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Research article

Affording digital transformation: The role of industrial Internet platform in traditional manufacturing enterprises digital transformation

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ABSTRACT

This study aims to investigate the role of industrial Internet platform in facilitating the digital transformation of traditional manufacturing enterprises. While prior research has predominantly focused on industrial Internet platform enterprises, there is a noticeable dearth of research concerning traditional manufacturing enterprises lacking the resources to establish such platforms. To address this research gap, we conduct an exploratory case study and propose an affordances upgrade model that elucidates the digital business transformation process of these manufacturing enterprises leveraging industrial Internet platforms. The research findings can be summarized from two key perspectives. Firstly, the industrial Internet platform offers valuable technical support and potential opportunities for manufacturing enterprises to achieve digital business transformation through three distinct affordances: consonance, resonance, and adaptation. These affordances enable enterprises to align their operations with the capabilities and possibilities provided by the platform, thus facilitating their digital transformation. Secondly, to effectively harness these affordances, enterprises must strategically leverage the platform's technical services and systems in their production and operational practices. Through the accumulation of practical experiences, enterprises gradually transition their production modes from experience institutionalization and standardization to a state of refinement. The dynamic leapfrogging process of digital transformation in traditional manufacturing enterprises, facilitated by the industrial Internet platform, is reflected in the realization of these three affordances and their underlying resource capabilities. This research significantly contributes to the field by expanding the scope of inquiry to encompass traditional manufacturing enterprises and presenting a stage model for their digital transformation utilizing industrial Internet platform.

1. Introduction

The digital transformation of traditional manufacturing enterprises has become a critical imperative in today's rapidly evolving business landscape [1]. To facilitate this transformation, the industrial Internet platform emerges as a crucial enabler, offering a comprehensive digital ecosystem that integrates advanced technologies such as cloud computing, big data analytics, Internet of

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Things (IoT), artificial intelligence (AI), and blockchain [2]. By harnessing the capabilities of this platform, enterprises can embark on a holistic journey of digitalization [3]. Within this transformative expedition, Business Process Digitalization (BPD) emerges as an indispensable and pivotal component, shaping the trajectory and outcomes of the overall digitalization process [4]. BPD represents a strategic approach to streamline and optimize business operations by digitizing manual and paper-based processes, replacing them with efficient digital workflows [5]. By integrating cutting-edge technologies, the Industrial Internet platform enables seamless data flow across different processes, departments, and systems, eliminating information silos and enabling end-to-end visibility and control. Furthermore, the platform's ability to collect and analyze real-time data enables enterprises to gain valuable insights into their processes, customer preferences, and market trends, allowing for informed decision-making and the ability to quickly adapt to changing market conditions [6]. These insights empower organizations to identify bottlenecks, optimize workflows, and make data-driven decisions for process improvement.

The industrial Internet platform has garnered global attention for its ability to drive digital business transformation in various industries. In the context of China's manufacturing industry, which currently occupies a middle and low-end position in the global production system in terms of manufacturing value [7], the platform becomes even more crucial. China's traditional manufacturing sector, known for its scale and complexity, faces the challenge of adapting to the digital era [8]. The rapid advancement of technology, evolving consumer demands, and intensifying global competition necessitate a profound shift towards digital transformation. In this dynamic landscape, the industrial Internet platform emerges as a crucial enabler for Chinese traditional manufacturing enterprises. Recognizing its transformative potential, the government has strategically prioritized its integration into national development plans [9]. Initiatives such as "Made in China 2025" and "Internet Plus" highlight the importance of upgrading the manufacturing sector through the infusion of advanced technologies, fostering innovation, and enhancing productivity [10]. With the support of government policies and the increasing demand for digital transformation, the industrial Internet platform has experienced rapid development in China.

Given its practical significance and increasing relevance, the industrial Internet platform has gained considerable attention and has become a subject of significant academic research. Scholars have undertaken extensive investigations to understand the implications and potential of the platform in facilitating digital transformation across industries [11]. One aspect of research has focused on the adoption and implementation of the industrial Internet platform in manufacturing enterprises [12]. Researchers have explored factors influencing successful adoption, such as organizational readiness, technological infrastructure, and change management processes. Additionally, they have examined the outcomes and impacts of platform adoption, including improvements in productivity, cost reduction, and enhanced customer experience [13]. Another area of research has centered around the role of the industrial Internet platform in enabling data-driven decision-making and advanced analytics [14]. Scholars have explored how the platform facilitates the collection, analysis, and utilization of big data generated from connected devices, sensors, and production systems [15]. They have investigated the application of artificial intelligence and machine learning algorithms to extract valuable insights from these data streams, enabling proactive maintenance, predictive analytics, and optimized resource allocation [16]. Furthermore, research has delved into the collaborative nature of the industrial Internet platform and its impact on supply chain management. They have also investigated the potential for platform-enabled collaboration and information sharing to drive efficiency gains, reduce lead times, and mitigate risks in the supply chain [17].

Overall, the existing research has provided valuable insights into the digital transformation facilitated by the industrial Internet platform [18]. However, it is essential to note that the majority of studies have predominantly concentrated on platform owners [19], neglecting the traditional manufacturing enterprises that lack the requisite resources, expertise, and capabilities to independently establish and deploy their own industrial Internet platforms. This research gap is particularly significant considering the vital role that traditional manufacturing enterprises play in the national economy, particularly in countries like China. These traditional manufacturing enterprises have played a pivotal role in driving the country's economic growth, serving as the backbone of industrial production and contributing to employment, economic expansion, and technological advancement [10]. Their ability to adapt and embrace digital transformation is crucial for enhancing competitiveness, productivity, and innovation within the manufacturing sector. The significance of these enterprises extends beyond their individual operations, as they often form extensive supply chains that support various industries and sectors [7]. Therefore, comprehending the challenges faced by these enterprises in adopting the industrial Internet platform becomes imperative for devising effective policies, strategies, and support mechanisms to facilitate their digital transformation. Such initiatives can empower these enterprises to optimize their operations, leverage data-driven insights, and foster collaboration across the manufacturing value chain.

Based on the aforementioned theoretical and practical background, this paper conducts an in-depth case study to explore how industrial Internet platforms support traditional manufacturing enterprises in implementing digital transformation. Drawing on the theory of IT affordance [20], which emphasizes the relationship between technology, its functions, and the user's intention to use it, this study provides a new perspective for explaining the relationship between industrial Internet platforms and the digital transformation of traditional manufacturing enterprises. In contrast to previous studies that primarily focused on platform enterprises [21], our research extends the investigation to encompass traditional manufacturing enterprises that lack the resources to establish their own platforms. By bridging this research gap, our study enriches the understanding of the digital transformation processes and challenges faced by a broader spectrum of organizations in the manufacturing sector. Furthermore, by analyzing the specific affordances of consonance, resonance, and adaptation, we elucidate the mechanisms through which traditional manufacturing enterprises align their operations with the capabilities and possibilities provided by the platform. This analysis contributes to the theoretical framework surrounding digital transformation, offering a more comprehensive understanding of the interplay between industrial Internet platforms and traditional manufacturing enterprises.

The structure of the article is as follows: Section 2 introduces the theoretical foundation, Section 3 describes the research design of the case study, Section 4 analyzes the case studies and presents the research findings, Section 5 is a case discussion, and finally, the conclusion summarizes the key findings and provides insights for future research.

2. Literature review

2.1. Business process digitalization and industrial Internet platform

The rapid development of digital technologies, including the Internet of things, cloud computing, and big data, has made it imperative for manufacturing enterprises to undergo digital transformation in order to achieve high-quality development [22]. However, research by Parviainen et al. [23] reveals that a significant percentage (60% to 85%) of enterprises undergoing digital transformation face the digital paradox and struggle to reap the benefits of their digital initiatives. On one hand, manufacturing enterprises have developed a business model focused on traditional manufacturing practices, driven by industrial logic. This results in a "path dependence" phenomenon, making it challenging to adapt to emerging digital technologies [24]. On the other hand, digital transformation often involves the adoption of technologies such as artificial intelligence, cloud computing, and the Internet of Things, which require substantial investments and can lead to increased costs [25]. In reality, achieving effective digital transformation requires more than just the adoption of digital technologies. It necessitates the transformation of business processes and the development of organizational capabilities [26]. Process digitization plays a crucial role in enabling the digitalization of production, management, and sales by integrating digital technologies.

Business process digitalization (BPD) involves strategically integrating digital technologies and internet-based systems into an organization's activities and processes [27]. Its objective is to convert traditional processes into digital ones, facilitating efficient information flow, communication, and transactions both internally and externally [28]. By enhancing productivity, streamlining workflows, improving decision-making, and creating new value creation opportunities, BPD enables organizations to gain a competitive advantage in the digital era [29]. Existing research shows that process digitization is primarily integrated with product design, supply chain management, and marketing within the enterprise [30]. Process digitalization in product design enables enterprises to gather comprehensive user profiles by leveraging machine learning to analyze user interactions on social media [31]. This data-driven approach facilitates the development of new products that effectively cater to the diverse needs of customers. Process digitalization in supply chain management enables real-time data capture and transmission through sensors and wireless technology, facilitating a transition to a decentralized intelligent network and improving inventory management and production efficiency [32]. Process digitalization in marketing offers inherent advantages in electronic channel promotion, enabling enterprises to easily introduce new products and services through reconfiguration and generativity provided by digital processes [33].

Existing research recognizes the importance of business process digital transformation (BPD) in gaining a competitive advantage, but there are still limitations and research gaps that need attention. One notable area that requires further attention is the exploration of digital production transformation modes within the context of BPD [34]. Digital production transformation modes encompass various strategies and approaches to optimize manufacturing processes using digital technologies, such as robotics, automation, AI, analytics, and IoT [35]. These technologies enhance productivity, quality, supply chain management, and operational efficiency. However, existing research lacks comprehensive insights into challenges, opportunities, and best practices for digital production transformation within BPD [36,37]. Thorough analysis and empirical studies are needed to understand the interplay between digital technologies and manufacturing processes, enabling organizations to develop tailored strategies and roadmaps for successful digital transformation initiatives [38].

Industrial Internet platforms have emerged as crucial enablers, leveraging industrial big data and integrating IT, OT, and CT to drive substantial transformations [16]. By seamlessly connecting IT systems and OT equipment, these platforms facilitate efficient collaboration with external industrial chains through the utilization of industrial big data. They also offer integrated solutions tailored to meet the specific needs of user enterprises [39]. This adoption effectively integrates digital technologies into manufacturing production processes, enabling organizations to leverage data-driven insights, optimize operations, and foster collaboration across the value chain [40]. With end-to-end visibility, streamlined workflows, and a unified digital ecosystem, these platforms enhance connectivity, optimize processes, and unlock new opportunities for innovation and growth [41]. Embracing industrial Internet platforms empowers organizations to harness the power of data, drive operational efficiency, and bring about transformative changes throughout their operations [42].

Previous research on industrial Internet platforms has primarily focused on platform construction and operational modes, often neglecting their transformative impact on the digitalization of production processes in traditional manufacturing enterprises [43–45]. However, these enterprises, integral components of the real economy, require digital transformation to enhance production efficiency. Limited resources and capabilities may pose challenges to their effective digitalization. Industrial Internet platforms can play a pivotal role in facilitating the digital transformation of production processes in traditional manufacturing enterprises [7]. By leveraging these platforms, enterprises gain access to cutting-edge technologies, advanced data analytics, and seamless connectivity, enabling comprehensive digitization and optimization of production processes. This transformation enhances operational efficiency, productivity, and competitiveness, allowing enterprises to adapt to the dynamic business landscape and meet the evolving demands of the digital era.

In summary, industrial Internet platforms offer a compelling solution to the challenges faced by manufacturing enterprises during their digital transformation. These platforms facilitate the seamless integration of digital technologies, data analytics, and connectivity, empowering organizations to enhance productivity, streamline workflows, improve decision-making, and create new value.

Recognizing the significant benefits of industrial Internet platforms in driving digitalization in traditional manufacturing is crucial for unlocking a multitude of opportunities for sustainable growth. Understanding the affordances provided by these platforms is essential, as they offer a wide range of capabilities to support and enhance digital transformation efforts. This research aims to bridge the gap between theoretical understanding and practical application, facilitating the seamless and effective integration of industrial Internet platforms into manufacturing enterprises' strategies, thereby enabling a smoother and more successful digital transformation process.

2.2. IT affordance

Affordance was first proposed by Gibson [46] to explain animals' perception of the environment, specifically, the possibilities for action that animals perceive in the objective environment. Since then, this concept has gradually been applied to the field of management information systems, referring to the potential actions that information technology provides for actors to achieve specific goals, including simple behaviors such as inputting data and complex behaviors such as strategic decision-making [47]. Affordance, as potential behavior, requires actors to take relevant practical activities based on expected goals to actualize the potential [48]. In the field of management information systems, the concept of technological affordances refers to the potential actions that technological tools provided for actors to help them achieve expected goals [49]. Since then, technological affordances have gradually been applied to various research topics in the information system field, from adoption and use to analyzing the impact of technological tools on organizational behavior, structure, and change, providing a new perspective for explaining how actors can effectively utilize technological tools to realize expected goals [50].

The concept of technological affordances plays a crucial role as a theoretical framework, assisting scholars in developing theories related to the utilization of technological tools [51]. In the field of Information Systems (IS), important principles regarding technological affordances have been outlined [52]. Firstly, affordances arise from the interaction between humans and technological tools, rather than being inherent properties of the tools themselves. Technological tools do not possess inherent affordances; instead, affordances emerge when behavioral agents utilize the properties of tools to achieve specific goals. [53]. Secondly, a distinction is made between technological affordances and their actualization as separate concepts. Affordances represent the potential to achieve goals and are possibilities for realization relative to those goals. Actualizing affordances requires behavioral agents to possess certain capabilities and engage in practical actions [54]. Furthermore, it is important to delineate different affordances and understand their interrelationships. Technological tools have multiple functional attributes and provide various affordances to behavioral agents. These affordances are not independent but interact and influence each other to ultimately achieve the desired behavioral goals [55]. Lastly, the realization of affordances is influenced by social environmental factors [56]. The context in which affordances are realized, including organizational culture, regulations, and relationships between behavioral agents, impacts the relationships between affordances, the behaviors that actualize them, and the outcomes achieved.

In summary, the principles of technological affordances in the field of Information Systems (IS) offer valuable insights into the dynamic interaction between actors and technological tools [53]. These principles also address the distinction between affordances and their actualization, the interplay among different affordances, and the influence of social environmental factors on their realization. These principles serve as a solid theoretical foundation for manufacturing enterprises aiming to achieve digital transformation through industrial Internet platforms. This study applies these principles to analyze the utilization of an established industrial Internet platform by representative manufacturing enterprises, focusing on their objectives, specific technological tools, and actions taken. By doing so, the study seeks to explore the dynamic relationship between industrial Internet platforms and the digital transformation of traditional manufacturing.

3. Research design

3.1. Research method

The case study method is a fundamental research approach in management studies that allows for an in-depth examination of specific events within a real-world context [57]. Unlike other research methods, the primary objective of case study research is not theory validation, but theory construction, emphasizing comprehensive understanding and detailed descriptions of the case at hand. This makes it particularly suitable for investigating "how" and "why" questions [58]. By adopting a single case study approach, this study aims to explore the intricate mechanisms through which the industrial Internet platform facilitates the digital transformation of manufacturing enterprises in their production processes. This method enables capturing and analyzing emerging phenomena, tracking changes over time, and providing a holistic perspective on the research questions posed [59]. Given the current development stage of the industrial internet platform and the lack of directly applicable theories, the single case study approach offers a valuable opportunity to generate new insights and contribute to the knowledge base in the field of digital transformation practices in Chinese companies.

To enhance the rigor of the case study, this research follows the three-step process of exploratory case study outlined by Gioia [58] to gradually extract and summarize a theoretical framework. The case study method is chosen for several reasons. Firstly, the research problem of this study primarily focuses on the "how" question, which necessitates the construction of the process by which the industrial Internet platform supports manufacturing enterprises in achieving digital transformation. This makes the case study approach more suitable. Secondly, this study explores a relatively new context of industrial Internet platforms that are still in their early stages of development, with limited existing research. Therefore, extensive case materials and data are required to provide robust support. The exploratory case study approach is considered more appropriate for developing new theories in such a context.

3.2. Sample selection

The main criteria for selecting cases in this study are as follows: manufacturing enterprises that have effectively utilized technical support from an industrial Internet platform that provides various products and services for their customers and manufacturing enterprises that have been established for a relatively long period of time, which can reflect the process of using such digital technology to support new business processes or supplement existing activities and processes.

Currently, ABC(pseudonym) serves about 4200 industrial enterprises in various industries such as airports, ports, tobacco, chemical, metallurgy, and manufacturing. Based on the principles of representativeness and theoretical sampling, this study selects the industrial enterprises on the platform of ABC as the research object for the following reasons. Founded in 1999, ABC is one of the earliest industrial software companies in China, providing equipment asset management software and comprehensive control services for industrial enterprises. With equipment management as the entry point, it helps large, medium, and small enterprises to achieve informatization. ABC utilizes its experience accumulated in industrial big data for many years and combines it with advanced Internet, Internet of Things, blockchain, cloud computing, big data, and equipment asset comprehensive control technology to build the CPC2025 industrial Internet platform. In 2017, ABC was selected as one of the first industrial Internet ecosystem suppliers in Guangdong Province. The platform has accumulated thousands of enterprises as platform users by providing related hardware and software products and integrated services for them to transform towards high quality development of enterprises' production processes. Therefore, it is well-aligned with the research questions of this study.

3.3. Introduction to case company

Based on primary and secondary data, and in accordance with the key events during the ABC's development process, as well as the comprehensive opinions of internal managers, the development history of the platform enterprise over the past twenty years can be divided into the following three stages.

In the first stage, from 1999 to 2008, ABC mainly focused on providing equipment management software and related services to small and medium-sized enterprise users. According to market demand, ABC independently developed the equipment management software EAM (Enterprise Asset Management System) based on the B/S architecture, and subsequently continued to deepen product development. Over time, ABC's equipment management software has undergone multiple functional upgrades and optimizations, resulting in increased functionality that covers procurement management, ledger management, technical standards management, and equipment operation and maintenance management, meeting the specialized needs of its users.

The period between 2009 and 2014 was the second stage of development, during which ABC provided comprehensive equipment asset control services to users of all sizes of enterprises. In 2009, ABC established the Asset Comprehensiveness Control and Management (ACCM) research institute and joint laboratory in collaboration with Xiamen University. Through this collaboration, ABC proposed a comprehensive service model for equipment asset control in the form of a project for users.

The third stage of development, from 2015 to the present, is based on the accumulation of industrial data, industrial knowledge, equipment management experience, and mechanism models. ABC started with equipment assets and built an industrial cloud platform, making manufacturing resources cloud-based. Through various services, ABC optimized the entire value chain by connecting industrial enterprises of different scales and promoting synergy between back-end and front-end units. This has facilitated collaboration between manufacturing enterprises and external stakeholders.

3.4. Data collection

Data collection officially began in September 2020, employing a combination of formal research interviews and informal research methods to form a triangulation of evidence. This approach aims to ensure the credibility and practical relevance of the research findings. Primary information is obtained through semi-structured and in-depth interviews, while second-hand information is obtained from materials on the company website, internal books and documents, media material and archives.

(1) Primary data. Primary data was mainly collected through in-depth interviews with executives and project leaders of the case company. The interviews covered the experiences and insights related to the establishment of an industrial Internet platform for empowering traditional manufacturing enterprises with digitization. The discussion topics included the journey of the case company, the process of platform establishment, and the development status of user enterprises. The average duration of each interview was about 2 hours, with about 5 – 8 researchers participating, including professors, associate professors, lecturers, doctoral students, and master students. One or two people asked the main questions, and the others supplemented the questions. The entire interview was recorded, and more than 3 people made detailed notes on the interview content. Within 2 days after the interview, all recordings were transcribed into documents. At the beginning of the interviews, the interviewers provided a brief introduction to the scope of the research and sought information about the organizational structure of the entrepreneurial team and its members within the company.

The in-depth interviews were conducted in three phases. In the first phase, open-ended interviews were conducted with the executive team to understand the process of platform establishment. Follow-up questions were used to delve deeper into how the case company empowered traditional manufacturing enterprises with digital transformation through the platform. Questions were designed in an exploratory manner, such as "How do you provide technological support for user enterprises' transformation?" or "How do traditional manufacturing enterprises adopt platform technologies?", to encourage the executive team to reflect deeply.

Table 1
Overview of interviews.

Stage	Interviewee	Time	Duration
First: contextual information	CIO	23-09-2020	75 min
	Project manager	8-11-2020	80 min
	CFO	19-12-2020	70 min
Second: potential affordance	Senior software manager	15-3-2021	65 min
	Production manager	27-4-2021	90 min
	Consulting manager	20-5-2021	95 min
	CEO	18-6-2021	80 min
	Marketing manager	25-9-2021	100 min
	Supply chain manager	27-10-2021	110 min
Third: affordance actualization	Project Manager	15-2-2022	75 min
	Production manager	10-3-2022	100 min
	CIO	20-4-2022	90 min
	CEO	18-5-2022	76 min
	Data scientist	28-6-2022	80 min
	Project manager	21-7-2022	105 min
	Production manager	10-9-2022	93 min
	Technology consultant	16-10-2022	86 min

Semi-structured interviews were conducted with project leaders in order to understand the specific operational processes of the projects.

In the second phase, semi-structured interviews were primarily conducted. The interviewees included the business management team, aiming to supplement the inquiries from the first phase. Additionally, some key customers or partners of the case company were interviewed to gain insights from a practical perspective regarding the adoption and utilization of platform technologies by user enterprises. This approach aimed to triangulate information from different sources.

The third phase continued with structured interviews. On one hand, it further supplemented the research data through additional inquiries. On the other hand, the coded data was verified with the case company to enhance the accuracy of the information. Table 1 illustrates the interviews conducted in this study.

(2) Secondary data. Firstly, the company's official website was used to understand the development history of the enterprise and the main products and services provided to manufacturing enterprise users. Secondly, the annual reports, internal publications, and external publicity materials were collected. Thirdly, information related to manufacturing enterprise users was collected through newspapers, news websites, and library retrieval platforms. In addition, the research team collected materials related to the platform's collaborations since 2020 and gathered information through field visits.

3.5. Data coding

Before conducting case analysis, we conducted a systematic review of existing literature to clarify the conceptual meaning and measurement of theoretical constructs. This process aimed to enhance the internal validity of our research conclusions and strengthen the generalizability of the new theory. Following the literature review, we performed in-depth case analysis using coding techniques. The key theoretical constructs explored in this study are technological affordances and affordance actualization. Technological affordances refer to the potential behavioral possibilities that digital technologies offer to specific entities. These affordances represent latent behaviors that can only be actualized through concrete practical activities aimed at achieving goals. Therefore, the realization of technological affordances involves the specific usage behaviors adopted by actors when utilizing technological tools to accomplish their objectives.

Based on the affordances theoretical constructs, we employed a combined approach of typical content analysis coding and inductive data coding to analyze the collected qualitative data. This approach involved breaking down, comparing, conceptualizing, and categorizing the qualitative data with the aim of extracting themes from a large amount of qualitative material [60]. The ultimate goal was to explore the logical relationships between the conceptual constructs. To ensure the scientific and systematic nature of the data analysis process, we use the latest version of the qualitative research software, NVIVO 12, to assist with data coding. This software can effectively identify important concepts, key processes, and logical relationships. Specifically, the analysis process involves three steps. First, we identify the key events related to the use of the platform's industrial services by manufacturing enterprises and code the raw data based on these events. We compare and merge the original codes into a valid range, forming first-order concepts. Second, we compare these conceptual descriptions with the literature and categorize them, further abstracting and summarizing the first-order concepts into second-order themes related to technical affordances. Finally, we logically aggregated the second-order themes into theoretical dimensions and delineated the formation and implementation path of the technical affordances for each stage. After summarizing the initial model, we continuously discuss and revise the theoretical framework until arrive the analytical conclusions.

The specific coding and classification process is as follows: First, the data is coded according to the source channel. For first-hand information obtained through interviews and research, different codes are assigned based on the source of the information. Information obtained from senior management at CPC is coded as M1, from senior technical personnel and workers at CPC as

Table 2
Key words and number of coding entries for conceptual measurement.

Concept	Variables	Conceptualization	Key word evidence	Coding	Numbers
Affordance	Consonance	The ability to facilitate communication and collaboration among different units within the organization	Compatibility between equipment and information systems compatibility between employees and information systems	A11	66
	Resonance	The ability to optimize production processes and improve production efficiency	Interaction between data and business processes interaction and communication between different departments	A12	55
	Adaptation	The ability to provide decision-making support based on real-time data analysis	Improvement of product/service model coordination of the entire value chain within an enterprise	A13	57
Actualization	Systematization	Systematization of production and operation experience	Conversion of production processes into data concrete representation of "manual production experience" as operation manuals	B11	60
	Standardization	Standardization of business processes through digital technology	Data-driven virtual production processes data-driven dynamic cross-process optimization	B12	62
	Refinement	Refinement of production and operation standards	New processes, new production flows, new operating manuals, open innovation in services	B13	58

M2, from junior managers as M3. Moreover, for the same or similar expressions from the same person, they are counted as only one entry. For second-hand information, information obtained through literature is coded as S1, and information obtained through archival records is coded as S2. Information obtained through physical evidence is coded as P. For the same or similar expressions from the same source, they are counted as only one entry. By coding the first- and second-hand information, this article obtained a primary entry database containing 358 entries. Next, the primary entry database is classified by period. The 358 entries are divided into three periods based on the three interview periods mentioned above, forming three secondary entry databases. Furthermore, the secondary entry databases are classified according to technical affordances. All entries related to technical affordances provided by the platform to organizations are directly identified from the secondary entry databases of each period, and classified into a third level entry database related to technical affordances. Then, with reference to existing research literature and interview text data, the third-level coding is completed, and the coding results are allocated to the third-level entry databases. Entries in the technical affordances concept entry database are coded based on the strength of the connection and the type of collaboration, while entries in the technical affordances realization concept entry database are coded based on the enterprise's practical behavior. As shown in the Table 2.

3.6. Data analysis

Case data analysis is the process of interpreting and extrapolating information from case materials, theoretical perspectives, relevant literature, and process models [57]. According to the conventions of case study research, data coding and analysis are conducted concurrently. It involves establishing connections, relationships, and explanations between these four elements.

The process of case data analysis unfolds in three progressive stages: first-order concepts, second-order themes, and aggregate dimensions [58]. First, the data is examined from the perspective of a service provider on the CPC enterprise industrial Internet platform. All the events and activities related to providing technical support to traditional enterprises are identified and named as first-order concepts. Next, an analysis is conducted on these first-order concepts from a theoretical perspective to understand their deeper implications. Similar concepts are grouped together and referred to as second-order themes. These themes help in understanding the essential roles of industrial Internet platforms in supporting traditional manufacturing enterprises. For example, the importance of collaboration between internal and external entities in the success of traditional manufacturing processes is explored. Finally, the second-order themes are combined and summarized into theoretical dimensions. This step helps in creating a clear structure (Fig. 1) and visualizing the relationship between the different themes. The refinement of this structure is done through discussions with colleagues and key interviewees to arrive at the final theoretical model.

In the following sections of this article, we will use typical citations and fragments from the interview texts to elaborate and analyze the main content of these concepts.

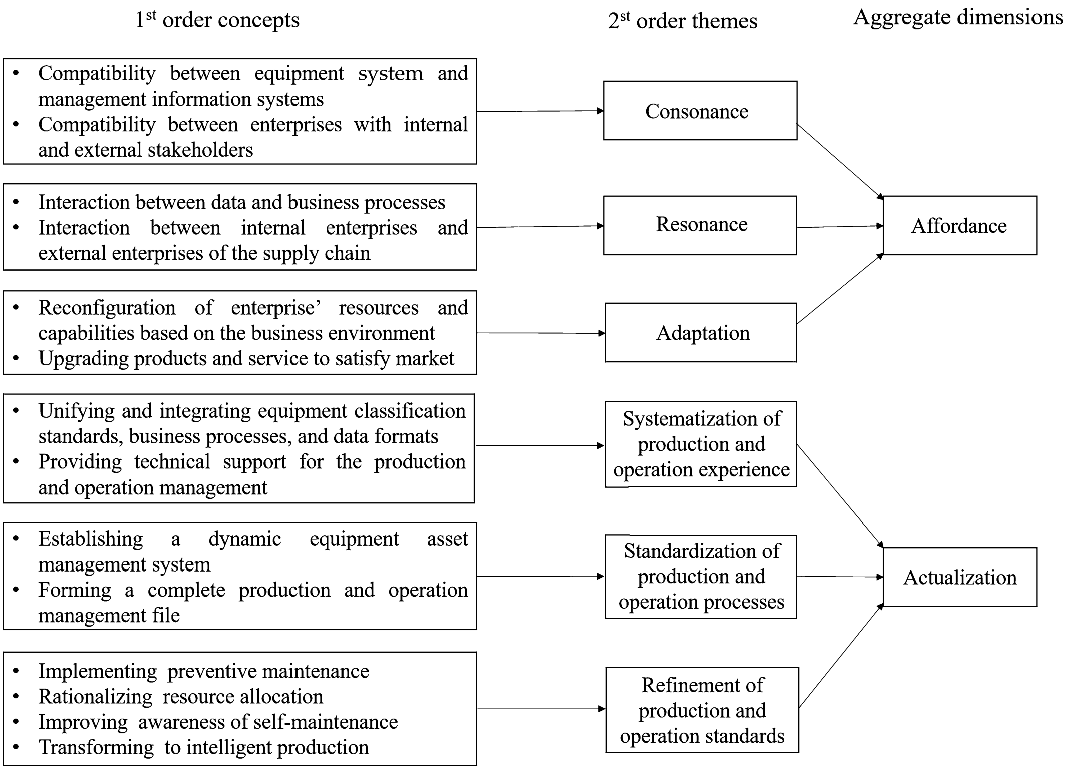

Fig. 1. Data analysis process and results.

4. Case analysis and findings

Building upon the aforementioned steps of case analysis, this section conducts a comprehensive analysis of how traditional manufacturing enterprises achieve digital production transformation by leveraging the industrial Internet platform. The analysis is based on the case material coding process illustrated in Fig. 1 and focuses on the stages of affordance and actualization. By organizing the original coded document data of the cases according to the established coding scheme, we identify three key affordances of the industrial Internet platform in the digital transformation of manufacturing production. Additionally, we explore the corresponding actualization processes that enable enterprises to realize these affordances.

By combining Fig. 1 with the analysis in this section, we systematically elevate the material derived from case studies to a conceptual level, categorizing and classifying it into constructs that align with the research theme. The objective of this analysis is to abstract experiential knowledge and observations from practical cases into more generalized conceptual representations. Through this process, we aim to gain a deeper understanding of the digital transformation process undertaken by traditional manufacturing enterprises as they leverage the technological support provided by the industrial Internet platform. Ultimately, this analysis yields structured data that facilitates subsequent analysis of conceptual relationships.

4.1. *Technological affordance*

According to recent literature in the field of information systems, affordances represent the potential opportunities for goal-oriented actors to take action, which are enabled by an object or technology. Based on the case material and insights shared by our interviewees, this study categorizes three types of affordances: consonance, resonance, and adaptation. Consequently, the following analysis will analyze these affordances by considering the interaction between the goals of manufacturing enterprises and the technical support offered by the industrial Internet platform.

4.1.1. *Consonance*

The affordance of consonance arises from the integration of small and medium-sized industrial enterprises with the technological support provided by the industrial Internet platform. By leveraging the platform's technological tools, such as EAM (Equipment Asset Management) systems, these enterprises can efficiently achieve their goals. Consonance emphasizes the compatibility between different production elements, which is crucial for creating value in enterprises. The possibility of consonance is mainly based on the modular architecture of the industrial Internet platform, which enables the perception, identification, detection, and collection of data from individual devices and sensors. This architecture enables the perception, identification, detection, and collection of data from individual devices and sensors. Through this data exchange and integration, the platform facilitates seamless information sharing, alignment of objectives, and collective efforts towards common targets. This collaborative ecosystem enhances overall production efficiency and effectiveness.

(1) The business goal of small manufacturing enterprises is to solve the dilemma of not being able to improve production efficiency in a timely manner. Traditional small manufacturing companies usually lack control over their production processes, and data is recorded by workers using pen and paper, and managed by frontline supervisors. From data recording to statisticians and shop directors calculating data, it can take days or even weeks for the information to reach managers, and there is often a significant amount of distortion. During this period, managers are unable to timely correct issues such as material waste and non-standard processes in production. As a result, companies are unable to timely and accurately understand the status of their production lines, such as raw material consumption, production progress, energy consumption, waste emissions, product quality, and other information.

The primary commercial motivations for small enterprises adopting the industrial Internet platform are to increase revenue or reduce costs. The most widespread application of platform technology is predictive maintenance and remote asset management, which can reduce equipment failure or unexpected downtime based on existing operational data. Another early value proposition of industrial Internet platform is to improve worker safety and working conditions, as well as increase worker productivity, which are sources of value in the operational efficiency improvement stage. It can be seen that the value creation of the service-oriented transformation of manufacturing is currently reflected in the direct aspects related to the product, such as the reduction of related costs, improvement of quality, and enhancement of brand value.

The Chief Technology Officer gives an example to illustrate this situation. A petrochemical enterprise DS (anonymous) has a variety of chemical equipment with different functions, sizes, and complexities, accounting for about 40% of the company's total assets and playing an important role in its production operations. The company's executives found that although their petrochemical products have good sales, their equipment asset utilization rate and maintenance costs per million yuan of output are significantly lower than other companies in the same industry. The existing equipment asset management indicators only focus on reducing maintenance costs, but the ability to timely grasp the production efficiency of equipment assets and improve the ability to create value with equipment is an urgent issue that hinders enterprise development.

(2) To connect production equipment, manufacturing enterprises use equipment management software provided by the industrial Internet platform for their production operations. These software programs can centrally monitor devices located in different geographical locations, providing necessary technical support for the ubiquitous compatibility of production equipment. Representative software products include i-EAM6 equipment asset management system, EAM11g equipment asset management system, EAM2015 equipment asset management software, ZTE equipment decision analysis system, ZTE material management system, ZTE engineering project management system, EAM2015 water edition, ZTE asset pass, and ZTE Zhengtai comprehensive control platform system. In addition, mobile standardized asset management software is also available, including InventoryEasy, InspectionEasy, Mobile Work Order, Mobile Inventory, Inventory Treasure, and Inspection King, among others. These software tools provide manufacturing enterprises with the flexibility to manage their equipment assets efficiently and in real-time, regardless of their location.

The technical support system is a necessary condition for enterprises to implement production control, which includes automatic sensing technology such as basic automation technologies, programmable logic controllers (PLCs) and human-machine interfaces (HMIs), as well as spatial positioning technologies, such as global positioning systems (GPS) and radio-frequency identification (RFID) sensors; detection and control technology such as PLS and DCS; and state detection technology. Manufacturing execution technology MES is also an important component of the technical support system.

As an example, the person in charge of equipment management at AT (anonymous) Company stated, "Using computer systems to monitor the entire process of equipment asset management can transmit information on equipment production, operation, and maintenance timely, and realize full lifecycle management of equipment on the computer side. At the same time, it can incorporate maintenance human resources, technical resources, financial resources, and material resources related to equipment into the system's management scope, and implement unified performance evaluation and management standards." The technical support system enables manufacturing enterprises to manage their equipment assets efficiently and effectively, ensuring production processes run smoothly and maximizing production efficiency.

In summary, the affordance of consonance, supported by the industrial Internet platform, enables small and medium-sized manufacturing enterprises to optimize resource compatibility, streamline operations, and improve their overall performance.

4.1.2. Resonance

The affordance of resonance emerges from the integration of diverse departments within conglomerate capital and technology-intensive manufacturing enterprises, facilitated by the industrial Internet platform. This is particularly relevant for enterprises in industries such as electrical and optical equipment manufacturing, transportation equipment manufacturing, and machinery manufacturing. To overcome organizational inertia and improve operations, conglomerate enterprises adopt integration technologies and cloud-based data management provided by the industrial Internet platform. This enables efficient communication, collaboration, and coordination among different entities within the manufacturing ecosystem. By leveraging the platform's support, conglomerate enterprises streamline operations, optimize processes, and integrate digital solutions across departments. This integration enhances productivity, reduces costs, and improves overall competitiveness in their respective industries.

(1) The business goal of large and conglomerate capital and technology-intensive manufacturing enterprises is to enhance the harmonious interaction between different departments. Especially, the large and conglomerate enterprises composed of multiple diverse departments with significant organizational inertia and a high proportion of traditional businesses, such as those in the capital and technology-intensive industries of electrical and optical equipment manufacturing, transportation equipment manufacturing, and

machinery manufacturing, have complex and extensive business operations. Their core business is based on traditional advantages accumulated over a long period of time. When preparing for digital transformation, these enterprises must focus on transforming and coordinating their traditional business operations, which serve as the starting point and key to their transformation. Taking manufacturing transportation service-oriented transformation as an example, from an internal enterprise perspective, the purpose of service-oriented transformation in manufacturing transportation is to effectively adjust production factors, reduce the time cost of export delivery, lower export risks and uncertainty, and improve productivity and product added value. From the perspective of the industrial chain, the goal of service-oriented transformation in manufacturing transportation is to deepen the division of labor and cooperation in the process among enterprises, optimize the spatial layout of the supply chain, promote the effective integration of global and regional advantageous resources, extend the industrial chain and the "production step" of enterprises, and increase the export added value of enterprises. At this point, the important goal for large and medium-sized capital and technology-intensive enterprises, is to strengthen the interaction between different departments and improve coordination and communication to avoid buck-passing. This can lead to improved production efficiency and reduced costs, ultimately contributing to the development of the enterprise. The core traditional business is the main source of enterprise value, while additional services also contribute to value creation, which is beneficial to the acquisition of enterprise service value.

Zhang, the technician responsible for the equipment management information system in the machinery industry, mentioned that the equipment maintenance department of Company B (anonymous) used to be divided into different functional groups, such as mechanical, hydraulic, and electrical repair groups, each equipped with several professional maintenance personnel. However, this division of labor is no longer sufficient for modern large-scale equipment. When a complex system fails, it requires integrated diagnostic methods and the cooperation of many specialized personnel, including the involvement of mid-level and senior management. Therefore, internal interaction needs to be strengthened.

(2) The industrial Internet platform affords technical support for the interaction of manufacturing enterprises through the integration of data from production sites, remote equipment operation, and maintenance with equipment management software and platforms. This integration is achieved primarily through horizontal and vertical integration of industrial technology, using the EAM system.

ESB (Enterprise Service Bus) technology is primarily used for achieving horizontal integration. ESB combines middleware technology with XML and web service technologies, effectively isolating the differences in heterogeneous operating systems and different development technologies. This provides upper-layer application software with a unified adapter/interface, allowing for communication between applications by passing messages to the enterprise service bus. ESB technology effectively solves the interaction problems between different business systems, allowing for more efficient and effective communication and collaboration among different departments and levels of personnel within the manufacturing enterprise.

Vertical integration technology refers to ETL (Extraction/Transformation/Loading) technology, which mainly includes the following steps: Data Extraction, Data Transformation, and Data Loading. In Data Extraction, data is extracted from different industrial automation systems, operating platforms, databases, data formats, and applications. In Data Transformation, data from different sources is transformed and standardized to form a unified data format, using deidentification rules to protect sensitive information and create visualized data. In Data Loading, data from different networks and operating platforms is loaded into the management system layer.

Vertical and horizontal integration technologies converge the massive data acquired from equipment into a cloud-based database, achieving real-time updates of user information for manufacturing enterprises. The cloud-based data links the entire value chain by providing equipment management software and enabling manufacturing enterprises to interact among different departments and information systems, such as ERP, CRM, SCM, and OA. This integration allows for more efficient and effective communication and collaboration among different departments and levels of personnel, ultimately improving production efficiency and reducing costs for the manufacturing enterprise.

In summary, the affordance of resonance, facilitated by the industrial Internet platform, enables conglomerate capital and technology-intensive manufacturing enterprises to achieve harmonious interactions among diverse departments, enhancing efficiency and competitiveness in the manufacturing ecosystem.

4.1.3. Adaptation

The affordance of adaptation arises from the alignment of large and medium-sized labor-intensive manufacturing enterprises with the technological support offered by industrial Internet platforms. This alignment enables them to effectively respond to a dynamic business environment and foster value co-creation. While these industries may not be highly technologically advanced, they operate with shorter product life cycles and have closer proximity to end consumers in the supply chain. The challenges and opportunities for digital transformation in these labor-intensive manufacturing sectors differ from those in capital and technology-intensive sectors. In these enterprises, digital transformation not only involves leading the adoption of digital technologies but also emphasizes the construction of digital ecosystems to achieve comprehensive and sustainable development for both the enterprise and its customers. The industrial Internet platform plays a crucial role in supporting these industries by facilitating their adaptation to digital technologies and optimizing their operations.

(1) The business goal of large and medium-sized labor-intensive manufacturing enterprises is to become more intelligent. Especially with the development of industrial Internet platform technology, the labor-intensive manufacturing enterprises have gained more opportunities for value creation, and the value network structure needs to be reconstructed, through business model innovation to add additional value. For example, the large and medium-sized labor-intensive manufacturing industries such as food and beverage, tobacco, leather, and footwear products, although the technical content of such industries is not high, the product life

cycle is short, and they are closer to the end consumer in the industrial chain. Therefore, these labor-intensive manufacturing enterprises require more investment in high-quality service elements such as R& D, design, marketing, and after-sales service. These enterprises need to optimize their existing business models in response to changes in market demand and achieve business growth while maintaining their existing competitive advantages. They must clearly understand customers' needs and focus on differentiation of demand. The core advantages of such enterprises mainly lie in their ability to provide services that meet customer needs, the non-imitability of services, the exclusivity of channels, and the stability of customer relationships. Therefore, the main goal of service-oriented transformation for enterprises at this stage is to use Internet platform and related technologies to segment customers based on differentiated needs, accurately understand their service requirements, and predict the best time and mode to provide services. These manufacturing enterprises can provide more comprehensive services based on market demand, enhance product features through services, and build differentiated advantages.

In order to realize these goals, many enterprises realize that they need an agile, practical, and effective intelligent control system to improve the overall efficiency of the production process. The integration of technology and management can help manufacturing enterprises to achieve this goal, allowing for greater coordination and collaboration among different departments and levels of personnel. By efficiently allocating resources and accurately positioning customer demands, the large and medium-sized labor-intensive enterprises improve their ability to meet market needs, which in turn increase the service value.

(2) Technical tools play an important role in the adaptation of manufacturing enterprises, and the industrial Internet platform provides technical support through the ACCM comprehensive equipment management system. This system mainly includes horizontal and vertical integration of industrial technology.

From a horizontal perspective, the platform promotes the construction of the supporting system based on container and microservice technologies represented by Docker, Apache Mesos, and Kubernetes, and establishes a standard enterprise information integration bus. The platform connects various independent equipment asset application systems through the integration bus, organizes the collected information, standardizes the representation of information from different equipment manufacturers into a user-friendly format, and stores the information in the data warehouse for convenient subsequent information application, analysis, optimization, and presentation. This ultimately achieves synergy across data, applications, business, and interfaces. At the same time, the platform utilizes edge data analysis processing and caching technologies to eliminate redundant data and improve the real-time analysis capabilities of equipment management information systems. This makes the overall technical architecture more unified and reduces the comprehensive cost of system applications.

In summary, the consonance and resonance within an organization offer additional potential to strengthen value co-creation and adapt to the competitive business environment, especially in large and medium-sized labor-intensive manufacturing sectors. The industrial Internet platform provided by CPC presents an opportunity for manufacturing enterprises to achieve sustainable production transformation through consonance, resonance, and adaptation. To realize these potential affordances, manufacturing enterprises must take specific actions and make necessary efforts in the production process to effectively utilize the industrial Internet platform. The following section elaborates on the actualization of these potential affordances.

4.2. Affordance actualization

4.2.1. Business implementation

(1) Systematization of production and operation experience. Manufacturing enterprises take actions in leveraging the products and services provided by the industrial Internet platform through standardized processes, execution sequences, continuous operations, and improvement mechanisms, to achieve the affordance of consonance. Manufacturing enterprises adopt different equipment management software based on their actual production and operation needs. Small and medium-sized manufacturing enterprises have relatively simple and homogenized equipment needs, and mainly adopt standardized products that can be self-installed and used, such as EAM2012 and EAM2015, to meet their needs. For example, Kunming General Water Co., Ltd. and Lanzhou Water Supply are water treatment enterprises that adopt similar standardized equipment management information systems with Shanghai Pudong Velida Water Co., Ltd. In the process of using the technical support provided by the platform to improve production efficiency, manufacturing enterprises gradually develop and possess the systematization of production capabilities. With the technical support of the industrial Internet platform, enterprises reduce unplanned downtime, quickly eliminate faults, improve equipment adjustment speed and time to shorten downtime, reduce equipment idling and brief downtime, and ensure production and operation efficiency.

Overall, the use of standardized processes and equipment management software can help small manufacturing enterprises to achieve greater efficiency and effectiveness in production and management activities. The industrial Internet platform provides the necessary technical support for this transformation, allowing manufacturing enterprises to become more intelligent and adaptable in the modern business environment.

(2) Large and conglomerate capital and technology-intensive manufacturing enterprises have the potential to standardize business processes through the digital management system provided by the CPC platform, especially the production and operation processes that can be continuously executed according to the PDCA cycle. This helps to achieve greater coordination and collaboration among different departments and levels of personnel, and realizes the affordance of resonance. The digital equipment management systems can improve production task completion rate, on-site operation standardization, production safety level, and production process innovation level gradually with standardized assessment indicators provided by the CPC platform, which comprehensively includes equipment production goals, production processes, safety measures, process innovation, and other aspects. On the one hand, the enterprises gradually form a certain organizational management ability and performance management ability and have a fixed KPI

indicator system to evaluate the performance of production and operation process implementation. On the other hand, the enterprises initially form the foundation of intelligent management and control, complete the sorting and optimization of business processes, and achieve standardized management of basic business processes.

Based on these actions, large corporate group manufacturing enterprise have the potential to continuously improve the condition of the control system, performance evaluation system, and business system according to the technical standards, and gradually develop standardized production and operation capabilities. For example, Henan Tobacco Company, a subsidiary of China National Tobacco Corporation, operates eight cigarette production factories in Xinzheng, Zhengzhou, Xuchang, Anyang, Nanyang, Zhumadian, Luohe, and Luoyang. The platform provides the Henan Tobacco Equipment Asset Management Information System, which facilitates the “one-to-eight” management model. This system enables connectivity among the various branches and production workshops of Henan Tobacco Company. It achieves this through the technical support and tools provided by the platform, allowing for the seamless implementation of standard business requirements and operational processes. Additionally, the platform helps standardize work processes and performance indicators across all its member factories.

Overall, the use of standardized processes and equipment management software can help manufacturing enterprises to achieve greater efficiency and effectiveness in production and management activities. The industrial Internet platform provides the necessary technical support for this transformation, allowing manufacturing enterprises to become more intelligent and adaptable in the modern business environment.

(3) Refinement of production and operation standards. The achievement of consonance and resonance can support large and medium-sized labor-intensive manufacturing enterprises in adapting to changing business environments and realizing the potential affordance of adaptation. When indicator values deviate from the predetermined range, they can be quickly corrected. The aim of digital process management is to adapt to the fierce competitive environment and to achieve the goal of maximizing corporate profits. The production and operation processes are quantitatively managed and controlled based on dynamic KPI indicators provided by the CPC platform, which can help to achieve compliance, increase efficiency, and improve equipment operation and business process-related indicators. In terms of supporting technical applications, the EAM system platform has been widely promoted and deeply applied within the entire enterprise. The EAM system has not only integrated with systems at production process, but also with the entire value chain. Business can be integrated and optimized in a timely manner through certain standards and experience.

As the equipment management business of manufacturing enterprises develops, the implementation gradually shifts from institutionalization to standardization and then from standardization to refinement. In this process, the technical and application capabilities of intelligent control systems, internal production system capabilities, and the ability to make sense of the data and information collected by the digital systems are shaped. The intelligent control system includes various information systems related to enterprise business implementation, such as databases, EAM systems, and status detection systems. The technical level refers to the degree of technological advancement used in building these systems, while the application level refers to the effectiveness of these systems in actual work. Internal system integration capability refers to the degree to which enterprise internal data and business departments are shared across departmental barriers through the standardization of technical system integration and data acquisition interfaces.

For example, the equipment asset management information system provided by the platform for the AUX Group runs well in multiple business units, meeting the needs of different product factories and production workshops. At the same time, it integrates basic management, technical management, and financial management functions, and incorporates the idea of digital production management into the entire management system. The powerful data collection and analysis capabilities of the digital system provide scientific decision-making insights for the top management team of the AUX Group.

Overall, the use of intelligent control systems and digital technology can help manufacturing enterprises to achieve greater efficiency and effectiveness in production and management activities. The platform provides the necessary technical support for this transformation, allowing manufacturing enterprises to become more intelligent and adaptable in the modern business environment.

4.2.2. Implementation results

The implementation of consonance and resonance facilitates the achievement of adaptation to the competitive environment. The digitalization of various aspects of production, management, and sales relies on the efficient utilization of technical affordances in business processes. With the technical support of the industrial Internet platform, manufacturing enterprises can access comprehensive information about their operations and product status throughout its life cycle, enabling effective integration of products with advanced service offerings. By adopting the software and digital services available on the platform, manufacturing enterprises can accumulate industrial big data related to product design, manufacturing, production, marketing, and competitive analysis. This enables the interaction of production elements and the sharing of information and resources.

Moreover, manufacturing enterprises in the industry have realized seamless integration of business processes and transparent sharing of information across different departments by connecting intelligent tools used by finance, production, marketing, and human resources departments. This promotes the goals of “full efficiency,” “full participation,” and “full system,” resulting in the smooth flow of business processes and transparent information sharing.

In summary, the technological tools provided by the CPC industrial Internet platform offer manufacturing enterprises the affordances of consonance, resonance, and adaptation, enabling sustainable production transformation. Through the implementation of corresponding actions, manufacturing enterprises can gradually realize these affordances and enhance their production capabilities. This is achieved through the institutionalization of experiences, standardization of processes, and refinement of production and operational practices. The described affordances of consonance, resonance, and adaptation provide distinct benefits for manufacturing enterprises. Consonance fosters effective communication and collaboration, breaking down silos and streamlining workflows. Resonance optimizes production processes, improving efficiency and resource allocation. Adaptation enables dynamic adjustments based

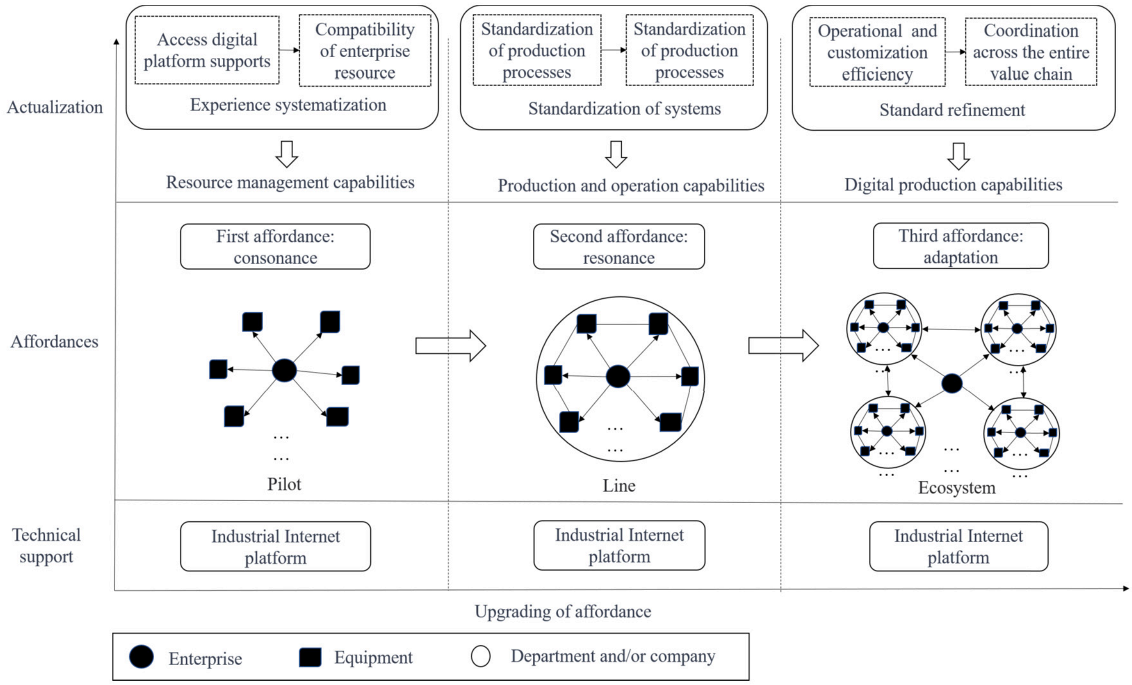

Fig. 2. Affordances for the digital production transformation of manufacturing enterprises.

on data analysis, facilitating agile decision-making and responsiveness. By leveraging the industrial Internet platform's technological tools and implementing appropriate strategies, manufacturing enterprises can harness these affordances to drive sustainable production transformation. This transformation leads to increased productivity, cost reduction, and improved competitiveness, enabling enterprises to thrive in today's rapidly evolving market.

5. Case discussion

In this section, the preliminary concepts are refined and compared with existing literature and theories. A comprehensive analysis is conducted to examine the alignment between research findings and the technology affordance theory, with the aim of exploring the inherent concepts of affordances and their dynamic actualization processes. To ensure a thorough understanding of the research question, this study underwent iterative iterations between case materials and theory, facilitating a comprehensive exploration of the connections between different concepts. Through this iterative process, the relationships among the concepts are synthesized, and conclusions are formulated based on a comparative analysis of case studies, existing literature, and theories. This iterative process culminates in the development of a dynamic and holistic framework that integrates the three-stage technological affordance and its realization. Graphical representations are employed to further analyze the emerging theoretical patterns, progressively enhancing clarity (see Fig. 2). The subsequent discussion provides a detailed elaboration of this theoretical framework.

5.1. The affordences of industrial Internet platform on the digital transformation of traditional manufacturing enterprises

This research paper focuses on the inherent affordance mechanisms of utilizing industrial Internet platforms by traditional manufacturing enterprises to achieve digitalized production. It recognizes the resource and capability constraints faced by these enterprises and analyzes how they can adopt technological support from industrial Internet platforms to drive their digital transformation processes. By bridging the gap between their existing capabilities and the digital technologies required for transformation, traditional enterprises can effectively navigate the challenges they encounter. The research findings indicate that industrial Internet platforms offer valuable technical support and potential opportunities for manufacturing enterprises to achieve digital transformation through three distinct affordances: consonance, resonance, and adaptation. These affordances demonstrate how the technology tools provided by industrial Internet platforms interact with and support manufacturing enterprises in enhancing production efficiency, effectiveness, and adaptability.

Affordance 1: Consonance

Consonance, in the context of digital transformation in manufacturing enterprises, refers to the ability to enhance communication and collaboration among different units or departments [61]. It focuses on aligning and ensuring compatibility between various production elements within the organization. In simpler terms, consonance ensures that different components, processes, and teams work together harmoniously and effectively, facilitating smooth information flow, coordination, and integration throughout the digital transformation journey [62].

By leveraging the technological support of industrial Internet platform, manufacturing enterprises can tap into the potential of consonance to streamline their operations and ensure seamless integration across various organizational functions. The industrial Internet platform provides an opportunity for resource compatibility, enabling real-time monitoring of production and dynamic data updates through the integration of business processes with digital sensing and detection technologies. This compatibility of resources also fosters the seamless flow of data and resources among different production lines and departments within the enterprise, facilitating connectivity between departments such as finance, procurement, production, marketing, and more.

The first stage of digital transformation driven by industrial Internet platforms in traditional manufacturing enterprises can be described as the “pilot experiment mechanism.” In the pilot experiment mechanism, the industrial Internet platform provides digital technological support and resource integration capabilities, helping manufacturing enterprises achieve initial success in digital transformation within a specific scope. The platform enables real-time monitoring of production and dynamic data updates through digital sensing and detection technologies, facilitating the integration of business processes with digital technologies and ensuring resource compatibility. This resource compatibility further promotes the seamless flow of data and resources among different production lines and departments within the enterprise, fostering connectivity between departments such as finance, procurement, production, marketing, and more.

Through the pilot experiment mechanism, manufacturing enterprises gradually recognize the benefits of digital transformation and establish a foundation for comprehensive implementation in the future. The mechanism provides a low-risk environment for companies to validate and adjust their strategies and methods of digital transformation in practice. This gradual approach helps companies adapt to the transformative process of digital transformation and continuously optimize and improve through practical experience, laying a solid foundation for the comprehensive advancement of digital transformation.

Affordance 2: Resonance

Resonance, in the context of digital transformation in manufacturing enterprises, refers to the optimization of production processes and the improvement of efficiency [61]. It involves aligning and synchronizing various elements, such as equipment, systems, workflows, and stakeholders, to achieve synergy and maximize production performance [63].

By leveraging the technological support of industrial Internet platform, manufacturing enterprises can tap into the potential of resonance to achieve higher levels of efficiency, responsiveness, and competitiveness in the digital era. The industrial Internet platform strengthens collaboration and coordination between different production lines by providing a centralized platform for data and information exchange. It enables real-time data sharing, production plan coordination, and cross-line collaborative optimization, thereby improving resource management, production efficiency, and the ability to respond to market demand changes. Furthermore, the industrial Internet platform supports intelligent optimization of production lines through the use of IoT sensors. These sensors monitor real-time data on parameters like temperature, humidity, and vibration. By analyzing this data using artificial intelligence techniques, companies can identify potential issues, predict faults, and perform preventive maintenance. This improves the stability and reliability of production lines.

The “line” phase represents the second stage of digital transformation, where enterprises extend digital applications to a wider range of production lines and business processes to enhance collaboration and optimization. The industrial Internet platform plays a crucial role in this phase. It enables the connection and integration of production lines, equipment, and systems, facilitating comprehensive data collection and monitoring. Through real-time visualization and analysis, enterprises gain a better understanding of operational status and efficiency.

Affordance 3: Adaption

The adaptation driven by industrial Internet platforms in traditional manufacturing enterprises refers to their ability to adjust and thrive in a rapidly changing business environment through data-driven decision support, collaboration, and optimization. This adaptation emphasizes the alignment between enterprise goals and the technological support provided by the platform. By leveraging the technical support of the platform and fostering organizational resonance within the company, enterprises can effectively adapt to the competitive business environment, foster value co-creation, and ensure sustainable development.

This adaptation represents the third stage of digital transformation, known as the “ecosystem” stage [4], where enterprises extend digital applications to various aspects of the entire value chain and business processes to achieve comprehensive collaboration and optimization. Industrial Internet platforms play a crucial role in this stage by acting as a connecting link between different departments, production lines, suppliers, and customers. They enable comprehensive data sharing and collaborative cooperation, facilitating real-time data exchange, enterprise-level production planning coordination, and cross-department and cross-enterprise collaborative optimization. This collaboration and optimization capability allows companies to effectively integrate resources, improve production efficiency, and respond quickly to changing market demands.

Moreover, industrial Internet platforms in the “ecosystem” stage also support enterprises in achieving intelligent production management and decision-making. By utilizing IoT sensors and big data analytics technology, the platform can monitor and analyze critical parameters in real-time throughout the production process. This data can be utilized for optimizing production plans, predicting faults, and performing preventive maintenance, among other applications. Through in-depth data analysis and the application of artificial intelligence techniques, enterprises can adjust production processes more accurately, enhance product quality, and achieve higher production flexibility and sustainable development.

In conclusion, the adaptation driven by industrial Internet platforms in the digital transformation of traditional manufacturing enterprises emphasizes comprehensive collaboration and optimization capabilities, as well as intelligent production management and decision support. This adaptability enables enterprises to effectively adjust to the rapidly changing business environment, leading to successful digital transformation and sustainable development.

5.2. Actualization of affordance in digital transformation

This study identifies three digital behaviors that enable technological affordances. The industrial Internet platform provides technical support for manufacturing enterprises to achieve sustainable production goals based on three different affordances: consonance, resonance, and adaptation. To realize these potential possibilities, manufacturing enterprises gradually upgrade their production and operation practices through experience institutionalization, system standardization, and standard refinement. The realization of each type of affordance lays the foundation for the next new affordance, and the interdependence between affordances forms an iterative updating process. By revealing these digital behaviors, the study sheds light on the intermediating mechanism through which digital technologies drive transformative changes in business operations.

The formation and implementation of manufacturing digital transformation affordances is a long-term and complex system that cannot be achieved overnight but requires a gradual and continuous process of optimization and development that is dynamic and evolving. In this process, the industrial Internet platform provides the necessary technical support, and manufacturing enterprises flexibly adopt the most effective technical tools according to their business scenarios and market demands, gradually realizing these affordances through the use of digital technology in production practices. In order to achieve their expected goals, manufacturing enterprises undergo an optimization and upgrade process in their business practices and related capabilities, with each stage of business practices laying the foundation for the optimization of the next stage. The affordance and actualization process provided by the industrial Internet platform for manufacturing companies is a spiral upward process.

The dynamic leapfrogging process of digital transformation in traditional manufacturing enterprises, facilitated by the industrial Internet platform, is reflected in the realization of these three affordances and their underlying resource capabilities. The case study presented in this paper demonstrates how enterprises utilize different resource capabilities to achieve digital transformation. Firstly, they enhance digitization by adopting technology, implementing information systems, and accumulating digital resources. The second stage focuses on accelerating learning and optimizing production and operational capabilities, leveraging knowledge and learning resources. Lastly, enterprises leverage intelligent systems to promote collaboration along the value chain, utilizing collaborative and network resources, leading to advanced digital production capabilities. Based on these findings, this paper proposes a theoretical model that captures the dynamic leapfrog development of production digitization in traditional manufacturing enterprises within the context of the industrial Internet platform.

6. Conclusions and implications

6.1. Conclusions

The digital transformation of manufacturing enterprises, facilitated by the industrial Internet platform, has emerged as a critical focus in today's business landscape. However, traditional manufacturing enterprises, which are the backbone of the national economy, face the formidable challenge of lacking the necessary resource capabilities to establish their own platforms. In order to maintain competitiveness and align with the demands of the digital era, these enterprises must explore alternative approaches to embrace digital transformation. The primary objective of this study is to provide theoretical insights into how traditional manufacturing enterprises can effectively leverage the technical support offered by the industrial Internet platform to achieve digital business production transformation. The results of this study can be summarized as follows.

First, the industrial Internet platform offers three distinct affordances that facilitate the digital transformation of traditional manufacturing enterprises' process digitization: consonance, resonance, and adaptation. These affordances enable enterprises to align their operations with the capabilities and possibilities provided by the platform. Second, to effectively realize these affordances, traditional manufacturing enterprises need to undergo a specific process. This process involves adopting technology, implementing information systems, and accumulating digital resources to enhance their digitization efforts. It also includes accelerating learning, optimizing production and operational capabilities, and promoting collaboration along the value chain. Third, the study proposes a theoretical framework that captures the dynamic leapfrog development of production digitization in traditional manufacturing enterprises within the context of the industrial Internet platform. This framework integrates the three-stage technological affordances and their realization, providing a comprehensive understanding of the digital transformation process. Furthermore, the digital transformation process in traditional manufacturing enterprises, facilitated by the industrial Internet platform, follows a dynamic evolution. It entails transitioning production modes from experience institutionalization and standardization to refinement. This progression reflects the continuous development and enhancement of business capabilities, leading to higher levels of digital production effectiveness.

6.2. Implications

This study provides important theoretical and practical implications into the digital transformation of traditional manufacturing enterprises using the industrial Internet platform.

The theoretical implications of this study are as follows. Firstly, this study expands the existing concept of digital business process transformation by considering both platform owners and traditional manufacturing enterprises within the context of industrial Internet platforms. Previous research has predominantly focused on the optimization of business processes by industrial Internet platform owners [7], neglecting the specific needs and challenges faced by traditional manufacturing enterprises. By redirecting attention towards manufacturing enterprises and examining their utilization of technological support provided by these platforms, this study broadens our understanding of digital business process transformation. Secondly, drawing on the theory of technological affordance, this research develops a theoretical framework that sheds light on the digital transformation process of traditional manufacturing firms within industrial internet platforms. By constructing an affordance mechanism, the study highlights how manufacturing enterprises leverage the technological support offered by the platform to achieve digital production transformation. This framework provides theoretical guidance for understanding the internal mechanisms through which operational efficiency and customization improvements are enhanced, contributing to a comprehensive understanding of digital transformation. Furthermore, this study refines the concept of digital transformation by specifically focusing on digital production process transformation. By analyzing the intricate details of digital production processes within the broader context of digital transformation, the research offers a comprehensive and nuanced understanding of how manufacturing enterprises can effectively optimize their production operations through the utilization of industrial Internet platforms.

The management implications of this study can be categorized into two aspects: one for traditional manufacturing enterprises and the other for industrial Internet platform companies. For traditional manufacturing enterprises, effectively navigating the digital transformation journey involves collaborating with existing platform providers instead of attempting to build their own industrial Internet platforms. This collaboration enables them to leverage the expertise and resources of these platforms to access advanced technologies, data analytics capabilities, and specialized services. By integrating their operations with established platforms, manufacturing enterprises can enhance their competitiveness and gain access to a wider network of customers and partners. Additionally, industrial Internet platform companies should prioritize understanding the specific needs of manufacturing enterprise users and promptly responding to market demands. They should develop tailored software products and services to address the practical development needs of users while continuously updating and improving offerings to adapt to evolving requirements. By adhering to these strategies, both traditional manufacturing enterprises and platform companies can effectively leverage the opportunities presented by digital transformation. They can capitalize on technology advancements, optimize efficiency, and maintain a competitive edge. It is crucial for both entities to navigate the digital landscape, align their practices with industry trends, and effectively meet customer expectations to ensure long-term success in this ever-evolving digital era.

6.3. Limitations and future prospects

This study provides insights into the process of achieving digital production transformation in manufacturing. However, it is important to acknowledge the limitations and consider future research prospects. One limitation is the reliance on data obtained from a single platform, which may restrict the generalizability of the findings. To obtain a more comprehensive understanding of digital transformation in manufacturing, future studies should collect data from multiple platforms. Furthermore, while this study identifies three types of affordances for digital transformation, there may be additional types that have yet to be explored. Future research should aim to investigate and uncover these additional affordances to enhance our understanding of the digital transformation process. Additionally, it is important to note the increasing utilization of AI technology in decision-making processes. The integration of resource complementarity and AI holds significant potential for future advancements in this field. To address these limitations and explore future research prospects, it is recommended to employ diverse research methods, such as surveys, simulations, and behavioral experiments. These approaches will help validate and expand upon the findings, ultimately leading to a more comprehensive and generalizable understanding of digital transformation in manufacturing.

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Ethics declarations

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Yi Liu: Conceptualization, Formal analysis, Validation, Writing – original draft, Writing – review & editing, Funding acquisition. **Yi Zhang:** Conceptualization, Formal analysis, Validation, Writing – original draft, Writing – review & editing, Funding acquisition. **Xiaoqing Xie:** Writing – review & editing, Funding acquisition. **Shengjun Mei:** Supervision, Funding acquisition, Project administration, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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