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Smart Factory Operation Management System and Innovation in the Era of Smart Manufacturing

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Abstract: This study is dedicated to the innovative research of smart factory operation management systems in the era of smart manufacturing. Against the backdrop of the rapid evolution of the information revolution, smart manufacturing, represented by a new generation of information technologies such as mobile Internet, big data, and artificial intelligence, is rapidly emerging. As an information-physical fusion system, smart factories interpenetrate physical and virtual resources by interweaving multi-scale production systems, forming an open, complex giant system with multiple levels and dimensions. It is found that smart factories face a complex and variable structure, and their production and operations involve a large number of cross-domain, cross-industry, and cross-region manufacturing resources, requiring the establishment of a new operation management system framework and breakthroughs in key theories and methods. This study provides comprehensive and in-depth theoretical and technical support for constructing a smart factory operation management system. It lays the foundation for the smart upgrading of the manufacturing industry.

Keywords: Smart Manufacturing, Smart Factory, Operations Management System, Knowledge Innovation

1. Introduction

In the era of smart interconnection, the process of information revolution continues to evolve rapidly, with the comprehensive penetration of new generation information technologies such as mobile Internet, big data, artificial intelligence, Internet of Things, and cloud computing in the industrial field, giving birth to a new manufacturing concept - smart manufacturing. The production and operation management mode and operation mode of the manufacturing industry have undergone fundamental changes, and Adams found smart manufacturing has become a common focus of global industrial development and industrial transformation and upgrading [1].

Smart factory is an information-physical fusion system formed by interweaving three dimensions of time, space and task under a multi-scale production system. The system's Physical and virtual resources penetrate each other; their respective boundaries tend to disappear and gradually evolve into a multi-level and multi-dimensional open complex giant system. In addition, Ahern considered that new technologies, materials, and processes continue to emerge, and personalised and customised production is booming, making the operation management of smart factories more complex and uncertain [2].

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The structure of a smart factory is complex and dynamic, and its production and operation involve many cross-field, cross-industry and cross-regional manufacturing resources as well as organisation and management problems. Building a new operation management system framework with systematic thinking and making breakthroughs in key theories and research methods is necessary.

The production process of a smart factory is no longer converted from raw materials to products by processing; more importantly, it is a process of knowledge creation, sharing and updating, and the demand for knowledge innovation activities is stronger. Ajinkya sum up the traditional knowledge acquisition and application mode based on expert experience and analysis model will be replaced by the innovative knowledge management mode based on deep mining and smart reasoning decision, providing reasoning and decision support for improving the smart level of smart factories [3].

The environmental changes brought by the Internet and big data have put forward new requirements for knowledge management of smart factories, which are as follows: (1) the existing knowledge discovery methods driven by big data need to be combined with the specific requirements for knowledge acquisition of smart factory operation management. (2) Smart factory knowledge sources are diverse, the structure is complex, the semantics are heterogeneous, and there needs to be more multi-level and multi-dimensional knowledge management methods. (3) The knowledge expression of the smart factory is not limited to the standardised description of the semantic level of the ontology model but also needs to solve the problem of knowledge dissemination, sharing and ageing updating among different levels of the smart factory.

A manufacturing system is a dynamic system affected by multiple production disturbances and constantly changing internal and external demands. With the increasing demand for highly customised and personalised products, the increasing diversity of products and the increasing complexity of production, Akbas consider the range and frequency of uncertain factors that cause production disturbances are increasing, making dynamic strain ability (adaptive ability) become an important embodiment of future manufacturing intelligence [4].

The environmental changes brought by the Internet and big data put forward new demands for the production scheduling of smart factories, which Akbas found manifested in (1) the need to build an adaptive scheduling system covering the whole production process and multiple disturbance factors. (2) Cyber-physical system (CPS) technology can help realise online disturbance identification, rapid response and real-time adjustment of scheduling strategies. (3) Introducing data-driven methods, mining and adjusting scheduling knowledge to optimise scheduling policies effectively solves adaptive scheduling [4].

2. Smart Factory Operation Management System

2.1. Smart Factory Operation Management Kernel

Based on the digital factory, the smart factory further enhances intelligence and effective decision-making ability with the help of emerging technological means and management innovation ideas and realises the transformation and upgrading of smart manufacturing. The smart promotion of smart factories aims to strengthen the active effectiveness of enterprise information management services, improve the dynamic adaptation of production process management, and achieve mutual coordination and cooperation between people and machines, environments and systems, which is comprehensively reflected in making the production system have the ability of self-organisation, self-learning and self-adaptation.

2.1.1. Self-organisation

The concept of “self-organisation”, proposed by Haken, founder of “synergetics” in 1976, Ahern considers usually refers to the process by which an open system achieves an ordered structure through

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internal organisation [2]. Enterprise self-organisation is the process of flexibly and cooperatively organising production resources to carry out production activities according to production tasks and environments, including inter-enterprise supply chain self-organisation and internal logistics system, production system and information system self-organisation.

2.1.2. Self-learning

Self-learning refers to the ability to automatically modify the structure or parameters of knowledge to improve its quality by evaluating the correctness or excellence of existing behaviours in the business operation process. Akbas considered the improvements obtained by learning can be preserved and fixed in the knowledge structure [5]. Through the processing and analysis of massive data, industrial big data technology enables the manufacturing system to have the ability to learn and continuously learn the complex evolutionary mechanism, knowledge, and experience of the manufacturing system through continuous data, thus endowing the manufacturing system with intelligence.

2.2. Smart Factory Operation Management System Architecture

Smart factories use various advanced information technologies such as the Internet and big data to strengthen enterprise information management services, improve the controllability of the production process, reduce manual intervention in the production line, and formulate reasonable plans and schedules so that the production system can self-learn, self-adapt and self-organize. Specifically, while improving the traditional digital factory model, the smart factory operation management system explores self-learning methods of knowledge discovery and knowledge management of smart factories based on industrial big data analysis, Baik considered adaptive scheduling and closed-loop optimisation, as well as operation and maintenance service management and self-organisation mode innovation [6].

The function of self-organisation is to automatically optimise and match the goals, tasks and resources in each level of the manufacturing system, which involves not only the reform of the service-oriented manufacturing mode at the upper level but also the operation and organisation mode at the middle level, and Baum sum up even the collaborative configuration of the tasks at the lower level [7]. Self-learning promotes the system's active cognition and self-learning ability by refining, applying and updating manufacturing knowledge management to maintain and continuously enhance the intelligence level of guiding manufacturing operations and decision-making. Self-adaptation is mainly reflected in the perception and adaptability of complex and diverse uncertain factors in the manufacturing environment. Adaptive innovation for smart manufacturing is realised through constructing multi-objective and multi-scenario robust scheduling - dynamic scheduling based on environment perception and disturbance analysis - adaptive scheduling three-level linkage system based on real-time monitoring and online optimisation. Baik considers these three aspects to be related and promote each other, ultimately achieving the all-round transformation and upgrading of digital factories to smart factories [6].

3. Self-organizing Innovation of Smart Factory Service Model

3.1. Service-oriented Manufacturing Mode of Smart Factory

The competitiveness of manufacturing enterprises fundamentally comes from the rapid response to consumers and the market, which involves three aspects: product, manufacturing, and business model. The manufacturing model integrates the manufacturing system, business model and product structure. Adapting to the specific national conditions, Berkman sums up the social system and economic and technological development of the country; the manufacturing mode of a smart factory integrates the service with production as the core and the production with service as the core, which is a new service-oriented manufacturing mode [8]. Integrating the resource advantages between enterprises and extending the value chain of products and services also emphasises the synergy of function operation. It pays attention to self-regulation, self-integration and optimisation of system organisation. Service-oriented manufacturing aims to realise the value addition of all stakeholders in the manufacturing value chain. Through the integration of products and services, the full participation of customers, and the mutual provision of productive services and service-oriented production by enterprises, Baum found the integration of decentralised manufacturing resources and the high degree of synergy of their respective core competitiveness is realised. A new manufacturing model with high efficiency and innovation is achieved [7]. In a service-oriented manufacturing organisation, coordinating the resources among enterprises and giving play to the advantages of horizontal integration between enterprises can not only realise the fine division of labour to create economic value but also enable enterprises to bear fewer risks, thus improving the efficiency of value creation in the whole life cycle of products. In product value chain creation, Beyer sums up the design, research and development, marketing, management, after-sales and other productive service activities based on homogenised products to create differentiated services conducive to enterprises to create service-oriented value [9].

3.2. Human Information Physical System Drive

Guided by the service-oriented manufacturing model, smart factories' operation and organisational implementation rely on the human cyber-physical system (HCPS) environment composed of human, information, and physical systems. By integrating people (customers and customer groups) and their social attributes into the CPS production system, an HCPS-driven smart production system is built to realise the integrated operation of the service value chain and product supply chain in smart factories and support smart production services and product services.

The tangible product supply chain is a product service system involving each enterprise's organisational link of the product life cycle. It is reflected in the collaborative integration at three levels: the deep collaboration of each node enterprise in the production network supported by the system platform, the information sharing and decision support supported by big data management, and the multiple “Internet +” supply chain finance models based on the premise of shortening the network supply, production and marketing supply chain.

The intangible service value chain is the aggregate of smart factory value added. On the one hand, value-creation services are provided to customers in a networked way. On the other hand, Bizjak sum-up value is extracted from the tangible product supply chain, and optimisation strategies are obtained after comprehensive, integrated analysis [10]. The value extraction and feedback execution between the service value chain and product supply chain form the closed loop of “product supply chain - service value chain - product supply chain” to realise the integration of the value chain. On this basis, by comparing each link of the service value chain and the product supply chain, manufacturing resources can be scientifically utilised and allocated, providing decision support for the operation management and optimisation of smart factories and realising the value chain extension.

3.3. Collaborative configuration, Management and Optimization

In the era of intelligence, the full life cycle services of marketing, sales, supply, operation and maintenance products are endowed with new content due to new technologies such as the Internet of Things, big data, and artificial intelligence. By means of the overall coordination of humans, information systems and physical systems in the human information physical system environment, vertical integration of internal logistics systems, production systems, information systems and service

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systems can be achieved, and horizontal integration of different manufacturing enterprises based on value chain and information flow can be realised. Implementing the collaborative innovation mechanism of smart factories is manifested as the collaborative management optimisation of product manufacturing services and the collaborative configuration optimisation of product operation and maintenance services.

4. Self-learning Innovation of Smart Factory Knowledge Management

4.1. Knowledge Discovery Based on Industrial Big Data Fusion

Under the smart manufacturing mode, whether it is the highly complex and uncertain characteristics of products, manufacturing and systems or the increasingly urgent need for independent innovation, knowledge creation, sharing and updating, higher requirements are put forward for generating and applying manufacturing management knowledge. The continuous maturity of data science and the continuous enrichment of data resources have laid the foundation for the knowledge discovery of smart factories, driving knowledge discovery based on expert experience to shift gradually to data-driven knowledge discovery.

Based on the knowledge discovery of industrial big data fusion technology, it is not only necessary to have the ability to identify regularities and characteristics from large-scale complex industrial data but also to deal with the challenges of heterogeneous and heterogeneous industrial information resources, difficult integration, and lack of unified standards and norms. It also needs to be based on domain knowledge and an object-oriented environment to meet the comprehensive application requirements, such as functionality and timeliness of smart factory manufacturing and services. Therefore, it needs to be implemented from two aspects: model and method.

The unified specification description of heterogeneous data from multiple sources is solved in knowledge modelling by constructing the knowledge ontology model based on the semantic web analysis framework. Through ontology mapping technology, Baum suggested that the mapping between domain ontology and local ontology and local ontology and databases be further completed to realise semantic queries and ensure the accuracy and efficiency of query data [7].

Regarding knowledge discovery methods, predictive analysis-oriented correlation feature selection is the key to realising automatic recognition and autonomous learning. To improve the ability of association knowledge discovery under large-scale complex data conditions, methods such as ensemble learning, evolutionary computing and statistics-based variable association recognition can be adopted to realise automatic identification of unknown variables with combinatorial association features with target objects, thus ensuring the efficiency and accuracy of data to knowledge transformation.

4.2. Knowledge Reasoning for Autonomous Decision Making

Through knowledge discovery, find and identify key information related to application problems to form a specific understanding of a problem. Based on this, knowledge reasoning is combined with the upgrading needs of smart factories to analyse, solve, and optimise problems and realise the application innovation of knowledge through knowledge-based independent decision-making.

For operation management applications of smart factories, it presents an ontology query and reasoning method based on a graph database. This can ensure effectiveness, improve scalability, and overcome the limitations of traditional ontology query and reasoning methods, making it difficult to deal with massive industrial data growth efficiently. By combining the production evaluation attribute weight matrix obtained from processing production evaluation big data with the customer evaluation attribute weight matrix reflecting the actual needs of customers, the man-machine joint hesitation fuzzy decision matrix is obtained, and the machine autonomous or man-machine joint reasoning decision is realised.

4.3. Knowledge update based on autonomous learning

Knowledge management is an important means to improve smart factories' adaptability, innovation ability, continuous cycle optimisation and spiralling value-added. In the complex manufacturing environment of the smart factory, the knowledge learned from the data is context-relevant and/or time-sensitive. It will deteriorate or even become invalid as the internal and external environment of the manufacturing system changes dynamically. The guarantee of satisfaction with the validity of knowledge and the effect of reasoning and decision-making comes from the continuous updating mechanism of knowledge in knowledge management.

If knowledge discovery is the learning of knowledge and knowledge reasoning is the application of knowledge, then knowledge updating is the increment of knowledge. The dynamic knowledge-updating process for smart factory operation management includes two steps: knowledge evaluation and knowledge updating. By monitoring and analysing the effect of knowledge application or predicting the trend of knowledge deterioration or failure, the former determines and decides whether to enter the updating process. The latter implements additions, deletions or adjustments to the knowledge base based on online learning. Aiming at the knowledge management of shop scheduling in smart factories, presents an online updating scheme of the knowledge of shop scheduling in smart factories.

5. Conclusion

As the mainstream organisation mode and production mode of smart manufacturing in the Internet and big data era, smart factories have become the main direction of transforming and upgrading world-class manufacturing enterprises. The level of construction of a country's smart factory largely reflects the level of development of the country's manufacturing industry, and the level of smart factory operation management reflects the level of intelligence of the country's manufacturing industry. Aiming at the operation management of smart factories in smart manufacturing, this paper systematically combs and constructs the architecture of smart factories' operation management system and studies the theoretical connotation and technical methods from three aspects. In terms of the self-organisation innovation of a smart factory service mode, the operation and organisation mode of a smart factory driven by human information and physical systems is constructed under the guidance of a service-oriented manufacturing mode. Regarding self-learning innovation of knowledge management in smart factories, knowledge discovery based on big data fusion, knowledge reasoning based on human-machine association and knowledge updating based on autonomous learning are proposed. Various robust, dynamic, and adaptive scheduling methods are proposed in the adaptive innovation of smart factory scheduling optimisation.

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