement of production stability. The Position of a company in the Value Chain will also affect its performance. Companies closer to the end-market will be able to obtain more timely information on changes in consumer demand through digitalisation, use this information to guide the development of new products, and thus the support they receive will be more dependent on coordination requirements and the extent of data sharing among core enterprises[5].

Irregular development of the transformation effect is not only due to the scale of digital investment and the results achieved. In the first stage of reform, concentrated investment will be made in the procurement of hardware and systems, training for new staff, etc.; thus, there will be a temporary drop in operating efficiency and a delay in the improvement of actual performance. With the spread of digital units and the improvement of system integration at all levels, synergy among all modules has begun to be achieved, and the growth speed of performance output has also increased. After some digitalisation, the improvement in the company's performance will be relatively small, and further investment will not bring in much profit. As shown in the S-shaped development curve, the effect of change is limited by the combined effect of technological absorption capacity, organisational adaptation and the extent of system integration; thus, the release of economic performance is also gradual[6].

Conclusion

The three parts of this paper are the reasons and goals of digitalisation, and the corresponding effects. Based on the above, we have digitised the manufacturing resources, organised organisational ambidexterity and resource-orchestration mechanisms to optimise the allocation of these resources, and finally strengthened the collaboration and resilience of production networks through the integration of digital technology. The three evolutionary paths of the transformation path are: gradual embedding based on modularisation of production processes, value extension based on the product-service system, and niche transition based on platform collaboration. Changes in the structure of operating efficiency, the endogeneity of the growth of innovative effectiveness, and heterogeneous nonlinearities in economic performance can all be considered the results of the reform. This paper offers a theoretical foundation for the research on the micro-mechanisms of digital transformation in small and medium-sized manufacturing enterprises, and in the future, more detailed studies will be carried out on the interaction mechanisms of all kinds of transformation paths and the moderating effect of enterprise capability structure.

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