Research on Evaluation of Digital Capabilities of Intelligent Manufacturing Enterprises

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Abstract. The rapid development of the digital economy is profoundly influencing the transformation of enterprises. Digital capability is the core competitiveness of intelligent manufacturing enterprises in the new era and plays an important role in the implementation of digital transformation of enterprises. Based on the intelligent characteristics and life cycle, this paper uses the grounded theory to construct a digital capability evaluation index system for intelligent manufacturing enterprises, and uses SPSS25.0 and AMOS25.0 for factor analysis and validation. The results show that the digital capability of manufacturing enterprises consists of five dimensions: digital infrastructure capability, digital perception capability, digital analysis capability, digital operation capability and digital security capability. The research results enrich the theory of digital capability and provide a theoretical basis for accelerating the digital transformation of intelligent manufacturing enterprises.

Keywords: Intelligent manufacturing · Digital capability · Grounded theory

1 Introduction

At present, the digital economy supported by the Internet of Things, cloud computing and information technology is flourishing, leading innovation and creation in all industries and driving digital transformation in enterprises. Digitisation of manufacturing enterprises has gradually become a research hotspot in academia, and the digital transformation spawned by digital technology has attracted widespread attention from the business and academic sectors [1]. All countries have placed the enhancement of digital technology in an important position in the new economic competition, but most manufacturing enterprises still have the problems of generally weak digital resource utilisation and weak digital technology application. Smart manufacturing enterprises, as the main direction of manufacturing development, have advanced smart manufacturing equipment and technology processes, advanced knowledge patents and highly qualified technical personnel, but just having resources is not enough to create value; they must also have the ability to effectively accumulate, integrate and develop resources in order to create value based on their capabilities, which are digital capabilities. Therefore, enhancing digital capabilities has become a new requirement for the development of smart manufacturing companies in the digital economy. Based on this, exploring

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the evaluation index system of digital capability of smart manufacturing enterprises is of urgent and significant practical significance for smart manufacturing enterprises to evaluate their own digital capability and accelerate their digital transformation.

2 Literature Review

Digitisation requires companies to focus on value creation, reallocate resources and design systems of competence based on systems. This means that companies need to build digital capabilities that can overcome challenges and create value [2] using digital technologies to achieve effective improvements in productivity and manufacturing [3] and maintain a competitive advantage.

Research on the concept and connotation of digital capability contains three different perspectives: from the technological perspective, digital capability refers to the integration of new-generation information technology with IT and OT, which can enable the implementation of an enterprise's digital capability strategy, lead to business model innovation [4], redefine people, objects, fields and processes [5] and improve inter-enterprise transparency [6]. From an industry perspective, digital capabilities have different effects in different industries. In the Internet industry, "platforms" are replacing "old world companies" [7], and digital capabilities are more dependent on stakeholder interaction, enabling digitalisation and the integration of procurement, production and marketing [8]. In the retail industry, digital capabilities are changing the traditional retail geography, accumulating quality consumer information through digital facilities, gaining consumer insights and improving competitiveness through demand management. From a management perspective, digital capabilities can help companies optimise their knowledge management practices [9] and enhance their innovation capabilities. Based on dynamic capability theory, this study defines digital capability as the multidimensional ability of an enterprise to acquire, allocate, integrate and reconfigure resources using digital and intelligent technologies, thus providing a technological driver for transformation and a foundation for operational efficiency.

In terms of dimensional research, Warner [10] constructed a dynamic capability model for digital transformation, including digital sensing, acquisition and transformation capabilities; Lenka S [11], through a study of Internet companies, argued that digital capabilities can be divided into digital intelligence, connectivity and analytics; Ritter and Pedersen [8] argued that digitalisation has the characteristics of high efficiency and low cost divided digital capabilities into three dimensions: data acquisition, licensing and analysis. Due to different research perspectives and focuses, many studies intersect in the division of dimensions of digital capabilities. At the same time, smart manufacturing enterprises have different digital capability characteristics from other enterprises. Existing studies fail to accurately portray the development and application focus of digital capabilities of smart manufacturing enterprises, and the dimensional research needs to be improved.

Table 1. Personal information of the interviewee

Survey Enterprise	Interview object	Interview duration	Years of Work
1	Middle manager	55 min	9
	Software development engineer	110 min	4
	Baseband development engineer	60 min	5
	Strategic management specialist	120 min	8
2	Software development engineer2	55 min	6
	Data management engineer	70 min	5
	Radio frequency technical engineer	65 min	5
3	HR Director	110 min	9
	Front-end engineer	60 min	4
4	Top management	70 min	15
	Top management2	70 min	10
	Inspection engineer	110 min	7

3 Research Methods and Data Sources

This paper uses a qualitative research methodology 'grounded theory' approach to continuously sample and code the data through 'continuous comparison' and 'theoretical sampling', and through continuous revision to form the final framework.

The primary source of information comes from interviews with experts and practitioners from four typical manufacturing companies, who have at least five years' experience in smart manufacturing companies or are well-known in the industry. In order to ensure the depth of the interview content, 4–6 interviewees were interviewed each week, and the interviews were conducted from August 2022 to September 2022. The interviews were recorded with the consent of the interviewees for follow-up purposes. The information on the specific interviewees is shown in Table 1.

The secondary data came from the official websites of some of the companies in the 2022 ranking of the top 50 smart manufacturing companies in China jointly published by the Internet Weekly of the Chinese Academy of Sciences and e-Net Research Institute, and a total of 86,160 words were selected from company cases, executive statements and news reports.

4 Implementation of Grounded Research

4.1 Open Coding

The spoken interview data of the nine interviewees were transformed into written expressions and coded sentence by sentence with the secondary data. After continuous fungal integration and correction, a total of 83 initial codes were obtained, see Table 2, and then processed to obtain 17 sub-categories, see Table 3.

Table 2. Examples of initial concept summary and refining process

Original material	Initial concept
The development of digital technology and the expansion of its application scenarios have brought new opportunities and challenges for the digital transformation of manufacturing companies	Digital technology
Computing infrastructure is represented by data centers and intelligent computing centers	Computing infrastructure
Intelligent manufacturing process is complex, enterprises need to face how to integrate product data and use data analysis to optimize decisions	Data processing
The use of digital means, do not engage in marketing stunts, users really participate in the creation of content, product, design, to achieve brand benefit sharing	User Co-create
Using laser technology to burn a QR code into the glass production process, consumers can scan the code to check the authenticity of the product	Production information tracking
…	…
Development of automated defence tools to protect data security on industrial internet platforms and to perform security risk detection	Automated defence tools
total	83 initial concepts

Table 3. Concept and category of open coding

subcategory	Initial concept
Key technology foundation	Digital technology, IoT technology, AR/VR technology, Industrial robotics, Additive manufacturing technology
Key digital equipment	Advanced production equipment, Communication network facilities, computing infrastructure, industrial internet platform, Intelligent equipment, Cloud Platform
Data acquisition	Network data acquisition, Device data acquisition, System data acquisition
Market environment identification	Identifying competitor threats, Sensing surprises, Recognising directions of change, Identifying industrial policies

(*continued*)

Table 3. (*continued*)

subcategory	Initial concept
Useful data identification	Commercially valuable data identification, Complete Data Extraction, Emotion recognition, Data filtering, Data mining, Enterprise level judgement
Basic data analysis	Use of analytical tools, Data processing, Application of algorithms, Simulation, Data mining
Results responsiveness	Data Integration, Information Interaction Standards, Data visualization, Data sharing
Intelligent decision making	System automatic decision-making, intelligent forecasting, value sustainable optimization
Digital research and development	R&D Platform, Digital Experience, R&D requirements analysis, R&D digital management, Process database, Digitisation of process management, User co-creation
Digital procurement	Social procurement networks, Automated Purchase Request, Automated ordering, Digital supplier risk assessment, Digital supplier management, Digital sourcing, Supplier collaboration, Automated sourcing
Digital production	Production site automation, Automatic command execution, Production process visualization, Production information collection, Production information tracking, Product fault indication
Digital marketing	Customer relationship digitalization, Sales process digitalization, Online and offline full scene marketing, Customer immersion experience
Digital logistics	Logistics network visibility, Intelligent distribution, Intelligent logistics parks, Route planning, Security detection
Digital human resource management	Learning Platform, Improving the Candidate Experience, Smart Recruitment, Intelligent Performance Assessment
Organizational Building Security	Security Governance Strategy, Security Management, Data security training, Capability security, security standards
Data lifecycle security	Key Point Security Controls, Data collection security, Security of data use, Security assessment
Technical equipment safety	Data Security Technology, Data leakage prevention, Audit platform creation, Interface security management, Automated defence tools

Table 4. Main category and connotation explanation of spindle coding formation

Principal category	subcategory
Digital Infrastructure Capabilities	Key technology foundation
	Key digital equipment
	Data acquisition
Digital Perception Capabilities	Market environment identification
	Useful data identification
Digital Analytics Capabilities	Basic data analysis
	Results responsiveness
	Intelligent decision making
Digital Operations Capabilities	Digital research and development
	Digital procurement
	Digital production
	Digital marketing
	Digital logistics
	Digital human resource management
Digital Security Capabilities	Organizational construction security
	Data lifecycle security
	Technical equipment safety

4.2 Axial Coding

According to the requirements of axial coding, this paper further classifies the subcategories generated by the above open coding into more advanced categories based on logical relations, and finally establishes 5 main categories, as shown in Table 4.

4.3 Selective Coding

Through the analysis and discussion of all the categories, the story line between the main categories is linked: with the digital infrastructure as a prerequisite, the company perceives the internal and external environment and useful data, and uses analytical models and algorithms to further process and present the data. At the same time, digital technology is used to reshape production, marketing and logistics, enabling companies to digitise all aspects of their business. Security capabilities are used throughout to guarantee the safety of all activities carried out by the company.

4.4 Theoretical Saturation Test

In this study, the theoretical saturation test was conducted using the prior data left behind, and it was found that the scope of the digital capability of smart manufacturing enterprises was largely complete. Therefore, it can be considered that the digital capability structure dimension of smart manufacturing enterprises constructed in this study has reached theoretical saturation.

5 Research Design and Data Analysis

5.1 Research Design

The questionnaire for this study was designed with reference to the items measured in the relevant studies by Verhoef, Ritter, Li, Mikalef, Kohtamaki, Lyytinen, Kim, Rehman [2, 6, 8, 12–15] scholars, and the questionnaire was initially designed according to expert recommendations, using a five-point Likert scale. In order to ensure the quality of the scale, a small preliminary study was conducted and 102 valid questionnaires were returned. The alpha coefficient and CITC coefficient were used to purify the items. One item in the digital operation competency had a CITC value less than 0.5, and after deleting this item the reliability of the digital operation competency increased from 0.886 to 0.9, and the number of items in the digital competency decreased from 19 to 18. Then, according to the research experience, the relevant intelligent manufacturing enterprises were selected to issue formal questionnaires. A total of 350 questionnaires were distributed, 311 of which were valid.

5.2 Validity Test

The alpha coefficient of the scale is 0.936, and the alpha coefficients of the five dimensions of digital infrastructure capability, digital perception capability, digital analysis capability, digital operation capability and digital security defense capability were 0.882, 0.876, 0.804, 0.915 and 0.817, respectively, indicating that the scale was stable and reliable.

The AVE method was used to assess the discriminant validity and is shown in Table 5. The AVE open root values of the specific latent variables were all greater than the correlation coefficients of the other latent variables and the model had good discriminant validity.

Table 5. Results of discriminant validity test

	1	2	3	4	5
1	0.847				
2	0.526**	0.845			
3	0.541**	0.521**	0.760		
4	0.594**	0.600**	0.595**	0.802	
5	0.477**	0.471**	0.474**	0.497**	0.780

5.3 Exploratory Factor Analysis

Exploratory factor analysis was conducted using SPSS 25.0. The results showed a KMO = 0.934, which is greater than 0.7, indicating that Bartlett's spherical test value is significant (SIG. < 0.001), and the questionnaire data meets the premise requirements of factor analysis. Using principal component analysis, the common factors were extracted with eigenroots greater than 1 and rotated using the maximum variance method, and the results are shown in Table 6, with a total explanatory power of 75.225% and good representation of the five factors, and each question item had a factor loading of >0.5 and a cross-load of <0.4, with each question item falling into the corresponding factor.

Table 6. Results of factor analysis

	component				
	1	2	3	4	5
DC41	0.8				
DC42	0.781				
DC43	0.75				
DC44	0.747				
DC45	0.738				
DC46	0.704				
DC11		0.816			
DC12		0.801			
DC13		0.784			
DC21			0.834		
DC22			0.795		
DC23			0.748		
DC51				0.828	
DC52				0.782	
DC53				0.766	
DC31					0.823
DC32					0.712
DC33					0.71
characteristic value	4.152	2.466	2.387	2.325	2.209
Cumulative variance interpretation	23.068	36.767	50.031	62.95	75.225

Table 7. Model fitting results

index	Recommended value	model
CMIN	——	147.261
DF	——	125
CMIN/DF	<3	1.178
RMR	<0.08	0.042
GFI	>0.9	0.951
AGFI	>0.9	0.933
NFI	>0.9	0.959
IFI	>0.9	0.994
TLI	>0.9	0.992
CFI	>0.9	0.993
RMSEA	<0.08	0.024

5.4 Confirmatory Factor Analysis

Confirmatory factor analysis was performed using AMOS25.0. In Table 7, CMIN/DF is 1.178, less than the standard below 3, and all model fitting indexes, such as GFI, AGFI, RMR and RMSEA, meet the research criteria, indicating that the model has a high suitability. The confirmatory factor analysis model is shown in Fig. 1. The path coefficients of all latent variables are equal to <0.5, indicating that the items contained in the scale can well measure latent variables.

5.5 Application Model Construction

The digital capability evaluation system includes 5 dimensions and 17 secondary indexes, as shown in Fig. 2.

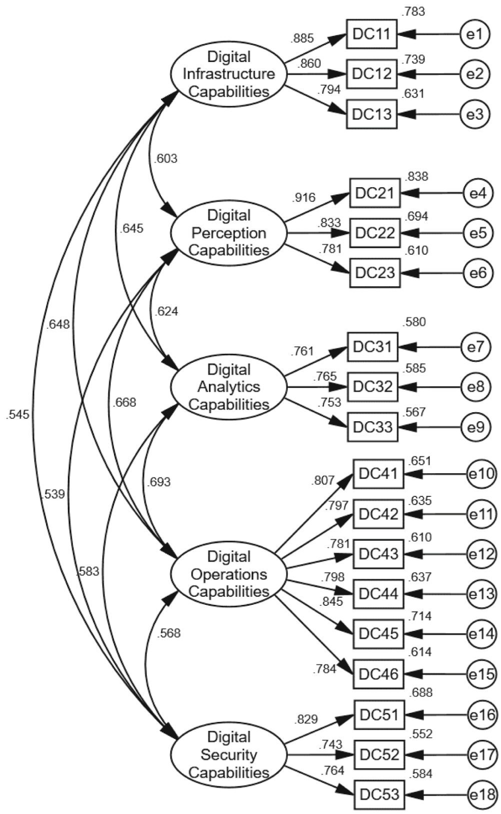

Fig. 1. Verification factor analysis model of digital capability of intelligent manufacturing enterprises

6 Research Conclusions and Implications

This paper is based on rooting theory and designs a digital capability measurement index system for smart manufacturing enterprises in five aspects: digital infrastructure capability, digital perception capability, digital analysis capability, digital operation capability and digital security defence capability. The results show that the digital capability index system constructed in this paper is reasonable and reliable, and the official scale with 18 items is finally determined. The design of this measurement index system has certain theoretical and practical value. On the one hand, it enriches the theoretical research on the digital capability index system of intelligent manufacturing enterprises, and the formal scale determined provides a reliable measurement tool for the subsequent relevant empirical research. On the other hand, it provides a scientific basis for the development of digital capabilities in smart manufacturing enterprises. Smart manufacturing enterprises should strengthen their awareness of digital applications, consider digital strategic

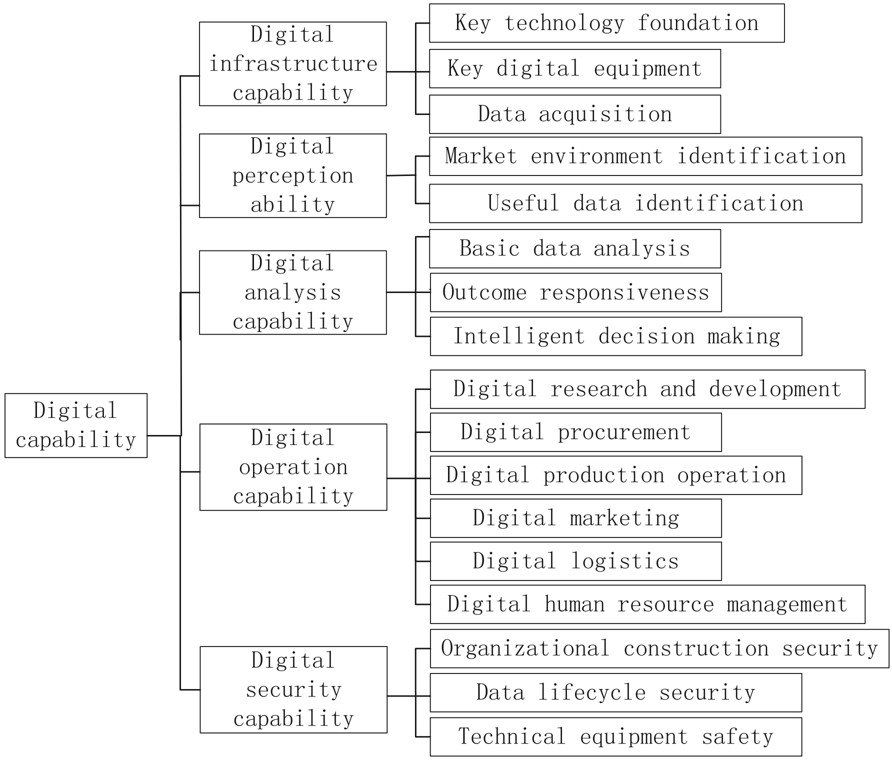

Fig. 2. Index system of digital capability measurement of intelligent manufacturing enterprises

transformation comprehensively, focus on digital capability building, vigorously introduce advanced digital technologies and facilities, enhance digital sensing and digital analysis capabilities that drive the digital transformation of enterprises, strengthen the organic and flexible integration of digitalisation with R&D, production and marketing, and strengthen the value utilisation of data resources, a process that will be related to the business model of enterprises This process will involve changes in the business model, competitive tools and management plans of enterprises.

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References

1. Ng, I. C., & Wakenshaw, S. Y. (2017). The Internet-of-Things: Review and research directions. International Journal of Research in Marketing, 34(1), 3-21. https://doi.org/https://doi.org/10.1016/j.ijresmar.2016.11.003

2. Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Dong, J. Q., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. Journal of business research, 122, 889-901. https://doi.org/https://doi.org/10.1016/j.jbusres.2019.09.022
3. Ceipek, R., Hautz, J., Petruzzelli, A. M., De Massis, A., & Matzler, K. (2021). A motivation and ability perspective on engagement in emerging digital technologies: The case of Internet of Things solutions. Long Range Planning, 54(5), 101991. https://doi.org/https://doi.org/10.1016/j.lrp.2020.101991
4. Trabucco, M., & De Giovanni, P. (2021). Achieving resilience and business sustainability during COVID-19: The role of lean supply chain practices and digitalization. Sustainability, 13(22), 12369. https://doi.org/https://doi.org/10.3390/su132212369
5. Vial, G. (2021). Understanding digital transformation: A review and a research agenda. Managing Digital Transformation, 13-66.https://doi.org/10.1016/j.jsis.2019.01.003
6. Lyytinen, K., Yoo, Y., & Boland Jr, R. J. (2016). Digital product innovation within four classes of innovation networks. Information Systems Journal, 26(1), 47-75. https://doi.org/https://doi.org/10.1111/isj.12093
7. Mark Fenwick, Joseph A. McCahery, & Erik P. M. Vermeulen (2019). The End of 'Corporate' Governance: Hello 'Platform' Governance European Business Organization Law Review. https://doi.org/10.1007/s40804-019-00137-z
8. Ritter, T., & Pedersen, C. L. (2020). Digitization capability and the digitalization of business models in business-to-business firms: Past, present, and future. Industrial Marketing Management, 86, 180-190. https://doi.org/https://doi.org/10.1016/j.indmarman.2019.11.019
9. Abbate, T., Codini, A., Aquilani, B., & Vrontis, D. (2021). From knowledge ecosystems to capabilities ecosystems: When open innovation digital platforms lead to value co-creation. Journal of the Knowledge Economy, 1-15.https://doi.org/10.1007/s13132-021-00720-1
10. Warner, K. S., & Wäger, M. (2019). Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. Long range planning, 52(3), 326-349. https://doi.org/https://doi.org/10.1016/j.lrp.2018.12.001
11. Lenka, S., Parida, V., & Wincent, J. (2017). Digitalization capabilities as enablers of value co-creation in servitizing firms. Psychology & marketing, 34(1), 92-100. https://doi.org/https://doi.org/10.1002/mar.20975
12. Li, H., Wu, Y., Cao, D., & Wang, Y. (2021). Organizational mindfulness towards digital transformation as a prerequisite of information processing capability to achieve market agility. Journal of Business research, 122, 700-712. https://doi.org/https://doi.org/10.1016/j.jbusres.2019.10.036
13. Mikalef, P., & Gupta, M. (2021). Artificial intelligence capability: Conceptualization, measurement calibration, and empirical study on its impact on organizational creativity and firm performance. Information & Management, 58(3), 103434. https://doi.org/https://doi.org/10.1016/j.im.2021.103434
14. Kohtamäki, M., Parida, V., Patel, P. C., & Gebauer, H. (2020). The relationship between digitalization and servitization: The role of servitization in capturing the financial potential of digitalization. Technological Forecasting and Social Change, 151, 119804. https://doi.org/https://doi.org/10.1016/j.techfore.2019.119804
15. Kim, G., Shin, B., Kim, K. K., & Lee, H. G. (2011). IT capabilities, process-oriented dynamic capabilities, and firm financial performance. Journal of the association for information systems, 12(7), 1. https://doi.org/10.17705/1jais.00270