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Logic Mechanism and Development Strategy of AIGC-enabled Intelligent Manufacturing Transformation of Pharmaceutical Manufacturing Enterprises

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Abstract: ***Currently pharmaceutical manufacturing enterprises are facing the urgent need for digital and intelligent transformation, but how to efficiently use emerging technologies to promote transformation is still an important issue. Based on dynamic capability theory, this paper explores how generative artificial intelligence generated content (AIGC) empowers intelligent manufacturing transformation of pharmaceutical manufacturing enterprises, and combs through its logical mechanism and development strategy. The study shows that AIGC has a profound impact on intelligent manufacturing in terms of knowledge generation, decision optimisation, process automation, etc., and can significantly improve the innovation ability and market responsiveness of enterprises. The research in this paper helps to deepen pharmaceutical manufacturing enterprises' understanding of AIGC-enabled intelligent manufacturing, provide theoretical guidance for enterprise practice, and provide valuable references for policy makers.***

Keywords: Artificial intelligence generated content (AIGC); Intelligent manufacturing; Pharmaceutical manufacturing enterprises; Dynamic capabilities.

1. INTRODUCTION

Pharmaceutical manufacturing enterprises are currently facing unprecedented transformation pressure, with the increasingly stringent global pharmaceutical regulatory system, the U.S. FDA, the European Union EMA and other agencies of the pharmaceutical production quality management norms (GMP) requirements continue to improve, the enterprise needs to ensure that the whole production process of traceability and compliance [1]. At the same time, competition in the pharmaceutical market has intensified, generic drug prices continue to decline, and the long R&D cycle and high costs of innovative drugs have put companies under tremendous pressure to make profits. According to a McKinsey study, the R&D efficiency of the global pharmaceutical industry declined by 5% year-on-year in 2024, while R&D costs rose by 7% [2]. In this context, digital transformation has become a key path for pharmaceutical companies to improve their competitiveness, and there is an increasingly urgent need for the application of new technologies such as Industry 4.0 and digital twins [3]. Together, these challenges constitute the core driving force for intelligent transformation of pharmaceutical enterprises.

Artificial intelligence generated content (AIGC), as a representative of the new generation of artificial intelligence technology, is reshaping the production paradigm of the pharmaceutical manufacturing industry. With its powerful multimodal comprehension and content generation capabilities, AIGC shows unique advantages in drug discovery, production optimisation, quality control and other aspects [4]. In the field of drug discovery, AIGC can rapidly generate potential drug molecular structures by analysing massive compound data, significantly shortening the R&D cycle [5]; in the production process, AIGC-based intelligent quality inspection system can achieve more than 99.5% defect identification accuracy, far exceeding the traditional manual inspection level [6]. These applications show that AIGC can not only improve the efficiency of various aspects of pharmaceutical manufacturing, but also promote the change of industrial innovation mode through knowledge automation. However, the application of AIGC in the manufacturing industry is still in the primary stage, and there is a lack of systematic theoretical analysis and development strategies to guide how to efficiently integrate it into the intelligent manufacturing system of pharmaceutical manufacturing enterprises.

Based on this, this paper systematically explores how AIGC empowers the intelligent manufacturing transformation of pharmaceutical manufacturing enterprises based on the dynamic capability theory, focuses on analysing the core mechanism of AIGC in intelligent manufacturing, and proposes adaptive development strategies. Through theoretical analysis and case studies, this paper hopes to provide pharmaceutical

manufacturing enterprises with scientific guidance on transformation paths, and at the same time provide policy makers with a decision-making basis for optimising the intelligent manufacturing ecology.

2. AIGC AND INTELLIGENT MANUFACTURING TRANSFORMATION OF PHARMACEUTICAL MANUFACTURING ENTERPRISES

2.1 Connotation and Characteristics of AIGC

AIGC is a deep learning-based large model technology that can automatically generate content such as text, images, audio and even code. Its core technologies include large-scale pre-trained models (e.g., Transformer architecture), Natural Language Processing (NLP), Computer Vision (CV), and Reinforcement Learning (RL) [7]. Compared with traditional AI technologies, AIGC has stronger autonomous optimisation and creation capabilities, and is able to learn and generate high-quality content from massive amounts of data, giving it the potential for a wide range of applications in the manufacturing industry.

In the manufacturing industry, the application of AIGC mainly focuses on intelligent optimisation, automatic knowledge generation and virtual simulation. Firstly, in intelligent optimisation, AIGC can analyse production data to optimise equipment scheduling and raw material usage, improve production efficiency and reduce waste. Secondly, AIGC can automatically generate knowledge content, such as automatically writing experimental reports and analysing research data to support corporate decision-making. Especially in the field of pharmaceutical manufacturing, AIGC can be used for the intelligent optimisation of drug R&D solutions, thus shortening the R&D cycle [8]. In addition, the virtual simulation function of AIGC can create highly simulated digital environments to help enterprises conduct production process simulation and product testing, and improve the accuracy of R&D and manufacturing.

2.2 The Core Demands of Intelligent Manufacturing Transformation in Pharmaceutical Manufacturing Enterprises

Intelligent manufacturing transformation of pharmaceutical manufacturing enterprises is an important initiative to cope with the challenges of the industry and enhance core competitiveness. Currently, the pharmaceutical manufacturing industry not only faces strict regulatory requirements, but also has to cope with multiple pressures such as intensified market competition, rising production costs and fluctuations in the global supply chain. The core objective of intelligent manufacturing is not only to improve automation, but also to optimise the whole chain from R&D, production, quality control to marketing.

Firstly, in the production chain, pharmaceutical manufacturing enterprises urgently need to improve production efficiency and product quality through automation and precision manufacturing. aIGC can optimise the drug R&D process, for example, accelerating drug screening through AI simulation experiments to improve the success rate of new drug development. At the same time, AIGC can optimise intelligent production lines, improve equipment utilisation and reduce operating costs. Secondly, in terms of quality management, AIGC is able to automatically detect quality defects in the production process through computer vision and deep learning technology, improving detection accuracy and reducing the rate of manual misjudgment. In addition, the AI system can monitor the production environment in real time to ensure that the company complies with international regulatory standards such as GMP (Good Manufacturing Practices), improving drug safety and traceability.

In terms of supply chain management, AIGC is able to analyse market data, predict changes in raw material demand and inventory, optimise supply chain management and improve supply chain stability. Through the intelligent scheduling system, pharmaceutical manufacturing enterprises can improve the efficiency of raw material procurement and logistics distribution, and reduce the impact of supply chain fluctuations. On the other hand, with the development of precision medicine and the growing demand for personalised medicines, AIGC is able to combine patient data to achieve flexible manufacturing, provide patients with personalised treatment plans and improve the quality of medical services.

2.3 Technology Path for AIGC-enabled Intelligent Manufacturing Transformation of Pharmaceutical Manufacturing Enterprises

The application of AIGC in the intelligent manufacturing transformation of pharmaceutical manufacturing enterprises is mainly reflected in four aspects: intelligent decision support, automated process optimisation,

intelligent R&D acceleration and accurate marketing.

Firstly, in intelligent decision support, AIGC can analyse enterprise production data, market demand and policy changes, and provide management with accurate and intelligent decision-making suggestions. the AI-driven intelligent analysis system can monitor production conditions in real time, warn of potential risks, and improve the efficiency of enterprise management. Secondly, in terms of automated process optimisation, AIGC can optimise the layout of production lines, improve equipment operating efficiency and reduce energy consumption. Combined with industrial internet and digital twin technology, AIGC can achieve intelligent scheduling, improve manufacturing flexibility and meet different market demands.

In terms of intelligent R&D acceleration, AIGC is able to automatically analyse massive scientific research papers and extract key information to accelerate new drug development through natural language processing technology. Meanwhile, through AI simulation experiments and biocomputing, AIGC can shorten the cycle of new drug R&D, improve the success rate and reduce R&D costs. In addition, in terms of precision marketing, AIGC can formulate personalised marketing strategies based on user data analysis to improve the precision of marketing.AI is able to automatically generate marketing copy and advertisement ideas to improve brand influence and customer conversion rate.

In summary, AIGC is becoming the core driving force for intelligent manufacturing transformation of pharmaceutical manufacturing enterprises. Empowered by intelligent decision-making, process optimisation, intelligent R&D and precision marketing, AIGC helps enterprises maintain their advantages in the increasingly fierce market competition and drives the industry to develop in a more intelligent, efficient and sustainable direction.

3. LOGICAL MECHANISMS: HOW GENERATIVE ARTIFICIAL INTELLIGENCE DRIVES TRANSFORMATION IN PHARMACEUTICAL MANUFACTURING ENTERPRISES

The development of AIGC provides a new driving force for intelligent manufacturing transformation of pharmaceutical manufacturing enterprises. From the perspective of Dynamic Capability Theory, the intelligent manufacturing upgrading of enterprises relies on the three core capabilities of Sensing, Seizing and Transforming, and the breakthroughs of AIGC in knowledge acquisition, data processing, human-machine collaboration and feedback optimisation are reshaping the business model and competition of pharmaceutical manufacturing enterprises. Based on this, this chapter discusses how AIGC empowers the intelligent manufacturing transformation of pharmaceutical manufacturing enterprises from four aspects: knowledge-driven, data-driven, human-computer collaboration and feedback optimisation.

3.1 Knowledge-driven Logic: AI Empowers Enterprise Knowledge Automation and Reduces Reliance on Manual Experience

Pharmaceutical manufacturing enterprises are highly dependent on professional knowledge and manual experience in R&D, production and quality management. However, the traditional way of knowledge management has problems such as information dispersion, lagging update and decision-making dependence on experts, which affects the operational efficiency and innovation ability of the enterprise. The introduction of AIGC can achieve automatic generation, optimisation and sharing of knowledge, promote the process of knowledge automation of the enterprise, and reduce the dependence on manual experience.

Firstly, AIGC can automatically integrate and refine industry knowledge to improve the knowledge management capability of enterprises. Through natural language processing (NLP) and knowledge mapping technologies, AIGC can extract key information from a variety of data sources, such as massive medical papers, patent databases, regulatory documents, etc., to form a structured knowledge base. For example, AIGC can automatically parse regulatory documents such as GMP (Good Manufacturing Practice) to help companies quickly understand and implement the latest regulatory requirements and improve compliance capabilities.

Secondly, AIGC can empower enterprises' intelligent decision support systems. Based on deep learning and expert systems, AIGC can simulate the decision-making mode of industry experts and provide intelligent suggestions for formulation optimisation, process improvement, and troubleshooting in the production process. For example,

during drug development, AIGC can automatically analyse the interactions of different drug molecules, predict potential side effects and improve R&D efficiency. In addition, in the production process, AIGC can combine historical production data to provide intelligent decision support for equipment maintenance and quality control, reducing production losses caused by human inexperience.

3.2 Data-driven Logic: AI Optimises Production Processes and Improves Decision-making Intelligence

Intelligent manufacturing upgrades of pharmaceutical manufacturing enterprises need to rely on efficient data management and analysis capabilities. AIGC, through deep learning, data mining and optimisation algorithms, can play a valuable role in the data flow of the whole industry chain, promote the optimisation of the production process, and improve the intelligence of decision-making.

First, AIGC can achieve intelligent optimisation of the production process. Through real-time analysis of various types of data (e.g., equipment status, environmental parameters, pharmaceutical ingredients, etc.) in the manufacturing process, AIGC can identify key variables, automatically adjust production parameters, and optimise the production process. For example, in the pharmaceutical process, AIGC can adjust the production temperature, humidity and mixing rate in real time based on drug stability data to improve product quality and production efficiency.

Secondly, AIGC empowers intelligent supply chain management to improve the accuracy and reliability of pharmaceutical logistics. The supply chain of pharmaceutical manufacturing enterprises involves multi-level procurement of raw materials, production planning, inventory management and terminal distribution, while market demand and supply are highly uncertain. aIGC can accurately forecast market demand and inventory levels, optimise purchasing plans, and reduce inventory costs through time series forecasting and optimisation algorithms. In addition, AIGC can be combined with an intelligent scheduling system to improve the efficiency of logistics and distribution of medicines and ensure that critical medicines can be supplied on a priority basis in emergency situations.

Finally, AIGC can improve production safety and compliance. Through computer vision and sensor data analysis, AIGC can monitor the production environment and product quality in real time. For example, in the pharmaceutical packaging process, AIGC can automatically identify packaging defects and labelling errors, improve the accuracy of quality testing, and ensure product compliance with regulatory requirements.

3.3 Human-machine Collaboration Logic: the Way AIGC Works with Manufacturing Personnel

Despite the powerful automation capabilities of AIGC, complete reliance on AI for manufacturing management may bring uncertainty and risk. Therefore, in the process of intelligent manufacturing transformation, how to achieve efficient collaboration between AIGC and humans is an important issue that pharmaceutical manufacturing enterprises must address.

First of all, AIGC can act as an ‘intelligent assistant’ in the production process, assisting human decision-making and improving work efficiency. For example, in the process of drug development, researchers can use AIGC to quickly screen candidate compounds, while the final experimental verification is still done by human experts. In terms of quality management, AIGC can analyse production data in real time, identify abnormal trends, and send early warnings to quality inspectors so that they can make human interventions and decisions.

Secondly, AIGC can improve the skill level of employees and enhance the talent competitiveness of enterprises. Through the intelligent training system, AIGC can provide personalised skills training and knowledge recommendation for employees. For example, production operators can learn how to operate and maintain intelligent production equipment through the interactive training system generated by AIGC, reducing training costs and improving skill levels.

In addition, AIGC can promote organisational innovation and cross-departmental collaboration. In traditional manufacturing enterprises, production, quality, supply chain and other departments are often relatively independent, and there are barriers to information flow. AIGC can be used as an enterprise information sharing and collaboration platform to break the information silos between departments and improve the overall operational efficiency of the enterprise.

3.4 Feedback Optimisation Logic: AI Optimises Manufacturing Processes based on Historical Data

One of the core features of intelligent manufacturing is the ability to continuously optimise the production process based on data feedback. AIGC's self-learning capability enables it to dynamically adjust production strategies based on the continuous accumulation of historical data to achieve continuous optimisation of the manufacturing process.

First, AIGC can achieve dynamic optimisation of production parameters. Through reinforcement learning and data retrospective analysis, AIGC can automatically identify key factors affecting production efficiency and product quality, and continuously adjust process parameters. For example, in the pharmaceutical preparation process, AIGC can identify the optimal mixing ratios of different formulations through historical data analysis to improve efficacy and stability.

Secondly, AIGC can be used for intelligent prediction and preventive maintenance to improve the reliability and service life of equipment. While traditional equipment maintenance models are usually based on fixed cycles or manual experience, AIGC can combine sensor data and historical maintenance records to predict equipment failure trends and issue maintenance recommendations in advance. For example, AIGC can monitor the operating status of pharmaceutical equipment, detect abnormal changes in parameters such as temperature, vibration, and pressure, and proactively alert maintenance before equipment failure occurs, reducing the risk of production interruption.

Finally, AIGC can optimise a company's product iteration and market strategy. By analysing consumer feedback and market data, AIGC can predict market trends and optimise product formulations and production plans. For example, based on patient feedback data, AIGC can analyse the efficacy and side effects of specific medicines and provide recommendations for improvement to drive the development of precision medicine.

4. DEVELOPMENT STRATEGY: PROMOTING THE DEEP INTEGRATION OF AIGC AND PHARMACEUTICAL MANUFACTURING ENTERPRISES

AIGC shows great potential in the intelligent manufacturing transformation of pharmaceutical manufacturing enterprises, but in order to truly realise the value of AIGC, a series of development strategies are needed at the levels of technology, management and industrial policy to ensure that AIGC can be deeply integrated with pharmaceutical manufacturing enterprises. This chapter will explore the specific paths to promote the integration of AIGC with pharmaceutical manufacturing enterprises from three aspects: technology, management and industrial policy.

4.1 Technology Level: Promoting Vertical Application of AIGC in Pharmaceutical Manufacturing

Strengthening the integration of AIGC with the industrial Internet and digital twin The intelligent generation and decision-making capabilities of AIGC are highly complementary to technologies such as the industrial Internet and digital twin. Industrial Internet connects equipment, data and business processes and can provide rich production and operation data, while AIGC can make intelligent analysis and optimised decisions based on these data. Digital twin technology, on the other hand, can build a virtual simulation model of the production process, enabling AIGC's decisions to be tested and optimised in a virtual environment, reducing the risk of practical application. For example, in the pharmaceutical production process, AIGC combined with digital twin can simulate the impact of different production parameters on the quality of pharmaceuticals, to help enterprises choose the optimal process plan. In addition, combined with industrial internet, AIGC can optimise supply chain management and improve production efficiency through real-time data analysis.

Promote the vertical application of big models in pharmaceutical manufacturing. Most of the current AIGCs are based on general-purpose big models, and although they have powerful natural language processing and data analysis capabilities, their application in vertical fields such as pharmaceutical manufacturing still needs to be further optimised. Therefore, enterprises should promote the industrialisation of big models and build dedicated AI models applicable to pharmaceutical manufacturing enterprises. For example, AIGC models dedicated to biopharmaceutical R&D can be developed to optimise drug molecular screening, protein structure prediction and clinical trial data analysis. In addition, for intelligent production management, AIGC-based process optimisation models can be developed to achieve intelligent regulation and fault prediction to improve production efficiency and quality stability.

4.2 Management Level: Enhancement of Industrial Landing Capability of AIGC Technology

Setting up AI-driven intelligent manufacturing labs to promote technology-industry synergy. Pharmaceutical manufacturing enterprises need to establish AI-driven intelligent manufacturing laboratories to promote the implementation of AIGC technology in the actual production environment. The lab can unite with universities, research institutions and technology enterprises to build an AI application testing platform to conduct research in the direction of intelligent production, quality inspection and supply chain optimisation. For example, enterprises can test the effect of AIGC in drug formulation optimisation and intelligent monitoring of the production process in the lab, and gradually promote it to the actual production environment. In addition, the lab can be used as a talent training base to enhance the internal AI technology application capabilities of enterprises and cultivate intelligent manufacturing professionals.

Improve data governance and privacy protection mechanism to ensure AI compliance application. The effective operation of AIGC relies on high-quality data, so pharmaceutical manufacturing enterprises need to establish a perfect data governance mechanism to ensure data integrity, accuracy and security. Firstly, a unified data management platform should be built to achieve data interconnectivity in different segments such as production, R&D, quality management, etc., and improve data sharing efficiency. Second, enterprises should strengthen data privacy protection and adopt technologies such as federated learning and differential privacy to improve the learning ability of AIGC while protecting sensitive information. In addition, they should establish a transparent audit mechanism for AI systems to ensure the interpretability of AI decisions, reduce the ‘black box’ problem, and improve the trust of regulators and enterprise management.

4.3 Industrial Policy Level: Creating an External Environment Favourable to AIGC Development

Establishing industry standards and specifications for AI+Pharmaceutical Manufacturing. The application of AIGC in the pharmaceutical manufacturing industry is still in the exploratory stage and lacks a unified technical standard and regulatory framework. Therefore, the government and industry associations should take the lead in developing technical standards and application specifications for AIGC in pharmaceutical manufacturing. For example, the application boundaries of AIGC in pharmaceutical R&D, production, and quality control should be clarified, and industry standards for data sharing and privacy protection should be established. In addition, regulators should introduce an audit mechanism for AI-generated content to ensure that AI-generated production optimisation solutions, quality testing results, etc. comply with industry regulations.

Promote the joint promotion of AI technology in the pharmaceutical manufacturing enterprises by the government, enterprises, and universities. The government should increase policy support for AIGC in pharmaceutical manufacturing enterprises, and encourage them to carry out AIGC technological innovation through special funds, tax incentives, and other measures. At the same time, a government-enterprise-university joint innovation platform should be established to promote in-depth cooperation between industry, academia and research. For example, the government can support universities and pharmaceutical manufacturing enterprises to build AI application research centres and jointly develop intelligent manufacturing solutions. In addition, the policy should also encourage enterprises to cooperate with AI technology companies to accelerate the industrialisation of AIGC technology and promote China's pharmaceutical manufacturing enterprises to move towards intelligent manufacturing.

5. RESEARCH OUTLOOK

With the rapid development of generative artificial intelligence generated content (AIGC), pharmaceutical manufacturing enterprises have entered a new stage of intelligent manufacturing transformation. AIGC shows great potential in improving production efficiency, optimising supply chain management, and promoting personalised manufacturing, etc., but at the same time, it also faces the challenges of data security, model interpretability, and arithmetic cost. In the future, the application of AIGC in the pharmaceutical manufacturing industry still has a broad space, and it is necessary to further optimise the technology, management and policy environment to promote its landing and development.

Firstly, the future direction of AIGC application in pharmaceutical manufacturing enterprises will be more in-depth, such as new drug development, precision medicine, intelligent quality control and other fields, which will gradually achieve the whole process intelligence. Secondly, the current application of AIGC still has certain limitations, such as insufficient data privacy protection and low transparency of AI decision-making, which need

to be strengthened in the exploration of technology development and industry regulation. Finally, future research should combine practical cases to deeply analyse the effectiveness of AIGC application in different types of pharmaceutical manufacturing enterprises, and explore interdisciplinary technology integration, such as the combination of AIGC with edge computing, blockchain, and other technologies, in order to further enhance the safety and efficiency of intelligent manufacturing.

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