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Review

Research on Intelligent Supply Chain for Intelligent Manufacturing

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Abstract: Leveraging computer systems and information technologies, intelligent manufacturing demonstrates enhanced collaborative capabilities and elevated decision-making capacity. From a digital cognitive framework and information system-oriented view, this paper focuses on the process of supply chain digital transformation, interpreting the methodology and approaches to eliminate obstacles such as the lack of data standards and inaccurate data analysis, lack of supply chain resilience, contradiction between customized and operational efficiency in production systems, uncooperative market conditions and other internal or external factors. To address these challenges, the systematic integration of big data analytics, deep learning-based intelligent optimization, and blockchain-enabled collaborative mechanisms establishes practical technical pathways. This convergence augments supply chain cognitive capabilities, advances intelligent production scheduling competencies, amplifies market adaptive intelligence, and facilitates sustainable evolution of intelligent supply chain ecosystems.

Keywords: intelligent manufacturing; intelligent supply chain; digital transformation

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1. Introduction

Intelligent manufacturing is transforming the supply chain in the direction of intelligence, using advanced means such as computer digitization technologies, the Internet of Thing and AI to strengthen the process of collaboration and decision-making, and strengthen the demand for intelligent deployment and resource optimization of the manufacturing industry. However, there are still many problems in the current supply chain, such as the gap in data standards, the fragile supply chain and the conflict between personalized manufacturing and manufacturing, as well as the optimization of computing resources for environmental transformation, improving the degree of intelligence and accelerating market response has become a key issue at present. The focus of this paper is mainly on supply chain digitalization. From a digital cognitive framework and information system-oriented view, the current situation and main constraints of the supply chain are deeply analyzed. Through big data management, AI scheduling optimization, block chain trust cooperation and edge computing scheduling, the supply chain is guided to develop in an efficient, intelligent and sustainable direction [1].

2. Core Elements of Supply Chain Digital Transformation

Digital supply chains using modern computer information technologies such as big data, AI and cloud platforms can aggregate information flow, logistics and capital flow, operate efficiently and make intelligent decisions. The data-based intelligent analysis is the foundation of the digital supply chain. The real-time collection of data flow, the establishment of machine learning models, and in-depth data analysis can further improve the predictive ability and accurate control ability of the supply chain while optimizing resource investment and reducing operating costs. The convergence and connection of information system is an important stage of the collaborative operation of supply chain.

Enterprises need to construct distributed data platform, so that ERP, WMS, TMS and other management platform software can be successfully connected, and improve the visibility, response speed and accurate and timely data transmission of the supply chain. The use of intelligent Internet of Things, blockchain, intelligent warehouse and other technologies enables the entire process to be tracked and recorded, immediately controlled, and flexibly adjusted, thus improving the intelligent level of logistics operations. Finally, the flexible supply chain model combined with artificial intelligence scheduling algorithm, edge computing and flexible distribution can meet a variety of manufacturing needs, improve the adaptability to the market, enhance the stability of the supply chain and have the ability to resist risks, in addition, improve the inventory and production scheduling methods, and further enhance the collaborative intelligence of the entire supply chain [2]. Figure 1 below shows the digital architecture of the intelligent supply chain.

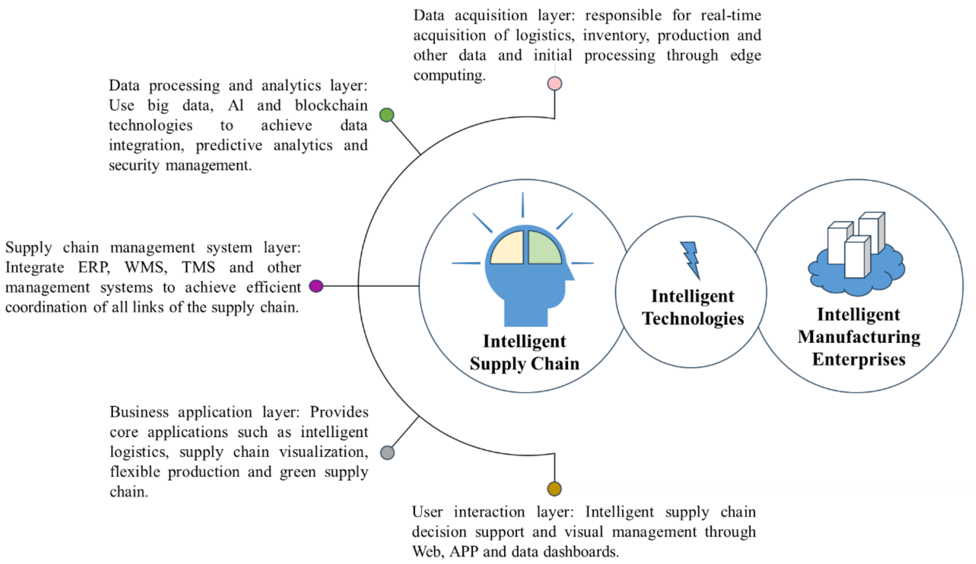

Figure 1. Digital architecture of intelligent supply chain.

3. Current Situation and Key Constraints of the Supply Chain in the Manufacturing Environment

3.1. Lack of Data Standards and Limited Supply Chain Collaboration

Because the supply chain architecture of each stage is different, and its data structure and data connection standards are not the same, resulting in a low degree of sharing information and weakened interaction [3]. At the same time, because there is no efficient data sharing mechanism, the response speed of the supply chain is slow, which increases the difficulty of production and logistics management. In addition, because of the low degree of standardization of industrial data construction, and the problem of data security and confidentiality, enterprises are reluctant to publish data, resulting in the development of supply chain intelligence is difficult to carry out. Table 1 below shows the circumstances affecting the absence of supply chain data standards.

Table 1. Main impacts of missing supply chain data standards.

Influence aspect	Problem
Data sharing difficulties	The enterprise systems are fragmented, the data formats are incompatible, and it is difficult to share in real time
Decision accuracy is low	The data source is incomplete, and the error of intelligent analysis model increases

Supply chain collaboration obstruction	Suppliers, manufacturers, logistics and other links can not be effectively linked
Data security risk	Lack of unified standards, enterprise data protection mechanism is not found
The industry standard is not perfect	The data specifications of different enterprises are not uniform, and the supply chain management is chaotic

As can be seen from Table 1, the data shows a lack of data standardization, which limits the development of intelligent supply chains, the outcome of information sharing, and the ability to achieve accurate decision-making and coordination of supply chains.

3.2. Lack of Supply Chain Resilience and Difficulty in Adapting to Market Fluctuations

In the context of intelligent production, due to repeated changes in the market and inflexible supply chains, it is difficult for enterprises to update their production plans in a timely manner [4]. Due to accidental events (such as epidemics, natural disasters, trade disputes, etc.), the supply chain of enterprises is poorly adaptable, increasing the risk of key parts of enterprises. In addition, the existing supplier management mechanism is rigid, the supply chain is not diverse, and there is no alternative strategy to find when the supply is interrupted. Table 2 below summarizes the main characteristics of insufficient supply chain resilience.

Table 2. Main manifestations of insufficient supply chain resilience.

Influence aspect	Problem
Production adjustment lag	Unable to respond quickly to changes in market demand, resulting in a mismatch between supply and demand
Weak risk coping ability	The supply chain is interrupted due to emergencies and the recovery period is long
High supplier dependence	Key raw materials rely on a single supplier, low risk resistance
Inventory management is not reasonable	Insufficient stock is easy to break supply, and excess inventory lead to strained cash flow
Inadequate Diversification of supply chain	The layout of regional supply chain is single, which is greatly affected by external environment

As can be seen from Table 2, it is difficult for enterprises lacking supply chain resilience to flexibly respond to emergencies in the market, and they can only bear the external risks of the market but cannot do anything about it.

3.3. Contradiction between Personalized Production Demand and Supply Chain Operational Efficiency

Although intelligent manufacturing tends to personalized product manufacturing, the traditional supply chain is still dominated by large-scale production methods, which cannot meet the needs of small batch and diversified manufacturing. Traditional supply chain planning methods are too rigid to dynamically adjust production resources [5]. The high dispersion of personalized product orders will lead to the increase of supply chain cost and the difficulty of supply chain inventory management. In addition, the immaturity of the current intelligent scheduling system also restricts the improvement of supply chain response time and accuracy. Table 3 below summarizes the impact of personalized production on supply chain operations.

Table 3. Influence of personalized production on supply chain operation.

Influence aspect	Problem
The matching degree of production mode is low	Traditional mass production is difficult to adapt to the personalized order mode
Supply chain cost increase	Small batch production leads to increased procurement, logistics, and warehousing costs
Order management complexity	Order dispersion is high, and supply chain planning is more difficult
The production schedule is difficult	Production equipment is adjusted frequently, affecting the overall efficiency
Supply chain response is slow	Supply chain planning lags behind, making it difficult to deliver orders quickly

Table 3 illustrates how the need for personalized production complicates supply chain management and affects operational efficiency.

3.4. Green Low-Carbon Transformation and Supply Chain Upgrading Pressure

Although the government has formulated energy conservation and emission reduction policies to promote the direction of sustainable development of the manufacturing industry, in the face of the high cost of environmental protection, scientific and technological difficulties and the lack of standardization, the manufacturing supply chain has to go through a long transformation process to the green supply chain. Due to the cost of using green raw materials, reducing transportation emissions and improving energy management efficiency, enterprises can hardly absorb the pressure brought by the cost in the first time. In addition, the greenhouse gas emission control system in the green supply chain industry chain has not reached the perfect state, resulting in manufacturing enterprises can not effectively measure the effect of their own green supply chain strategy, thus affecting the implementation progress. Table 4 below summarizes the main obstacles to the green and low-carbon transition.

Table 4. Main obstacles to the green and low-carbon transition.

Influence aspect	Problem
Cost pressure	The cost of green materials and environmental protection equipment is high, and short-term profits can be affected by various factors
Technical threshold	Green manufacturing technology is immature, and supply chain transformation is difficult
Insufficient monitoring of carbon emissions	The carbon footprint tracking system of the supply chain is not perfect, and the data is missing
High level policy requirements	Carbon emission reduction standards are becoming more stringent, and under increasing pressure companies must comply with specific the rules
Supply chain coordination is difficult	The diverse situation and financial status of suppliers are different in every possible way, and the supply chain coordination management is essential but difficult

As can be seen from Table 4, the cost, technology and policy problems of creating a green supply chain are quite big.

4. Adopting Intelligent Supply Chain and Intelligent Technologies to Improve Operational Performance in Manufacturing Industry

4.1. Optimize Data Standards to Improve Collaboration Efficiency

Building an intelligent supply chain requires compliance with data standards. However, at this stage, the information platforms of nodes are not connected, and the data types are inconsistent, which will lead to the failure of data flow, thus affecting the cooperation effect between enterprises [6]. Through computer digital technology, the establishment of a unified data standard can standardize the format of data and the way of data interaction, in order to achieve real-time information sharing and increase the cooperation between enterprises. Use blockchain technology, Internet of Things technology, etc., to ensure data security and traceability, and improve supply chain visibility. In addition, relevant government departments and industry organizations are encouraged to develop data standards to ensure that enterprises up and down the supply chain use uniform information standards, so as to avoid information silos. The formula for optimizing the supply chain data standard is as follows:

$$E_c = \frac{D_s \times I_t}{(S_f + C_l)} \quad (1)$$

Among them, supply chain collaboration efficiency E_c,data standardization degree D_s, information technology investment scale I_t, data format dispersion S_f, and data interconnection cost C_l are taken as variables. When D_s increases and I_t increases, S_f and C_l decrease, then E_c increases, that is, when data standardization is improved, the compatibility difficulty of the system is reduced. It can significantly improve the data flow capability of the supply chain, thus promoting the cooperation of all parties in the supply chain and improving the operation efficiency of the entire business process.

4.2. Strengthen Supply Chain Flexibility and Enhance Market Adaptation

The elasticity of supply chain is related to the ability of enterprises to cope with the change of market demand. In the face of short-term drastic changes in demand, the traditional rigid supply chain will be unable to cope with the changes, resulting in short supply and excess inventory [7]. With the help of computer information technologies, dynamic inventory management, intelligent planning system, variable manufacturing strategy, etc., improve the responsiveness of supply chain, so that it can flexibly change production and logistics strategies according to changes in demand. Dual-supplier strategy and regional supply chain layout are adopted to reduce over-dependence on a single supplier and improve the possibility of risk response. Coupled with predictive decision making by applying artificial intelligence, inventory strategy development is facilitated to reduce inventory costs and ensure supply chain resilience. The expression of supply chain optimality is as follows:

$$F_s = \frac{(S_d + R_m + I_a)}{C_o} \quad (2)$$

In the model, F_s was used to represent the flexibility of supply chain, S_d was used to represent the diversity of suppliers, R_m was used to represent the plasticity of manufacturing process, I_a was used to represent the intelligent forecasting ability, and C_o was used to represent the supply chain scheduling cost. When S_d, R_m and I_a are increased and C_o is decreased, supply chain flexibility is enhanced, which helps to improve the enterprise's market response ability, reduce the risk level of the supply chain, and enhance the stability of the business, so that enterprises can maintain competitive advantages in the rapidly changing market environment.

4.3. Balance Personalized Production and Improvement of Operational Efficiency

Although the use of computer technologies for personalized product customization can promote the development of intelligent manufacturing, it may also lead to inefficient operation of the supply chain. In order to achieve the balance between the two, enterprises must adopt intelligent scheduling scheme, elastic resource allocation scheme and modular design concept, so as to reasonably control production scheduling costs, and improve the supply chain's response ability to face changing demands. Improve the order processing process with big data analytics tools, which can make production more flexible and improve capacity utilization. The intelligent factory uses digital twins, automation equipment, edge computing and other means to monitor and optimize the production process in real time, so as to avoid the delay and cost increase caused by meeting personalized requirements, and improve the intelligence of supply chain management. The formula for the compromise between personalized manufacturing and supply chain efficiency is as follows:

$$E_o = \frac{(M_f + P_r)}{(C_p + T_d)} \quad (3)$$

This model selects five supply chain operation efficiency variables, E_o (Supply chain operation efficiency), M_f (modular manufacturing flexibility), P_r (production automation), C_p (custom product manufacturing cost), T_d (production cycle extension factor), to describe the efficiency of supply chain operation. If M_f and P_r are enhanced at the same time C_p and T_d are reduced, the operation efficiency of the supply chain is enhanced. In order to make this situation better, methods such as reforming the production mode, applying intelligent scheduling and balanced allocation of resources can be adopted to reduce the production impact of customized products, so as to achieve the goal of efficient management and control while maintaining production flexibility.

4.4. Promote Green Transformation and Achieve Sustainable Development

With the pursuit of computer technologies for sustainable development, the green supply chain needs to use intelligent algorithms to improve energy utilization efficiency under the carbon neutral policy, so as to achieve the purpose of energy saving and emission reduction. The carbon tracking system built by the Internet of Things and big data analysis can accurately calculate carbon consumption and further save energy and reduce consumption through optimization countermeasures of the supply chain. The intelligence energy saving mode controlled by artificial intelligence can improve the energy management ability of the manufacturing industry, while the blockchain ensures the data openness and data availability of the green supply chain, and the use of machine learning to build a set of green supplier evaluation system can promote the cooperation of the entire chain, and ultimately achieve the intelligent green production mode and its harmonious integration with green development and economic benefits. Green supply chain optimization formula:

$$C_r = \frac{(E_s + L_g)}{(C_m + R_t)} \quad (4)$$

In this model, C_r is the sustainability evaluation index value of green supply chain, E_s is the use degree of energy-saving technology, L_g is the construction level of green logistics system, C_m and R_t are the production cost degree and carbon emission degree of green supply chain respectively. When E_s and L_g are larger and C_m and R_t are smaller, the green supply chain sustainability evaluation index value C_r is larger. Through energy-saving technology, strengthening logistics methods and carbon absorption, the pressure on the supply chain can be greatly reduced, and the ability of enterprises to sustainable development can be improved and the development trend of green production can be complied with worldwide.

5. Conclusion

To promote the development of intelligent manufacturing through information technologies, the digital transformation of intelligent supply chain has improved the level of collaboration, market response rate and operational efficiency. Meanwhile, the digital transformation of intelligent supply chain can eliminate obstacles such as the lack of unified data standards, supply chain risks, contradiction of personalized and efficiency, and excessive carbon emissions. Therefore, it is essential to enhance network interaction with unified data docking, improve supply chain resilience with edge computing, optimize production scheduling with deep learning, strengthen trust relationships with blockchain, and build green supply chains with big data and Internet of Things technology. As supply chains evolve, next-generation technologies are paving the way for an intelligent, more sustainable future. Digital twins and generative AI are transforming decision-making processes, enabling manufacturing companies to operate with greater precision and agility.

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