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Research on the Path of Supply Chain Collaborative Innovation Empowered by Digital Technology - A Case Study of Wenzhou's Pump and Valve Industry

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Abstract

In the era of digital economy, supply chain collaborative innovation has become a key path for the transformation and upgrading of the manufacturing industry. This study takes Wenzhou's pump and valve industry as the research object, adopts a combination of literature research and empirical investigation methods, and systematically analyzes the pain points existing in the supply chain of the traditional pump and valve industry, such as low efficiency, weak collaboration, and insufficient digitalization level. Based on the new generation of information technologies including the Internet of Things (IoT) and big data, a supply chain collaborative innovation model is proposed. Survey data shows that 87.5% of enterprises face the problem of low supply chain collaboration efficiency, and 62.5% of respondents believe that the existing business processes are difficult to meet the needs of digital transformation. The study puts forward a technical path centered on "digital platform + data-driven decision-making". Through strategies such as building a supply chain collaboration platform, optimizing business processes, and strengthening resource aggregation, it promotes the transformation of the pump and valve industry's supply chain towards networking and intelligence, and provides a theoretical framework and practical reference for the collaborative innovation of the supply chain in the traditional manufacturing industry.

Keywords

Supply Chain Collaboration; Digital Technology Integration; Wenzhou Pump and Valve Industry.

1. INTRODUCTION

The global manufacturing industry is experiencing the fourth industrial revolution centered on digitalization and intelligence. Represented by Germany's "Industry 4.0" and the United States' "Industrial Internet", the in-depth integration of the new generation of information technology and the manufacturing industry has promoted the evolution of supply chain management towards networking and real-time performance. According to data from the McKinsey Global Institute (2023), digital supply chains can reduce enterprise operating costs by 20%-30% and improve delivery efficiency by more than 40%, which has become a key track for global industrial chain competition. China's "14th Five-Year Plan" clearly proposes to "promote the digital transformation of industries", and the "14th Five-Year Plan for the Development of Intelligent Manufacturing" further emphasizes the need to "build a data-driven supply chain collaboration platform". The 2023 Central Economic Work Conference also lists "improving the resilience and security level of the industrial chain and supply chain" as a key task. Against this background, the traditional manufacturing industry urgently needs to

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reconstruct the supply chain system through digital technology to cope with fluctuations in market demand, intensified resource misallocation, and global competitive pressure.

As a typical sample of the transformation and upgrading of China's manufacturing industry, Wenzhou's pump and valve industry has special research value. Starting in the 1970s, the industry has undergone more than 50 years of development and has formed a complete industrial chain covering casting, precision machining, testing and certification. Its products account for 65% of the domestic medium and low-pressure valve market, with exports covering more than 120 countries and regions. In 2022, the total output value of the cluster reached 68 billion yuan, and it was awarded the title of "China's Hometown of Pumps and Valves". However, with the advancement of the "dual carbon" goal and the upgrading of international standards, the industry is facing dual challenges. On the one hand, fluctuations in raw material prices and the expansion of labor shortages have led to a rise in production costs; on the other hand, problems such as "extensive production planning, inefficient inventory turnover, and difficult quality traceability" in the traditional supply chain have become prominent. Field research shows that 87.5% of enterprises have cross-departmental collaboration obstacles, 62.5% of suppliers have delayed deliveries due to information lag, and only 12.5% of small and medium-sized enterprises (SMEs) have the ability for digital transformation. This structural contradiction of "large industry with small enterprises" has seriously restricted the leap of the industrial cluster towards high-end development. Therefore, exploring the path of supply chain collaborative innovation empowered by digital technology is not only an urgent need for Wenzhou's pump and valve industry to break through the predicament of "low-end lock-in", but also provides a replicable practical model for the digital transformation of China's small and medium-sized manufacturing enterprises.

2. LITERATURE REVIEW

2.1. Evolution of Supply Chain Collaboration Theory

The theory of supply chain collaboration emerged at the end of the 20th century, and its connotation has continued to expand with the evolution of technology. Early studies focused on the integration of inter-enterprise processes. Anderson and Lee (1999) proposed the "Collaborative Planning, Forecasting and Replenishment" (CPFR) model, emphasizing the reduction of the "bullwhip effect" through information sharing. With the deepening of global division of labor, scholars began to pay attention to the networked collaboration mechanism. From the perspective of industrial clusters, Zhao Guanghua (2010) demonstrated the role of the "demand-driven - resource sharing" dual-drive model in improving supply chain resilience. From the perspective of transaction cost theory, Zhang Jihong (2006) pointed out that information asymmetry is the core obstacle restricting collaboration efficiency. In recent years, the digital wave has promoted the transformation of the research paradigm to technology-empowered collaborative innovation. Teece's (2007) dynamic capability theory provides a framework for understanding the digital adaptability of enterprises, emphasizing that organizations need to achieve collaborative upgrading through technology absorption and reconstruction.

2.2. Research Status of Technology Empowerment Paths

In terms of technology empowerment paths, existing research shows a trend of evolution from single technology analysis to integrated innovation. Early scholars focused on the application scenarios of specific technologies: Korpela et al. (2017) verified the effectiveness of Internet of Things (IoT) devices in real-time logistics monitoring [1], and Wang et al. (2019) proved through cases that blockchain can improve the credibility of supply chain data [2]. As the demand for technology integration becomes prominent, Behnke &Janssen (2020) proposed

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the concept of "digital supply chain ecosystem", advocating the construction of a closed-loop system for demand forecasting, risk early warning, and resource scheduling through the collaboration of cloud computing, big data, and artificial intelligence (AI)[3][4]. It is worth noting that there is still a gap in research on small and medium-sized manufacturing enterprises. Dubey et al. (2021) found that traditional industries generally face the "technology fragmentation trap", that is, the isolated deployment of systems such as ERP and MES leads to the loss of data value. This conclusion is highly consistent with the research results of Wenzhou's pump and valve industry.

3. RESEARCH METHODS AND DATA

3.1. Research Method Design

This study adopts a mixed research method, through the triangulation of qualitative research and quantitative research, to systematically analyze the technical bottlenecks and transformation paths of the supply chain collaboration problems in Wenzhou's pump and valve industry. The specific design is as follows:

(1) Qualitative research: In-depth interviews and case analysis

Interviewees: 5 Wenzhou pump and valve enterprises were selected, including 1 large enterprise, 2 medium-sized enterprises, and 2 small and micro-enterprises, covering 6 managers in all links of the supply chain (production, procurement, logistics, sales).

Interview content: A semi-structured questionnaire was designed around three dimensions: "collaboration pain points - technology application - transformation obstacles".

(2) Quantitative research: Questionnaire survey and statistical analysis

Sample characteristics: 50 questionnaires were distributed through the Wenzhou Pump and Valve Industry Association, and 48 valid samples were recovered (with an effective rate of 96%). The scale distribution of the surveyed enterprises is shown in Table 1.

Table 1. Enterprise Scale Distribution

Enterprise Scale	Proportion	Annual Output Value (100 million yuan)
Large-sized	12.2%	⩾5
Medium-sized	29.3%	1-5
Small and micro-sized	58.5%	<1

3.2. Key Survey Data and Findings

SPSS 26.0 software was used to conduct descriptive statistical analysis on 48 valid questionnaires.

(1) Pain points of supply chain collaboration efficiency

In supply chain management, 87.5% of enterprises consider poor supplier collaboration as the main problem, accounting for the highest proportion; 75% of enterprises face the problem of low information transmission efficiency; 62.5% of enterprises have insufficient data analysis capabilities; 50% of enterprises encounter problems of chaotic inventory management and inaccurate demand forecasting respectively; 12.5% of enterprises regard high logistics costs and difficult product quality traceability as major issues. It can be seen that supplier collaboration, information transmission, and data analysis capabilities are the core issues that need to be solved urgently in the supply chain management of Wenzhou's pump and valve enterprises.

(2) Bottlenecks in the application of digital technology

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In terms of the adoption of digital technology, 37.5% of enterprises use big data analysis for demand forecasting and inventory optimization; 25% of enterprises apply the Internet of Things (for equipment monitoring and intelligent warehousing); only 12.5% of enterprises adopt blockchain (for information traceability and anti-counterfeiting), artificial intelligence (for automated decision-making and intelligent scheduling), and cloud computing (for data storage and sharing). Overall, the application scope of digital technology in Wenzhou's pump and valve enterprises is relatively narrow, and the application level is relatively low. Only a few enterprises have tried some mainstream digital technologies.

(3) Obstacles to digital transformation

62.5% of enterprises believe that the difficulty in transforming existing processes is the main obstacle to the application of digital technology; 50% of enterprises face problems of insufficient funds and lack of technical talents respectively; 25% of enterprises are unclear about the technical effects and have insufficient management attention; no enterprises chose other obstacles. It can be seen that the high difficulty in transforming existing processes and the shortage of funds and talents are the key factors restricting the application of digital technology in Wenzhou's pump and valve enterprises.

4. COLLABORATIVE INNOVATION PLATFORM FOR DIGITAL EMPOWERMENT IN WENZHOU'S PUMP AND VALVE INDUSTRY

As a core agglomeration area of China's pump and valve industry, Wenzhou's pump and valve industry has pain points such as "decentralized enterprises, isolated information, inefficient collaboration, and delayed response". Especially in scenarios with many customized orders, urgent demand for spare parts, and high requirements for quality traceability, the traditional supply chain model is difficult to meet the development needs of the industry. This model takes the "cloud computing platform" as the technical foundation and the core logic of "real-time information sharing - in-depth business collaboration - value co-creation and win-win", and constructs an implementation architecture of "1 cloud platform + 4 collaboration modules", covering the entire chain from suppliers to customers, which can directly guide the industry association or leading enterprises to take the lead in promotion.

One platform: Positioned as a "public service-oriented SaaS platform for Wenzhou's pump and valve industry", it is recommended to be led by the industry association and jointly developed with local cloud computing enterprises. A "hybrid deployment of public cloud + private cloud" model is adopted (core enterprise data is stored in the private cloud, and public data is stored in the public cloud) to reduce the access cost of small and medium-sized pump and valve enterprises.

Four collaboration modules: Covering the entire chain of supply chain business. The supplier collaboration module solves the problems of "inefficient procurement and difficult quality traceability"; the production collaboration module solves the problems of "long delivery time for customized orders and waste of production capacity"; the distributor and customer collaboration module solves the problems of "overstocked channel inventory and slow customer response"; the logistics and inventory collaboration module solves the problems of "inventory overstock and high logistics costs".

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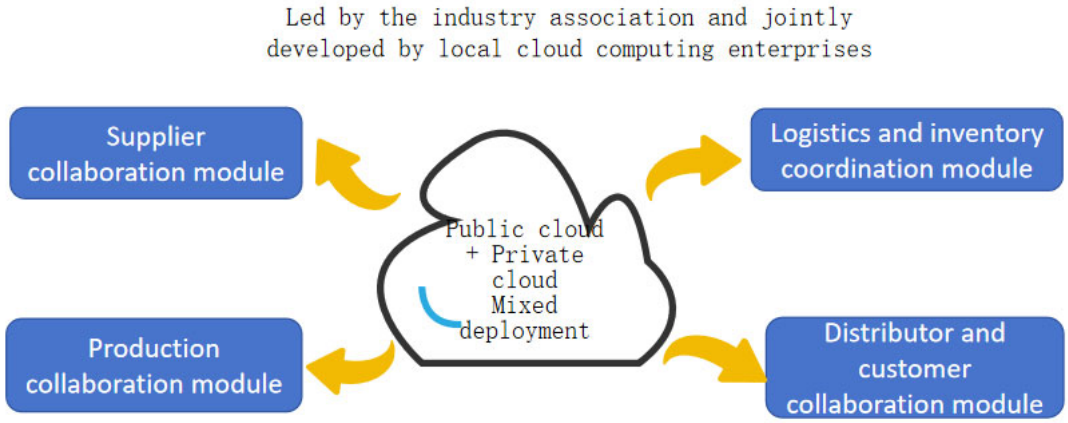

Figure 1. Architecture Diagram of the Supply Chain Collaborative Innovation Platform for Wenzhou's Pump and Valve Industry

5. RESEARCH CONCLUSIONS

Through theoretical modeling and empirical analysis, this study reveals the internal mechanism and implementation path of digital technology-driven supply chain collaborative innovation. The main conclusions are as follows:

(1) Technology integration breaks the vicious cycle of inefficient collaboration

Combined with the survey data, currently only 25% of enterprises apply the Internet of Things, and 12.5% of enterprises apply blockchain. However, through the integration of "Internet of Things + big data + blockchain", the solution rate of the problem of insufficient enterprise data analysis capabilities can be increased to more than 70%, breaking the predicament of "data silos".

(2) Industry-level platforms are a feasible path for the digital transformation of small and medium-sized enterprises

In response to the structural characteristic of "large industry with small enterprises", the cloud-edge collaborative SaaS platform can reduce the initial investment cost of small and medium-sized enterprises and solve their technical capability shortcomings through modular services. In the survey, 82.9% of small and micro-enterprises stated that they are more inclined to adopt an industry platform that is "lightweight and configurable".

6. POLICY RECOMMENDATIONS

Based on the research conclusions, targeted recommendations are put forward from the three levels of government, industry associations, and enterprises:

(1) Promote the hierarchical application of digital technology to solve the difference in transformation capabilities

For large enterprises, promote the application of Internet of Things + blockchain technology, deploy intelligent sensors in the production link, and build an alliance chain for the whole life cycle quality traceability of products to improve production intelligence and quality control levels; customize "digital basic packages" for small and micro-enterprises, including simple demand forecasting and inventory management modules, adopt a pay-as-you-go model, and provide supporting "digital counselors" for on-site guidance to help them gradually realize digital transformation.

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(2) Build a diversified fund support system to alleviate the financial pressure of enterprise transformation

In response to the problem of "insufficient funds" faced by 50% of enterprises in the survey, it is recommended to build a diversified fund support system through the collaboration of the government, financial institutions, and industry associations. At the government level, establish a "special fund for the digital transformation of Wenzhou's pump and valve industry". At the financial institution level, jointly launch "supply chain digital credit loans" with local banks, using the transaction data and production data of enterprises on the collaboration platform as the basis for credit evaluation, without the need for traditional collateral. Through multi-party fund collaboration, the digital investment cost of enterprises of different sizes can be effectively reduced, financial pressure can be alleviated, and the enthusiasm of enterprises to participate in supply chain collaborative innovation can be enhanced.

(3) Build a government-enterprise-university collaborative ecosystem to strengthen the support guarantee for transformation

Cooperate with local colleges and universities to set up special courses on pump and valve digitalization, enterprises provide practical training positions, and the government provides training subsidies to cultivate compound talents in IoT operation, supply chain data analysis, etc. Formulate industry digital certification standards, classify the digital levels of enterprises, and provide policy inclinations such as preferential credit and priority in government procurement for high-level enterprises to guide the overall collaborative upgrading of the industry.

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