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Review of Research on Development Countermeasures of Intelligent Manufacturing in China

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Abstract

How to develop intelligent manufacturing is a great theoretical and practical subject. In this paper, the research on the development strategy and countermeasure of intelligent manufacturing in China is taken as the object, and the related research progress is introduced from an academic perspective by using qualitative analysis method. The research on this topic began in 1990s, and had shown a rapid growth since 2014. At present, there are two kinds of research approaches: one is the speculative research led by qualitative research. Researchers rely on subjective analysis such as intuition, experience and logical reasoning, and put forward the development countermeasures of intelligent manufacturing on how to foster strength and avoid weaknesses. The other is the mixed research of qualitative and quantitative. Based on the comparison of statistical data or a comprehensive evaluation, the development countermeasures of intelligent manufacturing are proposed. In addition, according to the category of the research object, the related research involves the three levels of country, region, and enterprise.

Keywords

Intelligent manufacturing, Chinese context, Development countermeasure.

1. Introduction

Intelligent manufacturing (IM) is an advanced mode of production after artificial intelligence, and its idea originated from America and Japan in 1980s. At the end of 1980s, China began to pay attention to and reported the related information of intelligent manufacturing in developed countries. In the early 1990s, Chinese scholars, led by Professor Yang Shuzi, began to introduce and study the basic theory of intelligent manufacturing, and the National Natural Science Foundation of China began to support major projects in this field.

Since 1980s, intelligent manufacturing research in the international academia has presented two major themes: (1) Research on the basic theory of intelligent manufacturing based on technology realization. The rise of this research topic benefits from the application and development of artificial intelligence and computer integration technology in the manufacturing field. People's early understanding of intelligent manufacturing mainly includes intelligent manufacturing technology (IMT) and intelligent manufacturing system (IMS). This topic mainly involves the connotation and extension of intelligent manufacturing (Wright and Bourne, 1988)[1], Concept, technical support and system design optimization of intelligent manufacturing technology and intelligent manufacturing system (Yang Shuzi and Ding Hong, 1992; Yang Shuzi and Wu Bo, 1999; Madejski, 2007)[2][3][4] and the development trend of intelligent manufacturing (Yang Shuzi and Wu Bo, 2003; MaričIć et al, 2008) [5], [6]. (2) Research on the development planning and countermeasures of intelligent manufacturing. The rise of this research topic is attributed to the continuous development of the above-mentioned

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intelligent manufacturing technology. Meanwhile, influenced by changes in the global political and economic environment, especially since the global financial crisis in 2008, manufacturing powers such as the United States, Japan and Germany have re-examined the importance of industrial development and set off a wave of "re-industrialization". In order to adapt to the new normal of economic development and achieve the goals of structural adjustment, transformation and upgrading of the manufacturing industry, China regards intelligent manufacturing as the main direction of manufacturing development. Compared with the former, the subject research not only pays attention to the internal technical support of intelligent manufacturing, but also emphasizes the supporting role of external environment such as politics, economy, society and culture, and involves the policies, industrial planning and layout, scheme measures and other contents to realize intelligent manufacturing. Since 2010, the research on this subject has received special attention from governments and scholars in China and other countries. As a big developing country, China occupies an important position in the world economic development, and the development of intelligent manufacturing deserves attention. In this paper, the development strategy and countermeasure of intelligent manufacturing in China is taken as the research object, and the related research progress is introduced from an academic perspective.

2. Analysis of Research Status

In this paper, research on enterprise intelligent manufacturing, intelligent manufacturing of equipment manufacturing, intelligent manufacturing equipment industry, intelligent manufacturing and other development issues are classified into the subject research. In China national knowledge internet (CNKI), "Intelligent Manufacturing" and "Development Countermeasure" is used as the key/subject words to search for periodical papers, and 136 papers have been found. Since 2014, the research on this topic has shown an obvious growth momentum, and annually published articles from 2017 to 2021 are 15, 22, 21, 29 and 31 respectively. The overall research trend is illustrated in Figure 1.

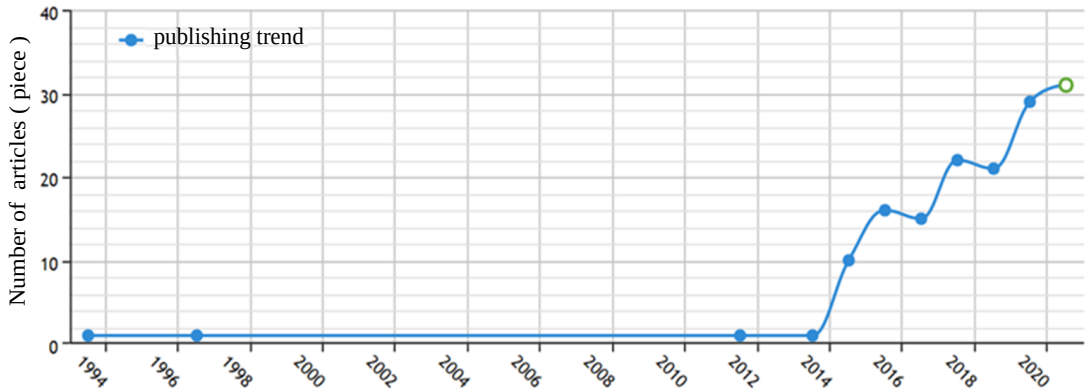

Figure 1: Publishing trend of intelligent manufacturing development research in China

Further analysis shows that relevant researchers include relevant departments of national and local governments and scholars. In terms of research methods, there are mainly two ways: one is using pure qualitative research, researchers rely on subjective analysis such as intuition, experience, logical reasoning, etc., and put forward development countermeasures of intelligent manufacturing on how to foster strength and avoid weaknesses; the other is combining quantitative research with qualitative research, based on statistical data for comparison, or according to a comprehensive evaluation and analysis, aiming at the problems, the development countermeasures of intelligent manufacturing are put forward. In addition, from the perspective of the subject category, the related research involves three levels: the state, provinces and cities, and enterprises.

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2.1. Perspective of Research Method

(1) The speculative research dominated by qualitative research. This kind of research usually uses induction, deduction, comparison and other methods to carry out research work, which generally belongs to pure qualitative analysis without involving quantitative analysis, and has strong recapitulatory and speculative color. For example, Zhang Chaoni (2021), based on the problem orientation, analyzed the problems and countermeasures of developing intelligent manufacturing in China's National High-tech zone around the cognitive level, infrastructure, supporting talents and services[7]. Qiu Ying et al. (2021) based on the value chain theory, discussed the composition and governance structure of micro value chain of Chinese intelligent manufacturing enterprises, and put forward the safeguard measures for sustainable development[8].

(2) The mixed study of qualitative and quantitative analysis. In order to ensure the scientific development countermeasures and suggestions of intelligent manufacturing, qualitative and quantitative studies are often used in practical research. Before quantitative research, researchers use qualitative research to determine the nature of research phenomena. In the process of quantitative research, the researchers also use qualitative research to determine the quantitative limits of qualitative change and the causes of qualitative change. Because the development strategy of intelligent manufacturing is inseparable from the analysis and evaluation of current situation, this kind of mixed research mainly focuses on two kinds of problems: "panel data analysis" and "intelligent manufacturing evaluation". The former research focuses on the direct analysis and comparative study of intelligent manufacturing panel data. For example, Yu Bo and Pan Aimin (2021) compared the import and export trade data of intelligent manufacturing equipment industry between China and the world from 2007 to 2019, analyzed the international competitiveness of China's intelligent manufacturing equipment industry and its influencing factors, and proposed the promotion countermeasures[9]. Wang Yuanyuan and Zhang Huarong (2020) constructed the "Manufacturing Intelligence Index (IMI)" from the perspective of input/output, compared and analyzed the overall and sub-industry intelligence development level of G20 countries from 2005 to 2015, and put forward countermeasures and suggestions for the development of intelligent manufacturing in China[10]. The latter category research focuses on data mining and evaluation with the help of decision-making and evaluation techniques. Up to October 21st, 2021, 89 journal literatures can be retrieved with the theme of "Intelligent Manufacturing Evaluation", with "CSSCI", "Core Journals", "CSCD", "EI Source Journals" and "SCI Source Journals" as filtering conditions, and the items inconsistent with the research theme are removed by content analysis, and finally 17 articles remain. By using the analysis of "Keyword Co-occurrence Network" of CNKI, it is found that these studies can be classified into five categories as showing in Figure 2.

Cluster 1 focuses on the comprehensive evaluation of intelligent manufacturing. The context system covers the basic elements of the comprehensive evaluation theory (evaluators, data, indicators, methods and evaluated objects), and involves high-frequency keywords such as "evaluation index", "index system", "evaluation method", "evaluation model", "China manufacturing", "comprehensive evaluation" and "resource allocation" (frequency > =2, numbers in brackets represent frequency). It occupies the main position of intelligent manufacturing evaluation. For example, Du Jinsong et al. (2021) used the analytic network process (ANP) to build an evaluation model for the maturity of intelligent manufacturing capability of garment enterprises[11]. Han Yating et al. (2021) put forward an PROMETHEE evaluation method of intelligent manufacturing capability based on interval number, aiming at the problems of compensation between indexes and uncertain index values[12]. The latter four clusters are evaluated in combination with specific problems. Cluster 2 pays attention to the credit evaluation of intelligent manufacturing. For example, Gao Hua and Wang Xiaojie (2018)

built an index system and method for credit evaluation of intelligent manufacturing enterprises for financing problems[13]. Cluster 3 focuses on the governance of intelligent manufacturing innovation ecosystem, including keywords such as "governance mechanism", "information transformation", "innovation ecosystem", "functional elements" and "functional evaluation". For example, Tang Linjia et al. (2019) combed the functional elements of innovation ecosystem, and built an evaluation system of the function of intelligent manufacturing innovation ecosystem from four aspects: innovation capability, service capability, support capability and development capability, and gave corresponding governance suggestions[14]. Cluster 4 discusses the construction of manufacturing power, including "regional manufacturing", "eastern region", "underdeveloped region" and "measurement model". Wu Minjie et al. (2020), based on the five-dimensional connotation characteristics of intelligent manufacturing, measured the development level of China's regional intelligent manufacturing by using the latent factor model, and put forward countermeasures and suggestions for regional development and building a strong country[15]. Cluster 5 has carried out the evaluation research of the top 100 intelligent manufacturing enterprises in China, it covers keywords such as "top 100 list", "remanufacturing industry", "machinery manufacturing enterprise" and "enterprise evaluation". For example, Wu Shan et al. (2020) investigated 15,145 Chinese intelligent manufacturing enterprises, evaluated the intelligent manufacturing capabilities of 322 selected enterprises with dual innovation capabilities as the core, and won the top 100 list, and put forward the development path of Chinese intelligent manufacturing[16].

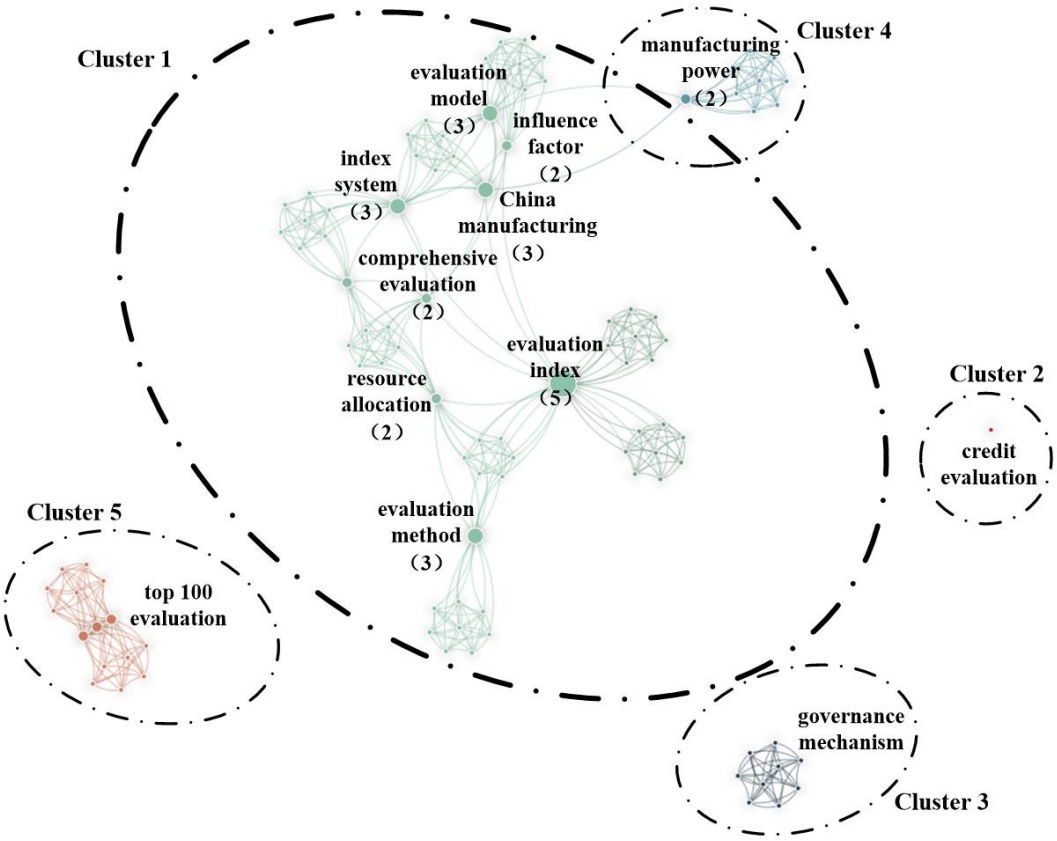

Figure 2: Co-occurrence analyses of intelligent manufacturing evaluation in China

2.2. Perspective of Research Level

(1) The national level. In recent years, the world's manufacturing power has made the planning and guidance of intelligent manufacturing an important topic of government work. For example, in 2006, Japan put forward the "Innovation 25 Strategy" plan. In 2009, the United States announced the "re-industrialization" plan. In 2010, the EU implemented the "Europe 2020"

strategy. In 2013, Germany put forward the "Industry 4.0 Plan". In 2014, Britain put forward the strategy of "high value manufacturing". In 2015, the State Council of China published "Made in China 2025". From the specific research of scholars, the research perspective includes not only the summary and study of international intelligent manufacturing development experience, but also the research of domestic intelligent manufacturing development status and promotion countermeasures. For example, Wang Desheng (2015) introduced the development status and experience of the world's intelligent manufacturing equipment industry such as industrial robots, computer numerical control (CNC) machine tools and 3D printing equipment by using the method of statistical data comparative analysis[17]. Zhu Sendi (2015) compared the statistical data, analyzed the development status of China's intelligent manufacturing equipment industry, and put forward suggestions to promote China's intelligent manufacturing[18]. Chang Tao et al. (2014), Xu Min (2016) and Yi Yihu (2020) respectively studied the overall development of intelligent manufacturing in China's foundry, Cotton weaving and petrochemical industries by using qualitative analysis methods[19][20][21]. Li Jianxuan (2020) used the comprehensive evaluation theory and technology to construct the evaluation index system of intelligent degree of Chinese manufacturing industry from the three aspects of intelligent technology, intelligent application and intelligent benefit, and evaluated the intelligent degree of Chinese manufacturing industry and the differences between provincial manufacturing industries by entropy weight method, and analyzed the corresponding influencing factors[22].

(2) The regional level. There are a large number of such studies about China. From the planning and guidance of government departments, by the end of May 2016, Hebei, Shanxi, Liaoning, Jilin, Shandong, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Henan, Hubei, Hunan, Guangdong, Sichuan, Gansu, Beijing, Tianjin, Guangxi and Ningxia have replied to Made in China 2025. Ten cities including Jinan, Nanjing, Zhenjiang, Quanzhou, Sanming, Zhuzhou, Guangzhou, Shenzhen, Foshan and Chengdu have issued docking measures and action plans. In terms of specific research, Chinese scholars mostly use qualitative research methods to put forward countermeasures or suggestions for the development of intelligent manufacturing, involving Zhejiang, Shanghai, Guangdong, Liaoning, Anhui, Fujian, Yangzhou, Wuxi, Luoyang and other places. Quantitative research is less, among which Chen Yong et al. (2015) analyzed the application of intelligent manufacturing equipment in electronic appliances, ceramics, textiles, food and medicine, metal processing, furniture, Internet of Things and other industries based on the survey data of 22 manufacturing enterprises in Foshan, and put forward relevant development countermeasures[23]. Dong Zhixue and Liu Yingji (2016) built an evaluation index system of intelligent manufacturing capability around the business performance level, enterprise innovation capability, product circulation capability and information service level, and evaluated the overall situation of intelligent manufacturing capability of 23 provincial administrative regions in China by factor analysis, and put forward development suggestions[24]. Generally speaking, apart from the relevant reports in local newspapers, there are few systematic and in-depth academic researches directly focusing on the development countermeasures of intelligent manufacturing in a certain place.

(3) The enterprise level. This kind of research mainly has two directions: one is the overall research on the development of enterprise intelligent manufacturing. For example, Jin Jiangjun (2012) focused on qualitative research, and put forward the countermeasures for developing intelligent manufacturing in China from the aspects of strengthening policy guidance, increasing financial support, strengthening the construction of talent team, promoting the docking between supply and demand of intelligent manufacturing, and developing intelligent manufacturing demonstration zones[25]. Guo Jin (2021) summarized the experience of developed industrial countries, analyzed the main contents and possible paths of upgrading Chinese traditional manufacturing enterprises to intelligent manufacturing from the three

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dimensions of technology chain, industrial chain and value chain, and put forward the "three-chain interactive upgrading" model[26]. In terms of quantitative research, Gong Bingzheng (2015) based on the connotation of intelligent manufacturing, built an evaluation index system for the development of intelligent manufacturing enterprises around the three dimensions of ecological environment, development level and benefit, and gave a linear weighted comprehensive evaluation model[27]. Yu Xiuming et al. (2016) combined the connotation of intelligent manufacturing, the architecture of intelligent manufacturing system and the maturity theory, and proposed the overall maturity model and individual capability model of enterprise intelligent manufacturing from the three dimensions of manufacturing engineering, manufacturing support and intelligent upgrading[28]. The other is the research on the development countermeasures of intelligent manufacturing of a certain type of enterprise. For example, Gao Hua and Wang Xiaojie (2018), Chi Renyong et al. (2020), Yang Zhibo and Yang Lanqiao (2020) respectively discussed the transformation and development of Chinese small and medium-sized intelligent manufacturing enterprises[29][30]. Chen Xinhua (2016) analyzed the existing problems in promoting intelligent manufacturing in iron and steel enterprises, and combined with the experience of Shanghai Meishan Iron and Steel Corporation Ltd., gave some suggestions on promoting intelligent manufacturing in iron and steel enterprises[31]. Zhang Zhibin et al. (2019) discussed the construction of intelligent manufacturing innovation system of garment enterprises in combination with the development trend of the manufacturing industry such as digital workshop and personalized network customization[32].

3. Conclusion

At present, the research on intelligent manufacturing theory based on technology realization is still widely concerned by scholars all over the world. However, with the publication of Made in China 2025, the research on the development countermeasures of intelligent manufacturing has been more favored by Chinese scholars, see Table 1 for more details.

Table 1: Research literature classification of Chinese intelligent manufacturing development countermeasure

Research perspective			Research level		
			Country	Region	Enterprise
Research method	Qualitative research		Hu Hengfa (2014); Chang Tao et al. (2014); Xu min (2016); Yang Jigang (2016); Zuo Shiquan (2014); Lin Hanchuan, Tang Linjia (2015); YiTiehu (2020); Zhang Chaoni (2021)	Cui Xiaowen, Yang Fan (2015); Lu Yingxiao, Wang Hongjun (2015); Wang Yu (2015); Wang Rongjie, Chen Jiaguo (2016); Zhang Jianhong (2015); Wang Binhua, Chen Xiaonan and Wang Kun (2016); Ma Peng (2015)	Jin Jiangjun (2012); Guo Jin (2021); Chen Xinhua (2016); Zhang Zhibin et al. (2019); Chi Renyong et al. (2020); Yang Zhibo, Yang Lanqiao (2020); Qiu Ying et al. (2021)
	Combination of quantitative and qualitative research	Based on statistical data analysis	Wang Desheng, (2015); Wang Ying, Leng Dan (2015); Zhu Sendi (2015)	Chen Yong et al. (2015)	——

		Based on comprehensive evaluation and analysis	Li Jianxuan (2020)	Dong Zhixue, Liu Yingji (2016)	Gong Bingzheng (2015); Yu Xiuming et al. (2016); Gao Hua, Wang Xiaojie (2018); Du Jinsong et al. (2021)
Source: according to the literature in the table					

(1) Taking countries, provinces and cities as research objects, qualitative countermeasures around PEST, SWOT and other environmental analysis frameworks are mostly studied, which provides reference for related research. However, due to the limitations of inherent thinking modes such as analytical framework and use mode, the factors considered are usually similar, which leads to the fact that some countermeasures and suggestions are similar in different regions, which affect the pertinence of countermeasures.

(2) The combination of quantitative analysis and qualitative analysis provides a guarantee for the scientific formulation of countermeasures. However, there are few researches at present, and quantitative analysis based on statistical data is only on the surface of numerical value, which lacks the deep mining of intrinsic value of data. In the aspect of comprehensive evaluation, scholars have carried out researches at different levels with the help of mature evaluation techniques such as analytic hierarchy process, ideal point, entropy weight, factor analysis, fuzzy evaluation and linear weighting, which provide reference for the analysis of intelligent manufacturing countermeasures based on comprehensive evaluation. However, most of the evaluations only involve the overall level of manufacturing industry, and some of the evaluation index systems of intelligent manufacturing capability are relatively simple. The evaluation method does not consider the individual differences and personality characteristics of the evaluated objects. For example, industrial structure, resource endowment, government work orientation and other differences.

To sum up, this paper believes that the development countermeasures of intelligent manufacturing are inseparable from the analysis of the development status of intelligent manufacturing. From the perspective of management science, we can start with the evaluation of intelligent manufacturing level, and then put forward the corresponding development countermeasures based on the systematic and comprehensive evaluation results. In addition, different provinces and cities have different characteristics and advantages. It is impossible to follow the same pattern in the development of intelligent manufacturing. There should be different modes and local characteristics. The future research should pay attention to the formation, identification and evaluation of the individual advantages among different evaluated objects, construct the corresponding management theory and evaluation method to identify and cultivate the objects' unique style, and promote the diversified development of different intelligent manufacturing objects.

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